DiverIMPACTS
European Conference on Crop Diversification
September 18-21, 2019
Budapest, Hungary

ECCD 2019

First European Conference on Crop Diversification

September 18-21, 2019
Budapest

Book of Abstracts

Edited by Antoine Messéan (INRA), Dóra Drexler (ÖMKI), Ildikó Heim (ÖMKI), Lise Paresys (INRA), Didier Stilmant (CRA-W) and Helga Willer (FiBL)

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The conference was convened by the DiverIMPACTS project in collaboration with its partners in the Horizon 2020 Crop Diversification Cluster: Diverfarming, DIVERSify, ReMIX, LegValue, TRUE. INSUSFAR was also supporting the organisation of the conference.

It was organised by the local host ÖMKI, the Hungarian Research Institute of Organic Agriculture and by INRA, the French National Institute of Agricultural Research

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FOREWORD

The temporal and spatial diversification of crops through rotation, multiple cropping and/or intercropping contribute to low-input agronomic practices and resource-**efficient farming systems**, and constitute a key pillar of the **transition towards sustainable agri-food systems.** Crop diversification can fulfil the need to simultaneously produce food, feed, industrial products and deliver other ecosystem services and public goods by exploiting **the potential of diversity** and biological regulation at field and landscape levels. However, diversified and low-input farming systems can only emerge if clear benefits to farmers and society are demonstrated, if the upstream and downstream **value chains** are fully engaged, and if the **sociotechnical regime** is more disposed to support crop diversification.

The objective of the European Conference on Crop Diversification was therefore to explore how to achieve diversified **agri-food systems** for improved productivity, delivery of ecosystem services, resource-efficient and sustainable value chains as well as to discuss the implications of implementing more integrated sociotechnical systems (i.e., which facilitate co-innovation across research and development, education, advisory, business and policy sectors).

The focus was on all scientific aspects of **agri-food system diversification**, including support for practical implementation of crop diversification in value chains and policy-related issues. In particular, the conference addressed the following themes:

- Benefits, barriers, lock ins, enablers and practical experiences of crop diversification
- Innovations and incentives to promote diversification along value chains
- Breeding for crop diversification
- Approaches to assess the performance of diversified cropping systems at various scales
- Co-designing approaches that foster crop diversification and accompany actors when transitioning towards European sustainable systems
- Policy recommendations to make systems more disposed to crop diversification.

The conference programme included:

- Presentations from five keynote speakers with a wealth of knowledge and experience in agricultural and food system diversification
- Sixteen parallel sessions, covering all aspects related to crop diversification and touching on critical topics such as valuing crop diversification products and designing and optimising interspecific mixtures
- Five workshops addressing how to promote crop diversification across Europe, challenges in breeding for crop mixtures, technology for spatial crop diversity, value chains business models and policy recommendations to make agri-food systems more disposed to crop diversification.

The conference provided a unique opportunity for scientists, practitioners, policy makers and other actors along the supply chain to gather and exchange about crop diversification.

The conference was convened by the DiverIMPACTS project together with the other members of the Horizon 2020 Crop Diversification Cluster: Diverfarming, LegValue, DIVERSify, ReMIX, and TRUE as well as the German programme INSUSFAR. The H2020 cluster on crop diversification was created with the objective to foster the co-design of technical, organisational and institutional innovations so that barriers to crop diversification can be overcome and diversified systems can be established and sustained.

Antoine Messéan

Chair of the ECCD 2019 Scientific Committee

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PROGRAMME

Wed. 18 September

18:00-	Registration and Welcome Evening

Thu. 19 September

9:00-9:15	Opening session: Welcome from ÖMKi and DiverIMPACTS			
9:15-10:00	Keynote Speaker I: John Ingram (University of Oxford, United Kingdom)			
10.00-	Coffee break			
10:15-12:15	Parallel sessions			
	10:15-12:15 Session 5: Enhancing agrosystem resilience and performances by crop diversification	10:15-12:15 Session 13: Breeding for interspecific mixtures	10:15-12:15 Session 17: Tools to design, manage and monitor diversified systems from the field to the landscape levels	10:15-11:15 Session 4: Connecting actors to foster crop diversification: how to turn theory into action and vice
				11:15-12:15 Workshop: Towards a crop diversification network
12:15-13:15	Lunch break			
13:15-14:00	Keynote Speaker II: Pablo Tittonell (CONICET, Argentina)			
14:00-14:45	Keynote Speaker III: Julie Dawson (University of Wisconsin-Madison, United States)			
14:45-15:00	Coffee break			
15:00-18:15	Parallel sessions			
	15:00-17:15 Session 10: New Inter and strip-cropping: crop and ecological performances	15:00-17:00 Session 12: Breeding for intraspecific diversity	15:00-17:30 Session 15: Barriers, lock ins, enablers and practical experiences of crop diversification	15:00-16:30 Session 3: Niche management and diversification projects: how to turn theory into action and vice versa?
				16:30-17:30 Session 2: Co-designing crop diversification at the field level: what do actors want?
	17:15-18:15 Poster session I	17:00-18:15 Poster session I	17:30-18:15 Poster session I	17:30-18:15 Poster session I
19:00	Gala dinner			

Fri. 20 September

9:00-9:45	Keynote Speaker IV: Phil Howard (Michigan State University, United States)			
9:45-10:30	Keynote Speaker V: Emmanuel Petel (European Commission, Belgium)			
10:30-10:45	Coffee break			
10:45-12:45	Parallel sessions			
	10:45-12:45 Session 9: Impacts of introducing service crops and legumes in cropping systems	10:45-12:45 Session 6: Diversification benefits: their economic value and carry-over effects	10:45-12:15 Session 16: Valuing crop diversification products	10:45-12:45 Session 1: Co-designing crop diversification: which actors to include beyond the farm?
12:45-13:45	Lunch break			
13:45-14:15	Poster session II			
14:15-16:45	Parallel sessions			
	14.15-15.45 Session 8: Cropping system diversification to support biocontrol	14:15-15:45 Session 14: Designing and optimising interspecific mixtures	14:15-15:15 Workshop: Technology inspired by ecology for the adoption in practice of spatial crop	14:15-15:15 Workshop: Supporting collaboration rather than competition between diversification value chains in
		15:45-16:45 Workshop: Breeding for crop mixtures: Opportunities and challenges	15:15-16:45 Session 7: Soil microbial functional diversity enhanced by cropping system diversification	15:15-16:45 Workshop: Policy recommendations to make the sociotechnical systems more disposed to crop diversification
16:45-17:00	Coffee break			
17:00-17:45	Closing session: feed-back from stakeholders and Conclusion			

Sat. 21 September

8:00-16:00	Optional excursion - discover the vineyards of Hungary

Keynote Lectures

Julie Dawson

Collaboration all along value chains to develop varieties for local food systems

Julie Dawson is an Associate Professor in the Department of Horticulture at the University of Wisconsin-Madison. Her background is in organic plant breeding and participatory research. Research topics include season extension methods, organic and participatory variety trials and variety selection for small-acreage farms and gardens as well as extension resources for urban growers. She leads a project called the Seed to Kitchen Collaborative with other plant breeders to test varieties with local farmers and chefs, focused on flavor for local food systems.

Julie Dawson

At the conference, Julie Dawson shared her experience about collaboration all along the value chain with plant breeders, seed producers, farmers, chefs and consumers to develop varieties for local food systems.

(link to presentation)

Phil Howard

Bridging information gaps between producers and consumers to develop more diversified and sustainable food systems

Phil Howard is an Associate Professor of Community Sustainability at Michigan State University, and a member of the International Panel of Experts on Sustainable Food Systems. He is the author of Concentration and Power in the Food System: Who Controls What We Eat? His visualizations of food system changes have been featured in numerous outlets including the New York Times, Washington Post, Wall Street Journal, and The Ecologist. More information about Phil Howard is available here: http://www.ipes-food.org/about/experts/Phil-Howard

Phil Howard

At the conference, Phil Howard shared his experience on bridging information gaps between producers and consumers to develop more diversified and sustainable food systems and how to make the sociotechnical regime more prone to crop diversification.

(link to presentation)

JOHN INGRAM

Linking agroecology, food security and environment

John Ingram

John Ingram's interests are in the conceptual framing of food systems; the interactions among the many actors involved and their varied activities, and the outcomes of their activities for food security, livelihoods and environment; and food system resilience. He has designed and led regional food system research projects in Europe, south Asia, southern Africa and the Caribbean and has conceived, developed and led a range of major international research initiatives. He has had substantial interaction with FAO, UNEP and CGIAR and many other international organisations, with national departments and agencies, with NGOs, and with businesses in the food sector helping to establish research on the links between food security and environment through the analysis of food systems. In addition to leading the food system research group within the University of Oxford's Environmental Change Institute, he also leads the multi-university post-graduate food systems training programme (IFSTAL) and coordinates the UK Global Food Security programme 'Resilience of the UK Food System'. He is an Associate Professor and Senior Research Fellow at Somerville College.

At the conference, John Ingram spoke about his approach to linking agroecology, food security and the environment.

(link to presentation)

EMMANUEL PETEL

Common agricultural policy post-2020 – The new green architecture and Research & Innovation

Emmanuel Petel

Emmanuel Petel is the policy coordinator at the Directorate-General for Agriculture and Rural Development at the European Commission. He is involved in the implementation of relevant support and tools in order to ensure the CAP is compatible with environmental policy and to promote the development of agricultural practices preserving the environment and the climate. Since 2015, he has been in charge of a team to manage a "greening" payment for agricultural practices: this payment per hectare, which represents 30% of the financial envelope for direct payments of each Member State, benefits the farmers who respect some relevant practices: crop diversification, maintaining existing permanent pasture, having ecological focus area on the agricultural area.

Emmanuel Petel gave a presentation on the last European Commission proposal, which was released on 1st June 2018. He focused on the European ambitions with regards to the environment and climate, and to research and innovation.

(link to presentation)

Pablo Tittonell

Ecological intensification as a transition to agroecological landscapes and sustainable food systems

Pablo Tittonell

Pablo Tittonell is the Principal Research Scientist at Argentina's National Council for Science and Technology (CONICET) with a seat at the Instituto Nacional de Tecnología Agropecuaria (INTA), in San Carlos de Bariloche, Argentina, and holds a part time WWF-endowed Chair Professorship on Resilient Landscapes at the Groningen Institute of Evolutionary Life Sciences, in The Netherlands. He is the former national coordinator of the Natural Resources and Environment Program of INTA and former Chair Professor of Farming Systems Ecology at Wageningen University, in The Netherlands. He acts as external Professor at the Ecole Doctorale GAïA of the University of Montpellier, France and at the National University of Lomas de Zamora, Buenos Aires, Argentina.

He is an agronomist by training and worked both in the private sector and in academic/research organisations. He holds a PhD in Production Ecology and Resource Conservation and his areas of expertise include soil fertility, agroecology, biodiversity and farming systems analysis.

At the conference, Pablo Tittonell talked about the approach of ecological intensification as a transition to agroecological landscapes and sustainable food systems.

(link to presentation)

PARALLEL SESSIONS

Session 1. Co-designing crop diversification: which actors to include beyond the farm?

Chairs: Luca Colombo (FIRAB, Italy),
Walter Rossing (Wageningen University and Research, The Netherlands)

ORAL PRESENTATIONS

- Co-designing crop diversification strategies from plot to sociotechnical system to manage root-knot nematodes in Mediterranean market gardening systems.
  Speaker: Yann Boulestreau, INRA, France
- Building diversification and inputs reduction in intensive arable farms in Italy: main concepts and experimental co-design
  Speaker: Emanuele Blasi, University of Tuscia, Italy
- Organic seed production and use in Hungary
  Speaker: Judit Fehér, ÖMKi, Hungary
- Towards effective networking for crop diversity in Europe
  Speaker: Judit Fehér, ÖMKi, Hungary
- The industrialisation of agri-food systems and the demise of home-grown legumes in Europe
  Speaker: Pete Iannetta, The James Hutton Institute, United Kingdom

POSTERS

- Crop diversification for organic agriculture in Scandinavia; a multi-scale feasibility study for soybean and lupine production in Sweden
  Presenter: Alexander Menegat, Swedish University of Agricultural Sciences, Sweden
- Facilitating insects in agricultural landscapes through integration of renewable resources into cultivation systems – FinAL
  Presenter: Jens Dauber, Thünen Institute of Biodiversity, Germany

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Co-designing crop diversification strategies from plot to sociotechnical system to manage root-knot nematodes in Mediterranean market gardening systems

Yann Boulestreau*±[1,3], Marion Casagrande[1,2], Mireille Navarrete[1]

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1 Introduction

Root-knot nematodes (RKN) are causing major yield losses in Mediterranean sheltered market gardening systems on the dominant crops (*e.g.* tomatoes, melon, lettuce). Climate change and crop specialization are the main causes of increased RKN damages. With the ban of most synthetic nematicides due to their toxicity, no unique and simple technique to control RKN exists. Crop diversification has been identified as one of the main alternatives. Crop diversification consists in introducing in crop successions non-host, trap or allelopathic crops for commercial and non- commercial purposes. However, scientific literature (Magrini et al., 2016; Meynard et al., 2018) has shown that sociotechnical lock-in hinders crop diversification, calling for simultaneous and organized actions of multiple actors to unlock crop diversification. This communication shows a methodology to codesign such collective strategies to favor crop diversification, from plot to sociotechnical system.

The design of strategies is based on previous analysis of the sociotechnical lock-in and on previous exploration of innovative strategies already implemented in other contexts. This communication shows how we applied this methodology in "Rhône-Durance-Vaucluse" territory, South East France, on sheltered market gardening systems.

2 Materials and Methods

First, we analysed the sociotechnical system (STS) on "Rhône-Durance-Vaucluse" territory responsible for the present soil pest and disease management implemented by market gardeners. We identified the actors with a strong influence on RKN management based on literature and on snowball sampling procedure (Salembier et al., 2016). To understand the main impediments to crop diversification and the sociotechnical lock-in around crop specialization, we interviewed 33 actors including 16 organic and conventional farmers, representatives of agricultural advisory services, wholesalers, input-suppliers and the head of the wholesale marketplace. We also reviewed white and grey literature, and led participatory observation of key meetings involving the STS actors. Then, we characterized existing innovative strategies in other contexts that could unlock crop diversification in ours, based on stakeholders interviews, literature review and key meeting observation.

Finally, we organized a collective design process of innovative strategies to unlock crop diversification with key STS actors. KCP methodology (Le Masson et al., 2009) was used as a 3-phase methodological framework for this collective design process. The **K**nowledge-phase consisted of sharing knowledge with participants about the RKN management techniques, the impediments for crop diversification, the lock-in of the STS and some existing innovative strategies in other contexts that could help them think "out-of-the-box" (e.g. potato farmers without land renting new fields from cereal farmers every year). A dynamic presentation of management technique posters by technical experts and simulations of the sociotechnical system evolution based on a serious game were used to share this knowledge. The **C**oncept-phase was an oriented exploration of strategy prototypes with the same "serious game" (Figure1). The **P**roject-phase will occur later in our research. K-phase and C-

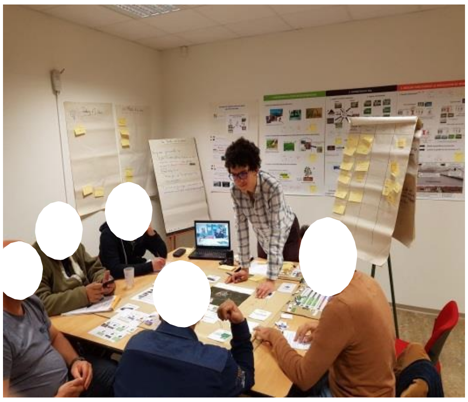

Figure 1. Collective design workshop phase were started during two workshops with two different groups of farmers: (i) a mix of six organic and conventional farmers selling their products to various whole salers, (ii) a group of six organic farmers selling to the same wholesaler and the wholesaler's crop planning manager.

3 Results

Besides market gardeners, the key stakeholders of the STS were the vegetable wholesalers and retailers, consumers, input-suppliers (seedlings, seeds), breeders, extension services (advisers, applied research stations), farmer cooperatives and agri-food chain coordinators. The main impediments identified for crop diversification were, from plot to agri-food chain level: unsuitable soils (e.g. too many stones for vegetable root crops), investment in tunnel or greenhouse limiting the species diversity that could be produced and a lack of local outlet for minor crops. The market-gardening sector was locked around the requirement to produce large volumes of a single product at low cost, especially for conventional production. Then, to satisfy brokers, middle size market gardeners needed to specialize in very few products. To unlock the system, innovative strategies were explored: coordination between farmers (e.g. exchange of fields between a RKN host plant producer and a non- host crop producer to diversify rotations without diversifying outlets) and coordination between farmers and brokers (e.g. the brokers open a new outlet enabling farmers to diversify their crops).

Thanks to the exchange with the STS stakeholders during the workshops, the understanding of the impediments for crop diversification and the lock-in was refined. Strategy prototypes were designed, integrating actions from plot to sociotechnical system. For instance, workshop participants proposed to insert new non-host crops such as spring garlic and artichoke in nematode infected plots in coordination with the brokers' needs and other existing spring garlic or artichoke producers. Actions at farm level only were also proposed such as moving the shelter structure from a RKN infected plot to another healthy plot.

4 Discussion and Conclusions

To conclude, we engaged market-gardeners and other key STS actors from the "Rhône-Durance- Vaucluse" territory in a common effort to understand and to analyze STS lock-in and explore strategies from farm to STS levels that could unlock crop diversification. Realistic RKN management strategy prototypes adapted to "Rhône-Durance-Vaucluse" sheltered market-gardening systems were designed. Even if we focus on crop diversification in this communication, it needs to be combined with other RKN management techniques (e.g. fresh organic matter supply) to effectively manage RKN populations. The next challenge is now to evaluate how effective these agroecological strategies are to control RKN populations, how they would impact the STS, and to detail how they could be implemented. Another stakeholder workshop is planned in autumn 2019.

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Building diversification and inputs reduction in intensive arable farms in Italy: main concepts and experimental co-design

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1 Introduction

Diversification of crops through rotation contributes to maintain soil fertility, reduce the use of external inputs and build-up of pests and to a great extent to mitigate the effects of climate change. An appropriate crop diversification in intensive agricultural systems also represents a step towards sustainability.

Despite the large technical and scientific consensus on the positive impact of diversification, the adoption of "new concept" crop rotations is still uneven from the farmers' side, due to the lack of knowledge on new crops, no awareness on the benefits of rotations, the costs of machinery or new labour organization and market uncertainty. Often, policies and strategies fostering the adoption of diversification and the reduction of inputs failed because of technical solutions were not affordable or yields were out of market.

The H2020 Diverfarming project (Grant Agreement 798003) was therefore designed to empower farmers and agro-industries to implement low-input innovative practices of crop diversification, to remove the barriers that limit their adoption. The research aims to co-develop and test a novel farming system defined by agri-food value chain up-stream actors to increase the overall sustainability of widespread intensive arable systems in the Po Valley in Italy that pursues scientific, economic and environmental objectives. This area was chosen as it is one of the most intensively cultivated in Europe with evidence of nitrate leaching, soil C depletion and loss of biodiversity (Perego et al., 2012).

2 Materials and methods

We set up a field experiment in three farms of Po valley (provinces of Mantova, Piacenza, and Cremona), sharing similar geographical features and farming systems. In all farms the cropping systems are planned to supply raw material to agroindustry (Consorzio Casalasco del Pomodoro-CCP, a farmers' cooperative) requests, which in turn, sets the quality requirements for acceptance and provides farmers with technical advisory. The 370 CCP associated farmers supply consortium with about 560 Mtons of fresh tomatoes yearly and about 2,5 Mtons of legumes for canned peas and beans productions.

Since 2009, farms producing fresh tomatoes for CCP have been certified Global Gap (Good Agricultural Practices) for environmental compliance to soil and waste management, product environmental fingerprint (based on irrigation techniques, crop protection and management, post-harvest treatments), health and safety of workers and their working conditions. Nonetheless issues such as low soil organic C depletion, soil compaction, potential nitrate leaching and landscape simplification, require to be tackled actively.

Having in mind both the sustainable intensification and agroecology principles, the case studies were co-designed with active engagement of the farmers and CCP's agronomist, and researchers with a view to the overall farming systems sustainability. Solutions and practices proposed are oriented to farm resilience and ecosystems services, through crop diversification, including other crops not processed by CCP, and organic fertilizers application (Pancino et al., 2016).

After a long process of co-identifications of problems and possible solutions, making by interviews, meeting and focus groups, the assumptions agreed by the actors to start the experiment were:

- an experimental plot size able to allow inference to farm level;
- technical solutions arranged on site specific constraints and local resources;
- diversification to be achieved through crop rotation.

3 Results

Based on the concepts above and on the Diverfarming outputs on "feasible diversified cropping systems" and based on data and information collection by interviews, meeting and focus groups, from 2017 each of three CCP associate farms committed four plots (20 ha total) to the goals of the study. The average 5 ha plot size allowed the farmer to include the plots into the farm multiannual arable land planning and made the collection of technical-economic data from a production unit comparable to that of a real farm.

Innovations were as follows: 1) introduction of a leguminous crop in the rotation; 2) introduction of the tomato as second crop after the legume; 3) application of an organic fertilizer (digestate).

The crop rotation was planned to ensure technical and economic viability.

At the same time, the experimental layout met the farmers' needs in terms of income, did not claim for new investments, and guaranteed tomato industry same supply, as tomato harvest was planned each other year per plot per farm.

During the project, effects on the soil-plant-water-atmosphere continuum will be assessed in field. Biophysical models and GIS-based analysis will be used to infer results in time and space, from field up to regional scale.

Details on the co-decision process, on the cognitive processes that led to this solution, the experimental design and preliminary results will be presented.

4 Discussion and Conclusions

During the last ten years, the sustainable intensification was designed around tomato as main cash crop. Consequently, the cropping systems management was optimized to improve tomato production yield and quality. Therefore, the new challenge in sustainability promoted by Diverfarming will be to shift from a farming system based on tomato as main crop (and yearly based decision) towards a multiyear perspective based on rotation. The goal will be to make the whole rotation cost-effective to the farmers and for the agro-environment.

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Organic seed production and use in Hungary

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1 Introduction

Conventional cereal and vegetable seed production has a firmly established market, and is well-practiced in Hungary. However, less interest and attention is given to organic seed production. Small market demand, low level of stakeholder organisation, and the lack of policy incentives create barriers for the development of the organic seed market. The economic value and opportunity of organic seed production is not recognised by most of the seed value chain actors, since the Hungarian organic sector is relatively small, and its demand for organic market seed is very low.

Farmers and research institutes are the main providers of organic seed and several seed companies who are certified and willing to produce organic (or conventional untreated) seeds, but only on demand. Often organic seeds are produced on a contract basis and certified and sold abroad.

Farm-saved seeds are commonly used by organic cereal farmers (>90%) in order to reduce input costs and to use material that is better adapted to local conditions. However, the quality management of farm-saved seeds often poses a major risk. Organic vegetable growers either use conventional untreated seeds from local seed producers, or order organic seeds from international organic seed companies.

In order to overcome current lock-ins of organic seed use in Hungary, farmers' awareness about the benefits of buying organic seed is crucial.

2 Materials and Methods

In the frame of the LIVESEED project a national visit (21-24 November 2017) and a national workshop (12th March 2019) was organised with the involvement of the competent authorities, relevant implementing organizations and several stakeholder groups (e.g. seed producers, farmers, researchers) of the (organic) seed sector.

The Hungarian Research Institute of Organic Agriculture (ÖMKi) conducts on-farm trials, aiming to connect research and farming knowledge, to test the performance of different cultivars under organic conditions. The LIVESEED project presents a unique opportunity to advance organic variety testing and breeding models, including new participatory approaches, working with landraces and dynamic populations.

3 Results and Conclusions

The following incentives are discussed within the project, to foster the development of local organic seed production and use:

- self-organization of farmers' or their organization through market actors in order to create a stable demand for organic seeds may motivate seed companies to regularly produce organic seeds
- policy incentives to foster the development of organic seed use and organic seed production. In frame of the new organic regulation (in force from 2021) farmer's selection and production of heterogeneous seed materials (landraces, cross composite populations, variety mixtures) may provide a new opportunity to enhance local organic seed supply chains and crop genetic diversity
- a working group on organic seed that involves all sector players can facilitate strategic planning and harmonize actions in favour of organic seed use

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Involving heterogeneous material (landraces, farmer's selection and dynamic populations, cross composite populations) in organic variety tests and participatory organic breeding is expected to have additional benefits on crop diversification.

In our presentation we will provide first results from the LIVESEED national workshops and the pilot case study on fostering organic seed use and production in Hungary.

Towards effective networking for crop diversity in Europe

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1 Introduction

The widespread adoption of genetically uniform high yielding crop varieties developed for intensive farming, has led to an overall loss of diversity in agriculture and increased vulnerability of production systems to the extreme and unexpected environmental conditions brought about by climate change. To achieve sustainable food production in the face of this challenge, strategies for *in situ* conservation and collaborative management of plant genetic resources (PGR), including farmers' varieties, or landraces (LR) and crop wild relatives (CWR), with complementary *ex situ* conservation need to be implemented throughout Europe.

2 Materials and Methods

The EU-funded project, 'Farmer's Pride' (www.farmerspride.eu) is addressing this need by establishing a European network of stakeholders and sites for *in situ* conservation and management of LR and CWR diversity across the region. The focus is on strengthening and integrating existing organizations and processes to work towards a more collaborative, efficient and sustainable PGR conservation and use system. Key stakeholders include farmer and gardener networks, community seed banks, gene banks, protected area managers, plant breeders and research institutes representing both the organic and conventional sector.

3 Results and Conclusions

In this presentation, we explain how part of this process is to better understand how local seed systems interact with national gene banks, authorities, and private seed companies. By improving the management of community seed banks and by defining the roles of these different stakeholders—for example, in ensuring seed quality, good information management, and in developing national cooperation projects—we are working to create stronger and long-lasting local, national and international networks to secure PGR diversity, mitigate the negative impact of climate change and increase healthy food choices for consumers.

The industrialisation of agri-food systems and the demise of home-grown legumes in Europe

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1 Introduction

The multiple benefits of well-managed legume-supported agri-food systems are known and include provision of: nutritious feed and food; natural nitrogen cycling; improved soil qualities; lowered greenhouse gas emissions; protection of biodiversity; and good-food culture and literacy. Yet, these benefits are all-but forfeited since the vast majority of the legume grains used in Europe are not home-grown, and only rarely (knowingly), consumed directly by humans. Legume grains are mainly imported in the form of soybean for use as animal feed. Consequently, European farmed systems are characterised by specialised and intensive approaches using crops dependent on synthetic nitrogen fertiliser and pesticide inputs - again mainly routed to meat production. Harmonising of '*The Three Pillars of Sustainability*' ('social', 'environmental' and 'economic': Passet, 1979), demands that greater functional understanding (Figure 1) is applied and with respect to legumes.

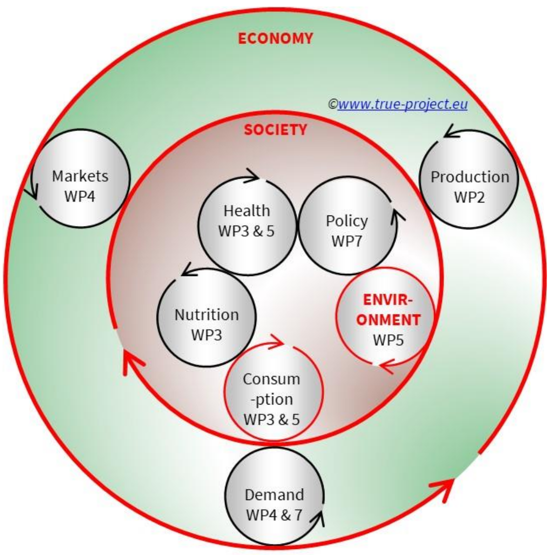

Figure 1. An illustrative model (opposite) which aims to help re-define 'The Three Pillars of Sustainability', in functional- or relational-terms, Each www.true-project.eu Work Package (WP) will define indicators of new sub-pillar components and WP8 (not shown, Transition Design is developing a Decision Support System to identify indicators of sustainable function for each pillar individually, and collectively.

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2 Materials and methods

New insight was gained from knowledge sources, including: 1, multi-stakeholder European Legume Innovation Network (LIN) workshops (www.true-project.eu/lin-workshops/); 2, the ECs report on, "*Market developments and policy evaluation aspects of the plant protein sector in the EU*" (https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/plants_and_plant_products/documents/plant-proteins-study-report_en.pdf); 3, abstracts and outputs made during the European Plant Protein Plan launch (https://ec.europa.eu/info/events/development-plant-proteins-europe-opportunities-and-challenges-2018-nov-22_en); 3, recent articles such as Eyhorn et al., (2019); and 4, public Deliverables published by the EU H2020 funded project TRUE, '*Coproduction of policy assessment*', https://www.true-project.eu/publications-resources/deliverables/.

3 Results

Modern day agri-food systems in Europe are characterised by high input dependency and a low level of environmental and societal safeguarding. However, the rejection of legume-based cropping systems preceded the global trade in grain legumes and the introduction of synthetic nitrogen fertilisers by several decades. This coincided with a period of increasing specialisation and intensification of production units to serve high-throughput processing units which demanded the highest possible yields - which could not be provided by grain legumes. These local market challenges have been exacerbated by current day global trade trends whereby political decisions permit the importation of soya (and other) legume proteins to the EU at low import tariff rates in exchange for low export tariff rates on cereals and oilseeds. If sustainable agri-food systems are to be enabled, effective policies and capacities must recognise these historical, and forfeited socio-ecological, contexts.

4 Discussion and Conclusions

Consumers are no longer passive recipients in a global protein market and wish to realise more-sustainable consumption. They question the nature of their food, such as its nutritional value, environmental impact of production plus authenticity and provenance. Demitarianism is increasing and specific types of carbohydrate are sought to help offset obesity and diabetes. The diversification of cropping systems and good agronomy will not by themselves realise more-sustainable legume supported food- and feed-chains. Greater cooperation among all supply chain actors is essential to establish a more-effective policy environment to help realise consumers' desires for access to the most-nutritious of food, affordably, and which is produced in a manner that ensures protection of the environment and biodiversity.

Acknowledgments

This research is supported by the European Union Horizon-2020 project '*TRansition paths to sUstainable legume-based systems in Europe*' (TRUE, www.true-project.eu), Grant Agreement 727973; and the Scottish Government's Strategic Research Programme. The James Hutton Institute (www.hutton.ac.uk) is supported by the Rural & Environment Science & Analytical Services (RESAS), a division of the Scottish Government.

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Crop diversification for organic agriculture in Scandinavia; a multi-scale feasibility study for soybean and lupine production in Sweden

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1 Introduction

Extending and growing a more diverse set of grain legumes is an opportunity to reduce the dependence on imported proteins as well as for diversifying agro-ecosystems. Lupine and soybean could be innovative solutions while offering a sustainable agronomic and economic alternative to organic farmers. Both species feature interesting characteristics for fodder production and for human consumption: while soybean is superior in grain protein content and oil, lupine is interesting for its high protein amount and especially its cysteine and methionine contents, which are scarce in locally produced grain legumes.

In recent years, attempts have been made to study the feasibility of soybean cultivation in Sweden, showing that early maturing soybean cultivars could cope with the growing conditions even up to 59° N with up to 2.4 t ha-1 grain yield and a typical protein content of 39-41%. Further, it has been demonstrated that narrow-leafed lupine can grow at latitudes of 60° N. Despite these advancements, there is a lack of scientific evidence for cultivar selection, crop management and productivity to support the development and realization of commercial soybean and lupine production in Sweden. Moreover, the cultivation of these crops was never done in contrasting Scandinavian pedoclimatic zones, in which differences in growing season- and day length are major constraints.

2 Materials and Methods

We address the raised aim and objectives in a broad interdisciplinary system research approach involving agronomists, biologists, weed scientists, entomologists, microbiologists and economists. The project aims to assess the biophysical and socioeconomic production potential for soybean and lupinees in Sweden, as well as the development and testing of economically and environmentally sustainable crop management strategies for these crops. The pedoclimatic suitability will be assessed in a spatial modelling approach. Here, we combine soil and climate data for comparison with the pedoclimatic needs of lupine and soybean cultivars and the production of site suitability maps. Based on these site suitability maps, we will design and test crop management strategies for the most promising cultivation regions in Sweden. The design and analysis of the crop management strategies will pay special attention on monitoring, prevention and control of weeds, insect pests and fungal diseases as well as on nitrogen (N) balance and carry over effects on subsequent crops. Furthermore, this study will assess consumer willingness-to-pay for fresh milk – a product which heavily relies on protein fodder as an input and thus a measure of a potential price for organic and regionally produced products based on these legumes – by means of a stated preference study (discrete choice experiment). The impacts of various soybean and lupine management and price scenarios will be assessed at farm level in terms of impact on farmer's revenues.

3 Expected results

The described project started in January 2019 for the duration of four years. The project will deliver detailed information regarding (I) site suitability, yield and quality potential for soybean and lupine grown in Sweden, (II) the economic and operational impact at farm scale, (III) consumers´ preferences and willingness-to-pay for food produced with locally produced plant protein as well as (IV) policy suggestions for fostering the cultivation of grain legumes in Sweden and beyond.

The group of stakeholders involved is covering the value chain from field to fork, comprising farmers, representatives from the food production industry, the Swedish Board of Agriculture as well as agricultural advisors. Although the project is focused on Scandinavia in general and Sweden in particular, we are seeking international collaboration with stakeholders along the value chain as well as other ongoing research projects in the area of organic grain legume production.

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Facilitating insects in agricultural landscapes through integration of renewable resources into cultivation systems – FinAL

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1 Introduction

Intensive agriculture is considered to be a major cause of the decline of insect diversity and biomass in rural Germany. The "FInAL" project will therefore establish Landscape Laboratories in representative agricultural landscapes of Germany where we will develop, demonstrate and evaluate innovative measures for facilitating insects through integrated cultivation of renewable resources in a landscape context.

The aim of FInAL is to demonstrate how diversity, biomass and functionality of insects can be enhanced in agricultural landscapes, especially through a diversification of the cropping systems by integration of renewable resources (i.e. energy crops and/or industrial crops). We consistently adopt a landscape approach based on regionalised guiding principles that encompasses both agricultural land and non-cultivated areas. The Landscape Laboratories, i.e. the landscape sections where crop diversification measures for facilitating insects will be established, will be investigated with respect to their initial state (base line), land-use options, and the effects of the measures on different features, primarily in relation to incidence and functionality (e.g. in integrated pest management) of various groups of insects.

2 Materials and Methods

The term Landscape Laboratory denotes a section of an agricultural landscape in which innovative measures for facilitating insects in cultivation systems are conducted (3 x 3 km). This involves a spatially extensive approach, i.e. the whole area of the Landscape Laboratory constitutes the object of study and, consequently, is treated with specific measures in its entirety. The selection of the Landscape Laboratories will particularly consider landscape types with high importance within the diversity of agricultural landscapes in Germany.

The choice and implementation of suitable measures will be based on a co-design process. This process in FInAL is orientated on the definition of Agricultural Living Labs (ALL Working Group 2019): *Transdisciplinary approaches which involve farmers, scientists and other interested partners in the co-design, monitoring and evaluation of new and existing agricultural practices and technologies on working landscapes to improve their effectiveness and early adoption*. The co-design process involves interviews with the farmers and other actors on their perception of practical measures form improving the landscape as habitat of insects. Together with an interdisciplinary panel of scientists, options for measures of cropping system diversification and biotope networks will be developed and discussed within workshops. From those, suitable measures for the respective Landscape Laboratories will be selected and prior to the implementation in the Laboratories, the measures will be pre-evaluated at test sites. The results from the Landscape Laboratories will be summarised and assessed in an integrative way with respect to the effectiveness of measures, acceptance by practitioners, transferability to other agricultural landscapes and the potential to provide frameworks for agricultural policies.

3 Discussion and Conclusions

The potential impacts on local biodiversity from energy crop cultivation needs to be considered in the context of severe biodiversity decline on agricultural land. Farming system-based approaches are relevant to answer the questions on whether a diversification of cropping systems by integration of energy and industrial crops could support diversity and abundance of insects and the ecosystem services performed by them, in particular biocontrol and pollination (Dauber & Miyake 2016). We therefore suggest linking the discussion on biodiversity impacts from energy and industrial crop production with those of agricultural land-management strategies for conservation of biodiversity and harnessing of ecosystem services, namely ecological intensification (Bommarco et al. 2013). Addressing both issues may be possible through the right selection of crop mixes (Dornburg et al. 2010) and the optimal agricultural practices (Chappell & LaValle 2011). Therefore, we are confident that a focus on the spatial-temporal scale of diversified farming system via Landscape Laboratories can provide solutions for food and energy security when considering biodiversity and ecosystem services as important features of sustainable production.

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SESSION 2. CO-DESIGNING CROP DIVERSIFICATION AT THE FIELD LEVEL: WHAT DO ACTORS WANT?

Chairs: Kevin Morel (Université catholique de Louvain, Belgium),
Anja Vieweger (ORC, United Kingdom)

ORAL PRESENTATIONS

- Co-design and multicriteria assessment of wheat variety mixtures for organic farming systems
  Speaker: Emma Forst, INRA, France
- Participatory strategy to build sustainable cropping system: upscaling from field to the territory
  Speaker: Corrado Ciaccia, CREA, Italy
- What do end-users expect from EcosysteMIX, a tool for supporting the design of crop mixtures?
  Speaker: Safia Médiène, INRA, France

POSTERS

- Enhancing diversification of cropping systems to minimize agri-environmental problems: Results of stakeholders' consultation in Italy
  Presenter: Claudia Di Bene, CREA, Italy
- Interplay: a serious game to design and evaluate the introduction of cereal-legume intercrops in cropping systems
  Presenter: Guillaume Martin, INRA, France
- Benefits and risks of companion plants sown with winter rapeseed according to farmers
  Presenter: Alice Baux, Agroscope, Switzerland

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Co-design and multicriteria assessment of wheat variety mixtures for organic farming systems

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1 Introduction

There are major challenges in agriculture, particularly in organic systems, such as stabilizing production in the face of increasing environmental heterogeneity. Increasing within-field diversity, especially by growing variety mixtures, represents an interesting lever to adapt to organic conditions, despite the limited varietal offer. Mixtures may allow to buffer abiotic stresses, stabilize productions (Østergård *et al* 2005), regulate pests and foliar diseases (Finckh *et al* 2000), improve weeds control, and optimize the use of resources, due to compensation and complementarity between varieties.

In the case of winter wheat, mixture components have been assembled primarily on the basis of their yield and protein content, their complementarity for disease resistances and to maintain homogeneity for height and maturity. Moreover, variety mixtures represent a simple lever to finely tune the choice of the varieties to fit with local context, through the opportunity of combining interesting variety traits. However, other criteria of interest for plant interactions such as tillering and earliness should be considered to design mixtures, but very few is known about plant interactions within variety mixtures despite the increasing surfaces sown with variety mixtures in France (Perronne *et al* 2017). We aimed to optimize the design of variety mixtures using relevant criteria and integrating farmers' practices and objectives for production (Barot *et al* 2017) and assessing designed variety mixtures in on-farm trials.

2 Materials and Methods

2.1 Co-design of assembly rules and wheat variety mixtures

In order to develop variety mixtures adapted to various environmental conditions and practices, an ideotyping participatory approach was implemented. This approach was first proposed on pure stand varieties by Debaeke *et al* (2014), and it was transposed to variety mixtures as part of the Wheatamix project. Here, we have adapted this approach to the context of organic farming with eleven organic farmers from the Ile-de-France region (GAB IdF).

i) Interviews were conducted with the farmers to describe their farming systems, practices and end-use requirements for wheat production.

ii) Workshops were carried out with farmers, technical experts and researchers to define assembly rules describing the traits to combine in a mixture (based on morphological, phenological, physiological characteristics and disease resistances) to buffer specific stresses or optimize resource use.

iii) Then, each farmer's wheat mixture was co-designed based on the assembly rules relevant to his context, the characteristics of available organic varieties and his practices.

2.2 On-farm assessment

These variety mixtures were evaluated in an on-farm strip experiment allowing for comparison between the mixture and the corresponding varieties in pure stands. They were assessed for three growing seasons (2015-2016, 2016-2017 and 2017-2018) on yield, quality (protein content, baking tests in 2018), competition against weeds (crop ground cover, wheat and weed dry biomass), development of foliar diseases and on their adequacy with respect to the farmers' specific objectives.

2.3 Multicriteria assessment tool

The assembly rules designed during the workshops and validated on the data are currently implemented in a multicriteria assessment tool, previously developed on rules to reduce disease development in mixture. This tool aims at helping farmers designing and evaluating variety mixtures tailored to their needs.

3 Results

3.1 Co-design of assembly rules and variety mixtures

The knowledge shared during the workshops has led to the identification of various strategies and assembly rules for designing mixtures for two major objectives:

- to increase weed control by limiting the weed density and development, and improving wheat competitive ability through diversified heights and growth habits,

- to face nitrogen stress by tolerating an early deficiency, spreading nitrogen demand with heterogeneous earliness, and favoring nitrogen utilization by mixing varieties with contrasted quality type.

3.2 On-farm assessment

The on-farm agronomical assessment of the 17 co-designed mixtures over three years showed a mean over-yielding of 4.8%. Mixtures never performed lower than the worst pure stand variety within trials, showing their ability to limit risks of important yield losses.

The mixtures stabilized the protein content (compared to the pure stands), and improved other evaluation criteria for farmers such as disease reduction and weed control. They obtained high scores on baking tests (compared to pure stands).

3.3 Multicriteria assessment tool

The tool should provide farmers with a detailed feedback on the assessment of their mixtures and the rules underlying this assessment, helping them in adjusting the choice of the varieties composing their mixtures.

4 Discussion and Conclusions

The results of the on-farm assessment of the variety mixtures tend to confirm the interest of mixtures in organic systems due to their ability to improve several criteria (quantity and quality) together. The high results on baking tests should be validated on further experiments.

Farmers designed a diversity of mixtures adapted to their local needs. However, the organic wheat variety offer remains limited, it should be enriched by varieties specifically bred for improved mixing ability and using mixture ideotyping.

This work emphasizes the interest to exchange knowledge and information between actors form different disciplines (agronomists, geneticists, ecophysiologists) and perspectives (theoretical, applied and practical) for co-designing ideotypes and for decentralized evaluation of the mixtures.

This ideotyping method based on shared knowledge between actors and on-farm trials might further benefit from exchanges with crop modelers for further understanding plant-plant interactions within wheat variety mixtures using simulated data.

The participatory approach was particularly relevant for identifying and addressing farmers' and practitioners' needs for optimizing mixture design in terms of practical recommendations, experimental results and flexible multicriteria assessment tool.

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Participatory strategy to build sustainable cropping system: upscaling from field to the territory

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1 Introduction

The intensification of agriculture derived from Green Revolution and an increasingly globalized system has led to the progressive specialisation of farms and a new organization of agro-industrial sectors. Several negative externalities are lionked to the – sometimes extreme - simplification of agricultural systems in term of structures, elements and processes (Meynard et al., 2013) or the progressive loss of farmer's central role in the food system in terms of decision-making power, and often reduced to simply implementing "recipes" (Lacombe et al. 2018). In this context, agroecology principles, as the ecology of the entire food system, can drive towards new food system, characterised by diversified agroecosystems and a radical change in governance processes (Gliessman, 2016). Pursuing this aim, food systems should encompass social and economic aspects, including communication and coordination among stakeholders, in a holistic and systemic approach (Wezel et al., 2016). This "system re-design" should be hence capable to overcome the weaknesses of agricultural models based on "input substitution", also in organic (Darnhofer, 2010), scale up to wider and more complex perspective, turning governance from individual to collective and tuning, meanwhile, effective mechanisms of participation (Gliessman, 2016). The multi-stakeholder involvement is indeed acknowledged for promoting dynamic innovation processes (Delate et al. 2016) and, in this context, long-term experiments (LTEs) can be field laboratories of participatory research, allowing the continuous exchange of innovation and information among all the stakeholders of the value-chains including also the scientific communities.

In the present study, we report the main goals reached by an ongoing participatory process carried out among researchers and farmers in Rome, Central Italy, and including activities in a LTE and in actual farms. With the final aim of setting up a pilot experience for further similar initiative at National scale, the process objective was twofold: i) engage stakeholders in an effective collaborative environment in identifying the research priorities for the organic production local area; ii) set-up a new LTE reflecting the research priorities identified within the multi-stakeholder platform previously defined.

2 Materials and Methods

Started in 2015 and still going on, the study stemmed from a CREA interest – CREA, Council for Agricultural Research and Agricultural Economics Analysis – in activating a re-design strategy able to encompass both the establishment of a loose network of organic farms in the Latium region, central Italy (i.e. stakeholder platform) and the identification of the local research priorities with the ultimate goal of establishing a new LTE and parallel trials in the farms of the network.

Participatory approach was used to sketch the research needs perceived by organic farmers within fruit production in Central Italy, following a three-steps process (Figure 1). In the first step, after a context analysis of fruit sector by researchers, a 'participation in information giving' strategy was put into place (Pimbert, 2011: 14): farmer participation was limited to the extraction of information by answering questions posed by researchers in a questionnaire surveys. The questionnaire was prepared by CREA researchers and administrated by the Italian Association for Organic Farming (AIAB), partnering with CREA for this specific purpose. In order to reach a collective perspective of research demands for organic fruit production, a frontal meeting was organized with the selected farms. Priorities of investigation were given for the joint research activities to be carried out in a new LTE and in new planted orchards in the farms of the network (third step). Overtime, before and after the orchards installation and trials, meetings were organized to share observations and collect feedbacks (step two). These activities were hence carried out following a modified 'Participation by consultation' approach (Pimbert, 2011: 14): participants were consulted by researchers able to catch the relevant issues and to define solutions, which might be modified in the light of participant's responses (O'Brien, 2001).

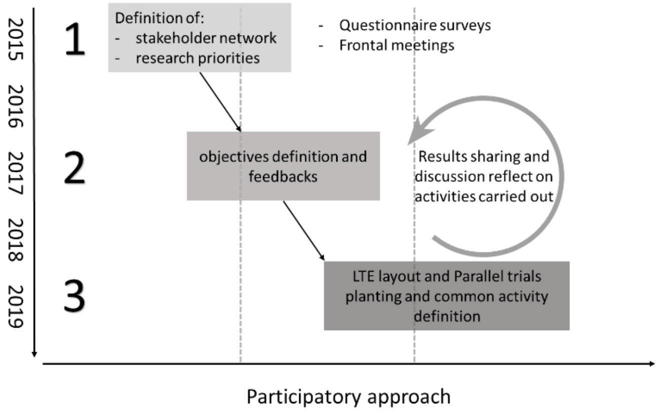

Figure 1. Three steps process followed to establish the farm network and the trials set-up

3 Results

Firstly, 5 farms were selected based on their representativeness of the organic fruit sector in Latium region. All selected farms shared similar needs in terms of research demand and market opportunities for fruit production. In the first frontal meeting with farmers, apricot (*Prunus armeniaca* L.) was identified as target crop whereas soil management and rootstock x cultivar choices were recognized as main issues to be investigated. Then, together with farmers, ten apricot varieties (driving characteristics in selection: precocity in fruit production, fruit colour and size, quality parameters) and two rootstocks (plant vigour) were selected as promising for organic agriculture and for Latium market. In the MAIOR (MAintaInance of Organic Orchards) LTE in Rome, a new orchard was designed to test two of the promising apricot varieties within three systems at different levels of "agroecological intensification" (Wezel et al., 2015: i) a Businness As Usual (BAU – common practices – soil tillage and commercial fertilizer), ii) Innovative diversified system with Natural cover and Compost use (INC – no soil tillage at transplanting, natural cover, Municipal Waste Compost), iii) Innovative diversified system with introduced Cover and Compost use (ICC – introduction of Agroecological Service Crops, tillage and MWC). The new orchard was planted in spring 2017. Lastly, parallel trials were realized in the early 2018 at farm level, and the "satellite orchards" with ten varieties and different rootstock combinations. The MAIOR LTE completed the "apricot network", and network meetings are organized on regular basis, where opportunities and bottlenecks are discussed in open-day visits.

4 Discussion and Conclusions

The studied process highlighted the feasibility of joint research activity by focusing the research priorities at local level as well as their implementation in experimental trials. Stakeholders (e.g. farmers, researchers) may collaborate in planning, management and coordination of the experiments, hence co-designing the cropping system represented by the trials. By including LTE as part of the network, the LTE can become a territorial hub of innovation, in which: i) research demands derive directly from stakeholders, ii) research issues are addressed and tested in the LTE and iii) results are discussed within the same stakeholder platform. Furthermore, the connection with satellite farms may maximise the impact of the activities at local/territorial scale. In this context, such participatory research activities may allow to overcome the lock-in of single field management, aiming to widen goals further than the only ones of the group of participants (Bruges and Smith 2008). The networking of experiences structured this way can be considered a scaling up strategy, to be followed also in other territories/contexts, activating a long-term co-innovation approach, towards a food system redesign according to Agroecology principles.

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DiverIMPACTS European Conference on Crop Diversification September 18-21, 2019 Budapest, Hungary

What do end-users expect from EcosysteMIX, a tool for supporting the design of crop mixtures?

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1 Introduction

Tools in agronomy are developed to enhance innovations by making the fruits of research accessible and usable among practitioners [1]-[5]. Although certain tools are popular and adopted among their targeted end-users, others are not, thus inducing a failure in the support for practitioners towards innovation. The major reason explaining this problem of implementation is the lack of implication of the end-users into the design process [6]. From the point of view of ergonomists, the design process should be shared between designers and users, since the use of a prototype by the end-users under realistic conditions highlights their issues and their needs [7]. Integrating end-users into the design process is possible through a three-step participatory approach [6]: (i) a diagnosis of use situations among targeted end-users, (ii) participatory workshops for designing a prototype of the tool, (iii) a test of an operational prototype by its end-users. EcosysteMIX, a tool for supporting practitioners in the design of crop mixtures with annual crop species grown in mainland France, will be designed following this approach. Here are presented the results of the diagnosis of use situations conducted in early 2019.

2 Materials and Methods

A diagnosis of uses was conducted for initiating the design process of EcosysteMIX. Three goals were intended [6]: (i) identifying the diversity of use situations and better characterizing the uses of existing tools for designing crop mixtures, (ii) describing innovative solutions developed by potential end-users themselves to face the considered problem of designing crop mixtures, thus achieving functionalities envisaged in EcosysteMIX, (iii) preparing the next steps of the design process, i.e. identifying actors with whom the design process of EcosysteMIX will be led, and use situations in which the test of EcosysteMIX prototype will be performed. The diversity of use situations being more important than their representativeness, a snowball sampling method was implemented for identifying the 35 actors that were contacted for a semi-structured interview between January and March 2019. These actors were potential stakeholders for the design and/or potential end-users of EcosysteMIX. Most of the interviews were recorded, and then transcribed to allow the analysis of the collected qualitative data.

3 Results

The interviews of the diagnosis of use situations were conducted in early 2019 among 35 actors with diverse professional categories: farmers, agricultural advisers, development actors, experimenters, companies and cooperatives, scientific researchers and higher education teachers (Figure 1).

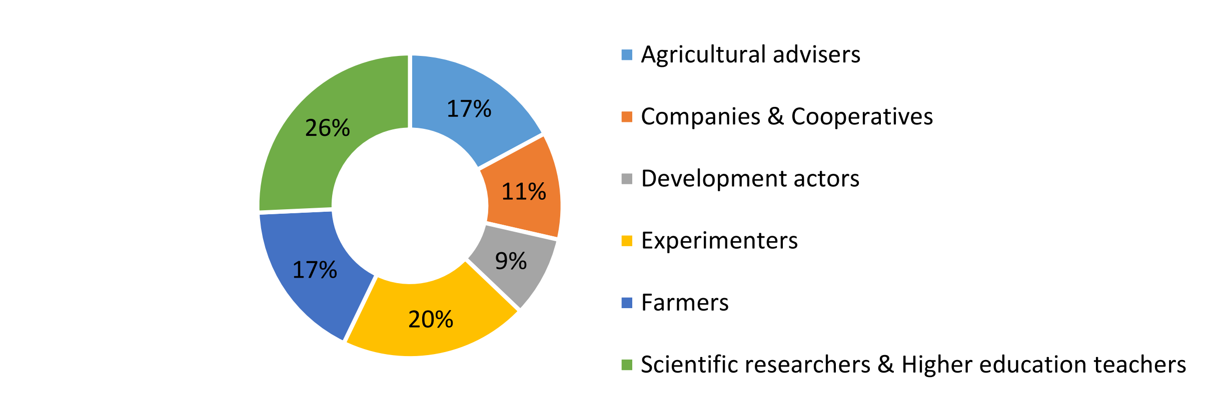

Figure 1. Professional categories interviewed for the diagnosis of use situations

The use situations, i.e. the way these actors represent and interpret the problem considered for EcosysteMIX (i.e. how to choose suitable crop species to mix under given agro-environmental conditions to deliver one or several ecosystem services) are being analyzed, as well as the way they decide and act when facing it, the innovative solutions and existing tools they found to address it, and all the material, organizational, informational constraints they meet and that hinder the implementation of the crop mixture practice.

4 Discussion and Conclusions

EcosysteMIX will aim at exploring and opening up new possibilities, and at sharing knowledge about crop mixtures in a didactic way. However, do all potential end-users have the same goals about mixing crop species? Do they need the same tool functionalities and will they use the tool in the same conditions? Answering these questions will enable the identification of new concepts that could support the design of crop mixtures and that could be incorporated into EcosysteMIX to better match the end-users' needs. In addition to that, the diagnosis of use situations will allow the identification of experts with relevant knowledge that could contribute in the design process of EcosysteMIX, and the identification of the situations in which the test of prototype could be conducted. Results of this diagnosis will be presented during the European Conference on Crop Diversification with the scope of providing clues and orientations for the development of relevant tools suited to end-users needs for supporting the design of crop mixtures. More generally, perspectives of such exercise in a tool participatory design process will be highlighted and discussed.

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DiverIMPACTS
European Conference on Crop Diversification
September 18-21, 2019
Budapest, Hungary

Enhancing diversification of cropping systems to minimize agri-environmental problems: Results of stakeholders' consultation in Italy

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1 Introduction

Since the late 1950s, the advances in agronomy, genetics, and chemistry significantly increased crop yields worldwide. However, the strong simplification and intensification of conventional farming systems, through a growing use of chemical inputs, water, fossil fuel energy, and agrochemical products (fertilizers, pesticides), have caused significant environmental impacts (Wezel et al., 2018). These impacts include groundwater pollution, greenhouse gas emissions, soil erosion, loss of biodiversity, and reduction of agroecosystem services – such as loss of soil fertility and soil degradation. Collectively, these impacts have implications for long-term farming system sustainability and environmental quality. Therefore, the adoption of crop diversification strategies (e.g. rotation, intercropping, and multiple cropping) and alternative management practices (e.g. reducing tillage intensity, organic and mixed fertilization, crop residue management, and optimizing water use efficiency for irrigated systems) allows to achieve sustainable systems and food production with lower inputs, and minimizing the environmental and social impacts of agricultural practices without compromising crop yields and incomes. In this context, the five-year Horizon 2020 Diverfarming project (www.diverfarming.eu) aims to define sustainable, diversified cropping systems with low-input farming practices, adopting a multi-disciplinary approach across Europe.

In the Mediterranean Basin, arable agricultural systems are highly specialized and characterized by a few improved high-yielding species, mostly oriented on cereal-based intensive cropping systems under rainfed or irrigated conditions as monoculture, or short rotations such as wheat-summer irrigated crops, or mixed succession with bare fallow (Di Bene et al., 2016; Francaviglia and Di Bene, 2019). The region is extremely vulnerable to environmental or anthropogenic pressures and increasing the diversification of cropping systems can stabilize agroecosystem productivity more than conventional agriculture (monoculture, intensive tillage, and higher external inputs), enhancing resilience to environmental stress. To achieve this, more attention should be given to the specific local knowledge of soil and land management, involving local stakeholders from the beginning of research activities with participatory methods (Bampa et al., 2019). Therefore, this study directly engaged stakeholders by public consultations to capture their practical knowledge of current farmer practices for promoting suitable diversified cropping system in Italy. In particular, both rainfed-cereal and irrigated-cereal cropping systems were addressed. The consultations also aimed to investigate the interest of stakeholders on potential crop associations and alternative low-input farming strategies for decreasing external inputs and minimizing agri-environmental and socioeconomic problems.

2 Materials and Methods

The consultation was based on a questionnaire organized in five parts: 1) general interview information; 2) identification and assessment of the most relevant agri-environmental problems in the study area; 3) selection of measures to tackle the identified problems; 4) selection of diversification alternatives; and 5) management strategies to reduce the impact of conventional cropping systems. The questionnaire, developed by the University of Cartagena (Spain), was implemented online and designed to be easily compiled using laptop, tablet or smartphone.

Between 20 and 30 representative stakeholders were intended to be consulted with the following distribution: 1) farmers and technical agricultural advisors (n=12-15); 2) field technical officers from public agricultural administrations (n=3-5); 3) technical experts from NGOs with experience on farming practices (n=2-5); and

4) researchers in agriculture (n=3-5). With the involvement of Italian farmers associations, agricultural cooperatives, and companies a total of 50 stakeholders were selected and directly invited to fill the questionnaire.

3 Results

The main outcomes were grouped by rainfed-cereal and irrigated-cereal cropping systems. We got 40 completed questionnaires: 1) farmers and technical agricultural advisors (n=25); 2) field technical officers from public agricultural administrations (n=7); 3) technical experts from NGOs with experience on farming practices (n=1); and 4) researchers in agriculture (n=7). The answers were downloaded in an Excel format template for validation and analysis.

In the rainfed-cereal systems, crop rotation, intercropping and multi-cropping were proposed as management alternatives, with crop rotation reaching 85% of the preferences. Faba bean, alfalfa and mixed legumes-cereals cropping systems were identified as the most feasible crop diversification strategy, accounting for 78% of preferences. In rainfed systems, organic matter inputs, conservation tillage (no-tillage and reduced tillage) and cover crops were preferred as soil conservation and weed management strategies, while integrated management was preferred for pest control.

In the irrigated-cereal systems, crop rotation, intercropping and multi-cropping were proposed as management alternatives, with crop rotation reaching 67% of the preferences. In these systems, limited-irrigation strategies are frequently adopted in horticultural crops (e.g. tomato). Moreover, precision agriculture was indicated to optimize fertilization, while organic matter inputs, cover crops, and conservation tillage were chosen as soil conservation and weed management strategies.

4 Discussion and Conclusions

The results presented allowed to identify relevant strengths and drawbacks for the implementation of diversified cropping systems under low-input agricultural practices. A major strength is that the crop alternatives selected for the diversification are already cultivated as monocultures and are adapted to the local pedoclimatic conditions. So, farmers just need to learn how to use them in combination as rotations, multiple cropping or intercropping.

On the other hand, a major weakness is that few farmers are experts in crop diversification. Thus, providing adequate training for public officers and agricultural technical advisors is crucial for successfully implementing diversified cropping systems among farmers. Additionally, the identified low-input farming practices are easy to implement, are not costly, do not require major investments in new machinery nor great farming skills to learn them. This suggests a further significant potential for their implementation at the technical level.

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Interplay: a serious game to design and evaluate the introduction of cereal-legume intercrops in cropping systems

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1 Introduction

The development of intercropping in European arable farms progresses slowly. A practical challenge to a larger spread of intercropping is the design of optimized and locally-adapted management practices. In the field, there is a diversity of farmer constraints and objectives, and hence of possible combinations between species and cultivars, sowing dates, densities, spatial design and even fertilization, weeding and plant protection strategies. Due to this complexity, very few farmers are innovative and try a wide range of possibilities of intercropping but most of them are rather conservative and limit their practice to cereal-legume mixtures with both species sown and harvested together.

Due to the resources required and to the complexity of intercropping, field experimentations and computer simulations are insufficient to quickly progress beyond the state of the art and provide sufficient locally-adapted knowledge. Building on innovative farmers' knowledge of intercropping management practices and their outcomes is an option currently undervalued by researchers and consultants. This silent empirical knowledge has a powerful potential to complement our scientific knowledge. One way to get this knowledge elicited and shared within the farming community is the use of serious games (i.e. games that educate, train, and inform).

We are developing a decision-support serious game called *Interplay* allowing farmers to explore locally the diversity of intercropping management options given expected services and constraints at the cropping system level among researchers, consultants and farmers.

2 Materials and Methods

Interplay is being designed following a problem-driven strategy to address the introduction of intercropping in cropping systems of European arable farms. It is being developed following a participatory approach involving agricultural consultants and farmers at every stage of the modelling process from selecting the components integrated in *Interplay* to interpreting the simulation outputs to eventually reframe the problem towards practicing intercropping. This way, the relevance of the game is confronted to a diversity of pedoclimatic and farming contexts, and expert knowledge is elicited for the corresponding range of situations.

3 Results

Interplay includes a game board representing a cropping system over time where, in a first step, crop cards can be placed to represent the crop sequence. In a second step, the ecosystem services expected from intercropping (soil structure conservation, erosion control, N supply, pest, disease and weed control, grain production and cereal protein content) are prioritized with the level of service specified using ecosystem service cards. Whether each service is expected at the intercrop level, at the cropping system level or both can be indicated on the game board. In a third step, intercropped species are chosen based on stakeholders' knowledge. If needed, the Ecosystemix tool can be used (Balandier et al., this conference). It allows sorting cereal and legume species according to their suitability to provide the expected ecosystem services when intercropped. In a fourth step, it is possible to specify the main

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decisions regarding intercropping management: the cereal and legume cultivars used (height, earliness, resistance to lodging), the spatial design (mixed or row intercrop), the sowing density (balanced or in favor of cereal or legume), the date of sowing (simultaneous or not, early or late) and the level of pesticide and fertilizer use. This way, scenarios of introduction of cereal-legume intercropping in cropping systems can be designed.

To evaluate the scenarios designed, we are developing a Dexi multi-criteria assessment model. This model assesses the level of ecosystem services provided by the scenario of cereal-legume intercropping and allows comparison of soil structure conservation, erosion control, N supply, pest, disease and weed control, grain production and cereal protein content levels expected and simulated. Thus, it is possible to check if the expected levels of ecosystem services are met. The Dexi model is being calibrated based on published scientific knowledge and on expert knowledge (advisors and farmers) gathered through interviews.

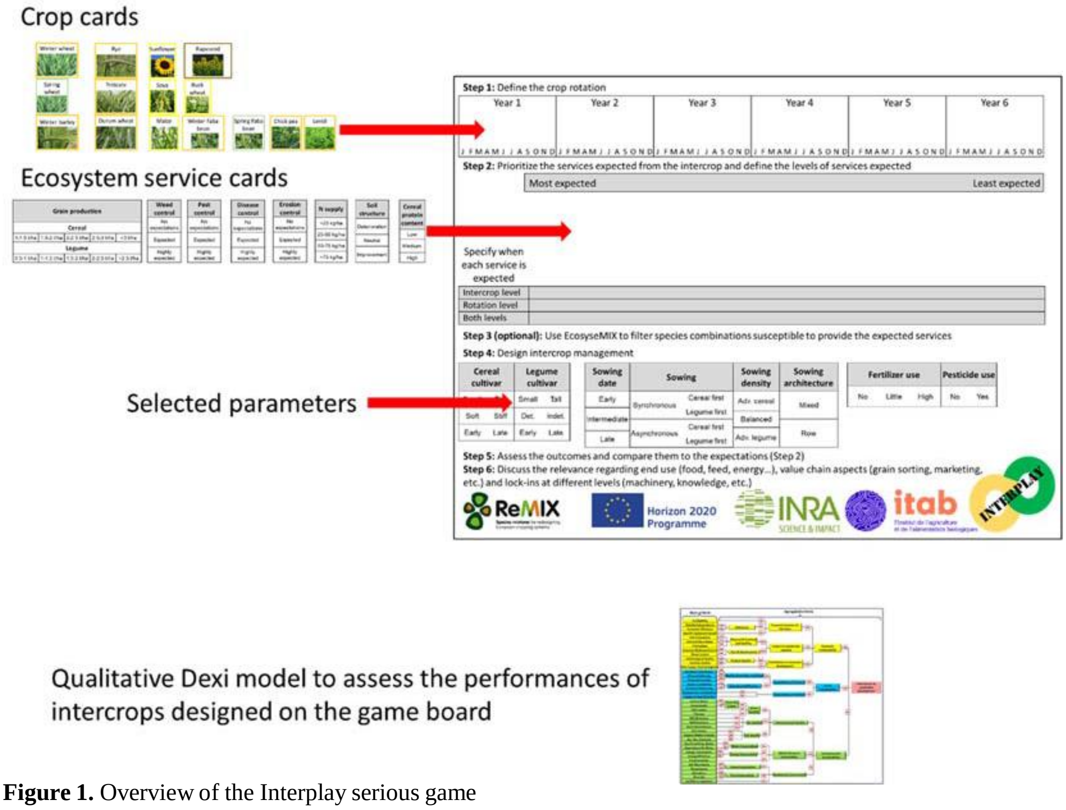

Figure 1. Overview of the Interplay serious game

4 Discussion and Conclusions

The prototype of *Interplay* is being tested in France with groups of farmers and consultants during 2-3 hour workshops. Participants iteratively design and evaluate scenarios. It is expected that *Interplay* will enable addressing the impacts of the management of cereal-legume intercropping on the cropping system, and in turn help farmers to test new combinations of species and management. This may promote co-learning through virtual experimentation, enriching discussions among researchers, consultants and farmers with visual and quantitative information, sharing of locally-adapted experience and knowledge on intercropping management, etc.

Acknowledgements

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Benefits and risks of companion plants sown with winter rapeseed according to farmers

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1 Introduction

The use of frost sensitive companion plants, sown with winter rapeseed (WRS), started a few years ago in Switzerland. It only represents a small fraction of the WRS area, but seduces more and more farmers, resulting in an increase in sales of seed packages for WRS. It is considered as an efficient solution to produce WRS with less phytosanitary products and nitrogen fertilizers (Cadoux et al. 2015), and thanks to legume species, could even result in slightly improved grain yield (Verret et al. 2017). In a context promoting more extensive systems, it seemed important to understand the motivations, concerns and fears of the farmers, toward the recent development of this technique, in order to identify opportunities of improvement of WRS management and better use of services plants.

2 Materials and Methods

A survey among Swiss WRS producers gathered their practices and opinions on intercropping with WRS. The survey was sent by email to Swiss producers, and could be answered online. The 33 questions asked about (i) general structure of the farm, (i) WRS management and (iii) farmers' opinion about companion plants. The last part (iv) was only for farmers who were growing their WOSR with companion plants, and allow them to share their experience and the improvements they wish for.

3 Results

The survey gathered 1063 answers, representing about one sixth of the producers. The data showed great disparities between Western and Eastern Switzerland. Whereas in the first one, intercropping is being more and more popular, it remains confidential in the rest of the country. Sowing WRS with companion plants was more frequent when the farmers chose to grow this crop with minimum tillage. Moreover, it was often combined with the "extenso" program, designed to support farmers producing without any fungicide or insecticide, resulting in a sharp reduction of crop protection treatments compared to the conventional management. Most farmers acknowledged that intercropping was efficient to reduce weeds and allowed them to give up herbicides, but the fear of a negative impact on yield is still very high.

The choice of species sown with the WRS revealed various strategies among farmers. Two third of them are sowing one of the "mixture for WRS" offered by seed retailers. The most common are a mixture of six species, both legume and non-legumes (niger, buckwheat, grass pea, common vetch, berseem clover, lentil), and a mixture of 3 legumes (lentil, grass pea and fenugreek). Other farmers made their own mixture on the farm, sometimes following the advices of extension services. They use some of the previously cited species, and sometimes add faba bean, or non-frost-sensitive legumes like white clover, red clover or alfalfa, that will remain alive after the harvest of the WRS.

4 Discussion and Conclusions

The particularly high response to the questionnaire showed a great interest for the technique, even from farmers who have no experience with intercropping. The one using services plants expressed a general satisfaction, in spite of doubts concerning the impact it may have on the yield. This seems to confirm that subsidies set up to promote low pesticide farming could play a decisive role in the decision of sowing services plants. However, large disparities remain among Swiss regions. The work of extension services in the western part of Switzerland seems to have a large part in the success of intercropping in this area. In order to extend this practice to other areas, and achieve low pesticide WRS production, it is necessary to better inform farmers, but also to propose better suited mixtures, adapted to the large diversity of farms, pedoclimatic conditions and soil tillage techniques.

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SESSION 3. NICHE MANAGEMENT AND DIVERSIFICATION PROJECTS: HOW TO TURN THEORY INTO ACTION AND VICE VERSA?

Chairs: Henrik Hauggaard¬Nielsen (Roskilde University, Denmark),
Barbara Koole (University of Amsterdam, The Netherlands)

ORAL PRESENTATIONS

- Diversification of cropping systems in a context of shallow soils: implementation and performances of both on-station and on-farm systems
  Speaker: Stéphane Cadoux, Terres Inovia, France
- Co-design and assessment of agronomical scenarios for reintroduction of legumes into a French territory
  Speaker: Elise Pelzer, INRA, France
- Investigating farmer-driven co-innovation for increased species mixture cropping in European agriculture using the Danish ReMIX multi-actor approach
  Speaker: Ane Kirstine Aare, Roskilde University, Denmark
- Multi-actor approaches for diversified cropping systems: fostering complexity-sensitivity through co-innovation in DiverIMPACTS
  Speaker: Walter Rossing, Wageningen University and Research, The Netherlands

POSTERS

- Analysis of a sample of strategies for sustainable development in arable crops
  Presenter: Anne Schneider, Terres Inovia, France

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Diversification of cropping systems in a context of shallow soils: implementation and performances of both on-station and on-farm systems

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1 Introduction

A shift towards new production systems, based on ecological intensification, adapted to local conditions, and manageable by farmers is expected (Duru *et al.* 2015). Diversification of cropping systems in space and time is often claimed as a main driver for providing the necessary ecosystem services (Gaba *et al.* 2015). In France, an important area of arable crop production called 'intermediate zone', crossing the country from west to east at the south of Paris, is characterized by shallow and stony soils with low potential. In these situations rotations are generally short and based on winter crops (rapeseed/wheat/barley) and tillage is often reduced. These systems typically encounter agronomic problems: yield stagnation, increasing difficulties in controlling weeds and pests despite a high pesticide use. In that context, the diversification of cropping systems is particularly relevant, but its implementation on farms is hindered by the high risk of crop water stress.

To adress this issue, we developped, wthin the frame of the French project 'Syppre[1]' and of the European project DiverIMPACTS, an approach combining (i) the support to farmers in transition in their farm and (ii) on-station experiment of an innovative cropping system co-designed with local advisors and farmers. The aim of this paper was to describe the approach used, the cropping systems implemented, their performances and discuss the strengths, weaknesses and obstacles to cropping system diversification in this context.

2 Materials and Methods

The work was carried out in the center of France, in a semi-oceanic climate. The soils were stony clay-limestone of shallow to medium depth with low water holding capacity.

The group of farmers was set up about ten years ago. Originally, they requested the support of Terres Inovia to understand the origin of problems of yield stagnation and pest control in rapeseed and to find solutions. The group's thinking has gradually broadened to the scale of the cropping system and now aims to obtain "a fertile soil for robust crops". It now includes 12 farmers. Its approach consisted of (i) field visits at several times of the year to share information on the practices implemented and their results, and (ii) indoor meetings to share the assessment of the agricultural campaign and ideas for improvements. Advisors from local development structures (cooperatives, agribusiness, chambers of agriculture, etc.) were systematically involved in these meetings so that they can bring their expertise in and benefit from group's ideas and approach.

In parallel, in 2014, the farmers of the group and the local advisors were involved in the co-design of prototypes of innovative cropping systems aimed at reconciling local (defined by the group) and global challenges (productivity, profitability and low environmental impacts), led by Terres Inovia as part of the inter-institute project Syppre[1]. The *a priori* most performing prototype was selected and has been tested on-station since 2016. Visits and discussions on the results were shared with those of the farmer network to stimulate innovation in both schemes.

The performances of farmers' cropping systems and of the Syppre experiment were evaluated using the French tool Systerre® (Weber *et al.* 2018). For farmers' systems, to reduce the workload of evaluating twelve farms over several years, we have described with the farmers a typical 'current' and 'before support' system for the two main soil types of the group's farms. In this paper we only present the results for the shallow clay-limestone soils.

[1] The Syppre project "Building tomorrow's systems together", co-led by Arvalis - Institut du végétal, Institut Technique de la Betterave (ITB) and Terres Inovia, was launched in 2013 for the long term.

3 Results

The rotation of the typical 'before support' cropping system of the farmers was rapeseed-wheat-barley. Identifying problems of soil fertility, the farmers decided to diversify their cropping systems with the introduction of legume crops. They first introduced multi-species cover crops and came up with the idea of intercropping rapeseed with frost sensitive legume crops. They developed this innovation that is now used on 12% of rapeseed surfaces in France (Wagner and Lecomte 2019). Then they gradually lengthened their rotations, often with the insertion of lentil, in order to disrupt weeds and bring symbiotic nitrogen. This spring crop is adapted to shallow soils and benefit from a growing market. The rotation of the typical 'current' system defined with the farmers was intercropped rapeseed-wheat-lentil-wheat-barley. The gross margin improved by 7% while the treatment frequency index of pesticides (TFI), the amount of mineral fertilizer-N, and the greenhouse gas (GHG) emissions were reduced by approximatively 25% (Table 1).

Table 1: performances of the typical on-farm and on-station cropping systems.

	On-farm systems		On-station systems			
			2016-2017		2017-2018	
	Typical 'before support'	Typical 'current'	Control	Innovative	Control	Innovative
Gross product (€/ha)	1110	1126 (+1%)	942	955 (+1%)	1094	935 (-14%)
Gross margin (€/ha)	585	624 (+7%)	437	545 (+25%)	613	549 (-10%)
TFI	7.56	5.85 (-23%)	6.8	3.6 (-47%)	5.3	3.7 (-29%)
Fertilizer-N (kgN/ha)	177	137 (-23%)	174	113 (-35%)	158	104 (-34%)
GES emissions (kg CO2-eq)	2645	2018 (-24%)	2149	1577 (-27%)	2276	1587 (-30%)

The farmers of the group were strongly involved during the co-design of the innovative cropping system to be tested on-station. The selected innovative cropping system was based on a nine-year rotation. It included a succession of lentil, durum wheat and intercropped rapeseed proposed by a farmer who successfully practices it. To disrupt weeds a succession of two spring crops: maize, sunflower, followed by a wheat, was selected. These two crops were rarely grown in this low potential context, but farmers were interested in seeing if the agronomic benefits could make their introduction profitable. The crop rotation ended with winter pea intercropped with wheat-wheat-winter barley. A control system with an intercropped rapeseed-wheat-barley rotation was experimented alongside the innovative one.

The environmental performances of the innovative cropping system over the first two years were satisfying. The treatment frequency index was reduced by 30 to 50%, the amount of mineral fertilizer-N and the greenhouse gas emissions were reduced by approximatively 30% compared to the control system. The productivity and the profitability were improved in the first year but were worse in the second year of experiment.

4 Discussion and Conclusions

Thanks to an interactive and participative support approach, farmers have diversified their systems over 10 years with the benefit of an overall improvement in performances. But weed control difficulties persisted for most of them. The on station cropping system was further diversified. The performances were very positive in the first year notably due to a summer rainfall pattern favourable to spring crops. At the opposite a summer drought in 2018 led to very low yields of summer crops, penalizing the system's profitability. Nevertheless, farmers remained interested in knowing long-term performances as well as the practical feasibility of such a diversified system. The involvement of farmers in the co-design and steering committee of the on-station experiment seemed to be an effective way to help them explore innovative pathways for the step by step re-designing of their on-farm cropping system.

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Co-design and assessment of agronomical scenarios for reintroduction of legumes into a French territory

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1 Introduction

Legumes have many interests in cropping systems because of their ability to fix atmospheric nitrogen, thus reducing nitrogen input use at the crop rotation scale. They are also an interesting source of protein for feed and food. Therefore, legumes can help meeting current environmental and food challenges. However, their cultivated areas have seriously decreased over the past decades (Voisin et al., 2014). A sociotechnical lock-in (organization of value and supply chains, major investments for storage and breeding companies, etc.) hinders the reintroduction of these minor crops. Increasing their production requires the implementation of specific coordinated actions between agricultural and industrial actors, and the territory is assumed to be a good scale for that, as it allows strong exchanges (Magrini et al., 2016). A participatory approach was proposed to the stakeholders of the Plateau Langrois territory (89,800 ha in Burgundy, France) to help them thinking about the modalities for overcoming the socio-technical lock-in toward legumes reintroduction by designing scenarios of introduction of legumes in their territory.

2 Materials and Methods

The stakeholders involved in this study came from various organizations specialized in agriculture (farmers, technical advisors from local cooperatives and Chambers of Agriculture), in environment (water union and the National Park of the Champagne-Bourgogne Forests) and in research.

The participatory approach was displayed in three steps: (i) design, with local stakeholders, of agronomic scenarios for the reintroduction of legumes, (ii) *ex ante* assessment of these scenarios with their chosen criteria, and (iii) discussions on the conditions for their implementation in the territory. These different steps were based on the analysis of national statistical data and surveys of local actors as well as on the facilitation of participatory workshops. In total, three one-day workshops were conducted: a workshop on the design of innovative cropping systems including legumes and two workshops on scenario design and evaluation. The Coclick'eau optimization tool (Chantre et al., 2016; http://coclickeau.webistem.com/bac/) was parameterized by the research team based on these data and the ideas expressed during these workshops.

3 Results

First, current and prospective crop management sequences were described and assessed, based on statistical data, on the results of individual surveys, and on the results of the first workshop on the design of innovative cropping systems including legumes. This made it possible to share with the stakeholders a representation of the current territory, corresponding to a distribution of crops and their crop management sequences. This scenario was used as a baseline for assessing prospective scenarios.

The stakeholders then expressed their expectations for this territory, in the medium and long term, according to their individual motivations or those supported by their structure. The expectations expressed during these exchanges led to the emergence of eight ideas of scenarios. Objectives and constraints corresponding to these ideas where translated in four sets that were used as inputs for the Coclick'eau optimization tool: (i) developing a local high quality organic flour (by increasing the organic areas), (ii) increasing the production of protein-rich forages and crops, (iii) reducing the impact of crop management on underground water quality, and (iv) a fourth scenario combining the objectives and constraints of the previous ones. Each scenario, simulated with the optimization tool, is a distribution, at the territory scale, of crops and crop management options and its resulting agronomic (yields, proteins produced for cattle), socio-economic (margin, input costs, work load), and environmental (use of pesticides, risk of nitrogen leaching, fuel consumption, etc.) performances.

Finally, these results were presented and discussed with the stakeholders. The discussions focused on (i) the ways of differentiating productions in this territory that is not very competitive on world markets, and the conditions for achieving this, and (ii) the possibilities for exchanges between production systems (cereal-livestock) for fertility and feed autonomy in the territory.

4 Discussion and Conclusions

The method implemented in the plateau Langrois territory made it possible to initiate discussions on the issue of the reintroduction of legumes into this territory. Indeed, the workshops organized allowed to share perceptions of the current territory and technical data between stakeholders from different spheres (research, professional agricultural organizations, local authorities and farmers). In addition, the scenarios proved to be a good basis to discuss about the future of agriculture in the plateau Langrois territory, and on new levers for reintroducing legumes. Some participants proposed to mobilize the method and the results of this approach in order to pursue the reflections undertaken and raise public authorities' awareness on the problems in the plateau Langrois and more generally in the low potential agricultural zones. This participatory tool-based approach could be used in other territories, particularly to work on the development of low-impact agriculture and supply chain, a theme at the core of current public policies.

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Investigating farmer-driven co-innovation for increased species mixture cropping in European agriculture using the Danish ReMIX multi-actor approach

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1. Introduction

In the interdisciplinary H2020 project "Redesigning European cropping systems based on species MIXtures" (ReMIX) 23 partners from 13 European countries are investigating "the benefits of species mixtures to design more diverse and resilient arable cropping systems, making use of agro-ecology principles"(remix-intercrops.eu). Across Europe 11 Multi-Actor Platforms (MAPs) are established as physical units in which local farmers, advisors, enterprises, researchers and others develop, implement and assess species mixture adjusted to local settings. Apart from locally designed solutions, MAPs facilitate the creation and sharing of local and demand-driven knowledge.

Farmers of the Danish MAP are navigating in a Danish agricultural sector characterized by increased mechanization and specialization justified by demand for high productivity in order to maintain competitiveness in a global market. A development based upon greater inputs of fertilizer, water and pesticides, new crop cultivars, and other technologies of the 'Green Revolution' (Tilman *et al.*, 2002). With this development, and despite a long history of diverse and locally adapted cropping systems, species mixtures have more or less disappeared from the Danish agricultural landscape.

Today Danish farmers are struggling to make a living due to high investment levels and falling prices in key agricultural commodities combined with high agricultural market volatility. Impact of climate change such as more extreme heat and precipitation events influencing pests and diseases dynamics leading to increased crop yield variability is likewise challenging the practice of present specialised farmers (Duru *et al.*, 2015). An increasing number of studies document yield gains using crop mixture strategies without increased inputs, and greater stability of yield with decreased inputs (Raseduzzaman and Jensen, 2017). Increased emphasis towards such 'sustainable intensification' using crop mixtures (Jensen *et al.*, 2015) may be a means to address some of the major problems associated with specialised 'modern' farming (Altieri *et al.*, 2015).

For sure, crop mixtures challenge current farmers' habits as well as other actors in the different agricultural value chains. Nevertheless, farmers are key actors in designing robust scientifically credible and socially valuable knowledge (Prost *et al.*, 2017). The focus of the Danish MAP is therefore to unfold how crop mixtures can resonate with the wishes, beliefs and possibilities that exist among the involved farmers and empower them to create satisfying solutions.

2. Materials and Methods

Apart from a central experimental field the Danish MAP is composed of 13 individual farmers (satellites) experimenting with the use of species mixtures at their own farms. All satellites practice some degree of reduced tillage but vary in age, experience, farm size, production, geographical location etc. Following a participatory research approach, the collaboration with satellites is explorative and activities influenced by farmers' needs and wishes. The methodology is inspired by co-innovation approaches aiming to collectively "produce knowledge that will be useful for farmers to enable them to adopt new practices and techniques in their own context, and to guide them in their understanding and use of this knowledge" (Lacombe, Couix and Hazard, 2018). The process include iterations of central co-designing steps as i) diagnosis, ii) design of prototype, iii) implementation, iv) evaluation and dissemination (Vereijken, 1997).

In spring 2018 in depth semi-structured interviews were conducted at each satellite gathering information about their individual motivations, barriers and experience with species mixtures (i). In autumn 2018 all satellites established the same catch crop mixture to evaluate the potential at each farm (iii). Satellites decided individually how and when to establish the catch crop depending on the contextual conditions, knowledge and strategy. Just before frost researcher and farmer conducted biomass cuts combined with an in-field evaluation. At a seminar in January 2019 dry matter biomass yields from the on-farm trials were interpreted and discussed among satellites (iv) followed by an interactive workshop session to generate new ideas for species mixtures and rotations enhancing ecosystem functions and services (ii). To conclude the seminar each satellite choose the species mixture(s) to test in the following season (iii). In summer 2019 another seminar was held at one of the satellites to carry out common evaluation of species mixtures established at this satellite and discuss individual experiences from on-farms trials among the other satellites (iv).

3. Results

The results presented include i) the motivations and barriers for using species mixtures among Danish satellites and ii) the concrete yields of satellite on-farm trials of catch crop mixture.

The initial interviews and continues communication reveal that Danish satellites are motivated to use species mixtures to improve soil structure and health, increase use and fixation of nutrients, reduce weed and diseases, increase soil carbon storage, spread risk, improve economy, provide structural support for legumes, inclusion of legumes in rotation, to stimulate farmer curiosity etc. The satellites also articulate that their use of species mixtures is limited due to that lack of resources (time, capacity, economy), logistics, technical issues (separation of grains, mixing of seeds, machinery for seeding and harvesting), lack of knowledge and experiences, decreased opportunity for pesticide use, conservatism and habits in the sector, unpredictability, doubt about the effects etc.

The results of the first year on-farm trial (Figure 1) show a great difference between dry matter biomass production of the catch crop mixture among the different satellites. Farmers explained the differences in biomass production with variation in sowing date, method of establishment and precipitation. Lacy phacelia dominated the mixture at all satellites except one where the catch crop mixture was mixed with oil seed radish by mistake. Farmers explain this result with the specific annual conditions with very little precipitation discussing the possibilities for achieving the same biomass production taking advantage of the abilities of other species in a year with different climate conditions.

4. Discussion and Conclusions

The Danish MAP illustrate an interest and potential for increased species mixture cropping in Denmark. Saying that, the satellites articulate that species mixtures introduce severe technical, structural and social challenges. Nevertheless, the on-farm trials showed an effective spatial and temporal utilization of local growth resources indicating interspecific compensation in the mixture grown when adapting to the contextual situation.

Farmers are the key actors in designing cropping systems. The joint evaluation of the common catch crop mixture grown in autumn 2018 and the following interactive workshop turned out to be valuable to create discussion and knowledge sharing within the group of satellites. Situated challenge within various parts of the production and management system was addressed as well as co-innovation needs beyond the farm boundaries, e.g. within the supply chain. Multiple actors are involved and will need to change their practices and routines.

Through ongoing contact with satellites it is clear that motivations, possibilities and challenges change over time and among farmers. Not all satellites participate in the trials and activities with same engagement. The aim is to follow the temporal learning process and practice of each satellite to understand the diverse trajectories and uptake or denial of the use of species mixtures. In the coming two years workshops including adjacent actors like advisors, enterprises and others are planned. The aim is to facilitate discussion and seek common solutions to the barriers identified by farmers in order to enhance the possible benefits of species mixture cropping in Denmark.

In the presentation, we will elaborate on the co-innovation approach used in the Danish MAP and present the coming activities to challenge and empower both satellites, other farmers and actors in order to explore the opportunities for increased use of species mixtures in Denmark.

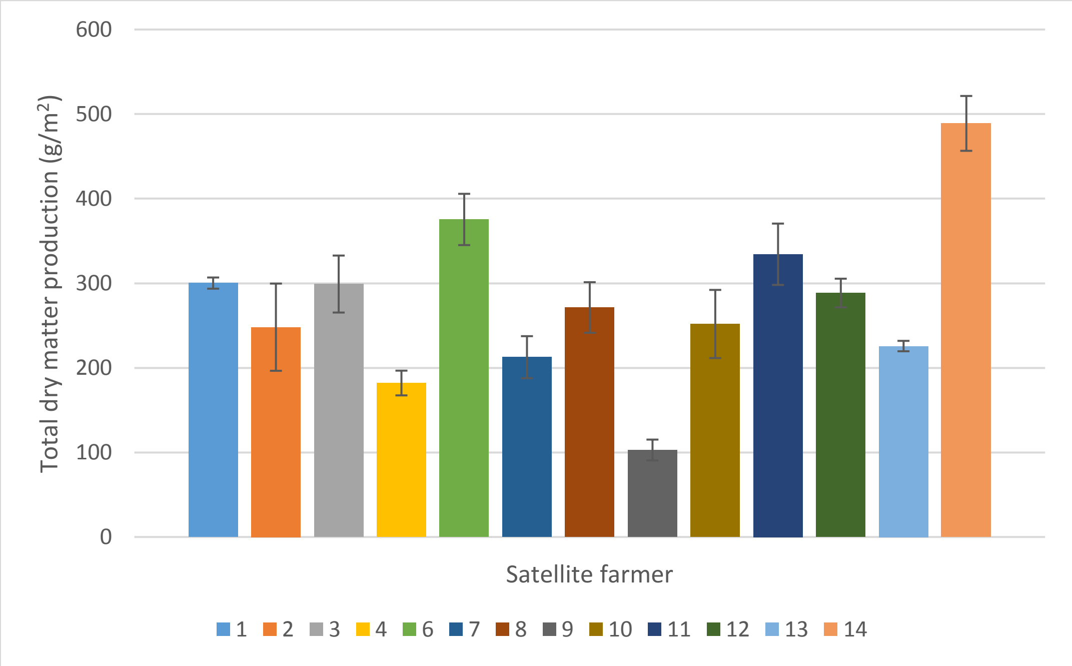

Figure 1. Average total catch crop (pea, clover, serradella, phacelia, buckwheat and vetch) dry matter production (g/m^2) at 13 Danish satellite farmers.

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Multi-actor approaches for diversified cropping systems: fostering complexity-sensitivity through co-innovation in DiverIMPACTS

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1 Introduction

The scientific literature abounds with suggestions on usefulness of scientific insights for practitioners seeking sustainable development. Where follow-up research has been done, however, actual uptake of such potentially valuable knowledge has often been disappointingly low (e.g. Clark et al. 2011). To make scientific knowledge work for sustainable development, insights from innovation sciences may contribute to new ways of organizing collaborative spaces and languages between scientists and society. Here we refer to these new ways as multi-actor approaches, in line with the terminology used in the Horizon 2020 research funding program of the European Commission.

Recent publications (e.g. Clark et al. 2016) point out the need to consider the production of usable scientific knowledge as part of dynamics in social-ecological systems (SES). This perspective implies that an academically sound discovery only becomes useful for society if attention is given to its local embedding, which in turn may lead to adaptation of the initial idea. This concept of 'coproducing' changes in SES has important consequences for the way action-oriented researchers should consider the systems they work in, and for the way their interventions should be organized. Aim of this contribution is to review the conceptual basis of coproducing and illustrate consequences with the way this has been implemented in the co-innovation approach in DiverIMPACTS.

2 Conceptual framework

SES can be considered as complex adaptive systems (CAS) with elements that are linked through many, partly unknown feedback mechanisms – making them complex, which adapt themselves through evolutionary learning processes in which best fitting changes are selected from the range of alternatives. Consequences of this CAS perspective are that outcomes of interventions cannot be fully predicted, that diversity of alternatives is needed to enable fruitful selection processes, that monitoring of results is needed to adjust interventions in learning cycles, and that designing sustainable SES should operate from a perspective of safe-to-fail, rather than assuming the system to be fail-safe.

Another consideration is that action-oriented research will bring scientists into the political system, with its debates and controversies. Contestation of scientific knowledge may then be driven by interests and influence of societal actors well beyond those initially considered relevant for change. In addition, recognition that the choice of research object may favour the position of some actors and disfavour others challenges traditional perception of value-free science and requires scientists to explicate their position. Against this conceptual background for engagement in SES, we introduce the multi-actor approach developed in the DiverIMPACTS project.

3 Results

The multi-actor approach in DiverIMPACTS is referred to as *co-innovation* (Dogliotti et al. 2014; Rossing et al. 2010) and builds on insights from niche governance, participatory impact pathway analysis, RIO (Bos

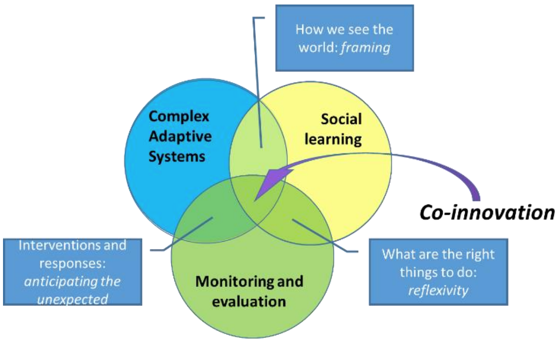

Figure 1. Schematized representation of the three domains of Co-innovation in DiverIMPACTS.

& Grin 2008), outcome mapping, and various other practical reflexive monitoring tools. Co-innovation in DiverIMPACTS combines a complex adaptive systems perspective with the creation of social learning spaces and dynamic (reflexive) monitoring (Fig. 1). Jointly the three spheres provide a setting that fosters adaptive management of complex systems. Two complementary types of monitoring were distinguished. Performance monitoring is based on sustainability assessment and uses indicators designed to measure results that contribute to the DiverIMPACTS overall goal of showing the benefits of crop diversification. Complexity-aware monitoring addresses the way in which DiverIMPACTS considers that it will cause changes in behaviour of stakeholders (i.e. outcomes) and greater crop diversity in the EU in the longer term (i.e. impact).

Each of the 25 Case Study (CS) teams in the project engage with societal actors engaged in crop diversification with the aim of helping to structure knowledge generation and change at farm and value chain levels. A team consists of a CS leader and a CS monitor, enhancing a reflective stand. The co-innovation approach was shared with the CS teams in 3 3-day workshops over the first 20 months of the project. In the workshops concepts were applied to practical case study work. Working in 5 clusters of 5 CSs visions, missions, causal systems analyses and logframe-type action plans were developed and, at the next workshop, evaluated and adapted to evolving insights. Three-monthly skype meetings between individual teams and a 'cluster leader' created additional reflection moments. CSs were given time to evolve plans with their actors, develop their indicators for success, and articulate needs from the analysis-oriented work packages of the project. The Annual Meetings are being structured to take the role of spaces of interaction. The extent to which the annual as opposed to half-yearly face-to-face interactions are sufficient to 'keep energy high' in the CS is still open.

4 Discussion and Conclusions

A preliminary impression of the co-innovation approach after two years is that it allowed CSs to develop their crop diversification projects such that in many cases true engagement of actors was created. The prominent role of the CSs in the project hierarchy resulted in re-thinking of the roles of the participants. Scientists had to engage in negotiations on their involvement in the CSs, while practitioners were stimulated to consider novel actors and methods to engage with them as a result of the systems analysis. Peer-to-peer contacts among CSs were highly appreciated as learning spaces, in some cases resulting in mutual visits and knowledge exchanges. This multi-actor approach is demanding in terms of time, budget and knowledge. At the same time it enabled creating a platform for learning about stimulating innovation that may inform new modes of knowledge generation beyond the project.

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Analysis of a sample of strategies for sustainable development in arable crops

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1 Introduction

Facing today the limits of the current agricultural model resulting from past trends, many actors are reconsidering their practices. Redesigning agricultural production towards more sustainable cropping systems is increasingly considered, however the effective change at a large scale is still a challenge.

For this transition, storage organizations (such as farmers' cooperatives and trading organisations) have a key role to play. Indeed they mobilize numerous farmers and their central position within the agri-food chain makes it possible to drive new interactions between producers and customers. Several of them have already initiated approaches by developing specific mechanisms, accounting for the diversity of local situations and structures.

To better understand their possible role and to identify best practices towards greater sustainability, Terres Inovia and INRA carried out a qualitative study (1) in France to address the following question: how do traders and cooperatives take up the issue of sustainability and how can they help farmers adapt their field crop production methods?

2 Materials and Methods

Following a preliminary literature analysis and 16 semi-open interviews, the methodology was based on face to face interviews of 13 coordinators of different strategies, carried out by nine storage organisations, two associations, an industry actor and a local authority. The criteria for characterizing sustainable development (SD) approaches were defined by complementing some criteria used in a published study (2). The interviews were conducted (under confidentiality) with the support of an interview guide based on the standard analysis grid which was adapted according to the specific approach considered: either "strategic and proactive" or "tactical and reactive". The reports and transcripts of the interviews enabled to describe the main features of each approach.

The public outputs of this study result from a transversal analysis of all the cases to (i) analyse the types of processes and instruments which are mobilised, and (ii) identify criteria for success – via the footprint of the approach – to progress towards more sustainable crop production, such as the levers used, the added value they provide, the fact that the approach is more or less demanding, its type of organization and its driving effect (estimated with the number of farmers involved in the approach).

3 Results

3.1. The components

The study provides a characterization of SD approaches for stakeholders in field crop production (Figure 1).

Several reading filters enable to understand the functioning of the approaches and their definition of sustainability: the history of the commitment to such an approach (sponsor), the challenges faced by the actors (stakes), the types of tools used (coordination and support instruments, management and measurement tools, public instruments), the types of levers and markets targeted and the difficulties encountered.

The results show a heterogeneity in the way to apply a SD approach among the surveyed organisations, which combine the use of coordination and/or support tools, from different existing instruments (regulatory, market…) and/or the development of their own plans. Thus, the approaches take on the concept of sustainability through several dimensions which are weighted according to each actor (or individual). They value the productions according to the challenges faced, in some cases by considering environmental benefits as an opportunity for differentiation.

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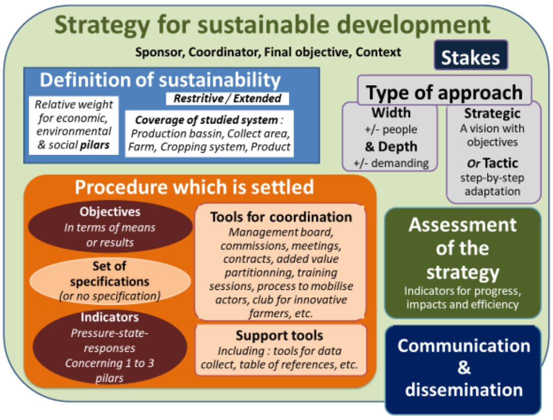

Figure 1. Components to characterize a sustainable development strategy hold by agricultural actors in order to target more sustainable agriculture. A. Schneider, M.-B. Magrini, E. Montrone.

Within the coordination instruments (Figure 2), the use of audits, mentioned in one third of the approaches with specific identified mechanisms, underlines the importance of certification in these cases: the audit allows both a reference to a recognised reference (international standards or national environmental value reference framework) and a tool for exchange and coordination among the stakeholders in the process. In addition, contracts are widely used (especially in tactical approaches) to ensure the mutual commitment of the various stakeholders (price, volume and visibility).

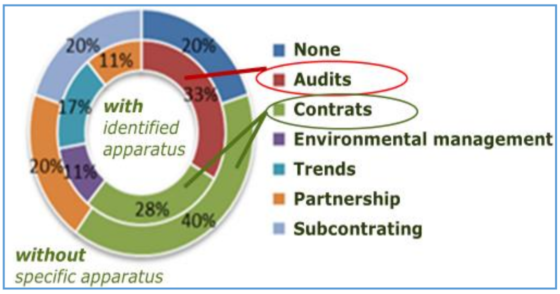

Figure 2. The coordination instruments used, when there is an identified mechanism to implement the SD approach (inner circle) or not (outer circle).

3.2. The quantitative and qualitative footprint of the approach

To understand the key levers for the success of the SD approach, it is necessary to measure how the coordinator assesses its effect on the way the other actors conduct their activities. One also seeks to evaluate the driving effect of the approach and the degree of progress towards sustainability it generates.

First of all, the study shows the absence of correlation between the level of requirement of the approach and the number of farmers involved, unlike a published study (2). This depends above all on the status of the coordinator, its scope of action and its willingness either to get as many people as possible being involved or to specifically target a specific innovative group.

Second, several criteria were analysed to understand the links between the characteristics of the approach and what makes it more or less successful. Redesigning of crop systems is more often associated to the more demanding SD approaches (with objectives in terms of results) while practice adjustments are more often linked to approaches with objectives in terms of means. Several levers considered or already implemented appear in order to bring added value to the production activity targeted by the approach: differentiation (frequency of 32% among the levers mentioned, concerns 9 out of 13 approaches), adjustment of practices (21% frequency), change of practices (18%), security (11%), communication (11%), complementarity between plant and animal productions (7%). In terms of key elements that should encourage farmers to get involved, the first two elements quoted spontaneously were: financial assistance (additional premium to the market price or contract price) (35%) and recognition (21%). A major bottleneck, both in terms of costs and difficulties, is the difficulty to convince producers and all actors to be fully involved in the SD strategy and to demonstrate the value of such change in the medium term (expressed by 9 out of 13 coordinators).

4 Discussion and Conclusions

The analysis of the 13 cases highlights a range of existing strategies, according to their degree of organisation and coordinator's objectives. This study remains qualitative and dependent on the individuals who were interviewed and therefore not representative of all French agricultural organizations.

These initiatives would benefit from being part of more readable standards for citizens and more transparent and co-designed specifications. They also require easier access to agri-environmental knowledge on the one hand and tools for assessing the effective environmental impacts of production systems on the environment on the other. The study also emphasizes that people need to give meaning to their efforts or activities and that the coordinator should first invest in time for sharing knowledge and co-designing solutions to be implemented collectively. These are the prerequisites for ensuring that actors are involved in a process of changing practices or paradigms in the field of arable crops.

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SESSION 4. CONNECTING ACTORS TO FOSTER CROP DIVERSIFICATION: HOW TO TURN THEORY INTO ACTION AND VICE VERSA?

Chairs: John Grin (University of Amsterdam, The Netherlands),
Guillaume Martin (INRA, France)

ORAL PRESENTATIONS

- Translating knowledge for legume-based farming for food and feed (Legumes Translated)
  Speaker: Donal Murphy-Bokern, Germany
- Building and fostering trust as a craft
  Speaker: Barbara Koole, University of Amsterdam, The Netherlands
- Knowledge exchange in 'plant team' cropping with on-farm participatory research
  Speaker: Alison Karley, The James Hutton Institute, United Kingdom

POSTERS

- The association Rheinische Ackerbohne e.V. - A contribution to the diversification through the revival of a traditional culture, nearly forgotten crop
  Presenter: Ina Stute, FH-SWF, Germany
- Lessons from co-innovation process for increasing grain legume production and consumption in Southern Sweden
  Presenter: Iman Raj Chongtham, Swedish University of Agricultural Sciences, Sweden

Translating knowledge for legume-based farming for food and feed (Legumes Translated)

Murphy-Bokern, D*±[1], Dauber, J.[2], Rittler, L. and Krön, M.[3], Schuler, J. and Reckling, M.[4], Willer, H.[5], Haase, T.[6], Schauman, C. and Lindström, K.[7], Zimmer, C.[8], Dewhurst, R[9], Barkas, D.[10], Recknagel, J.[11] Iancheva, A.[12] , Petrovic, K.[13], Alves, S.[14] O' Donovan, T.[15], Orestis, R.[16], Watson, C.[9]

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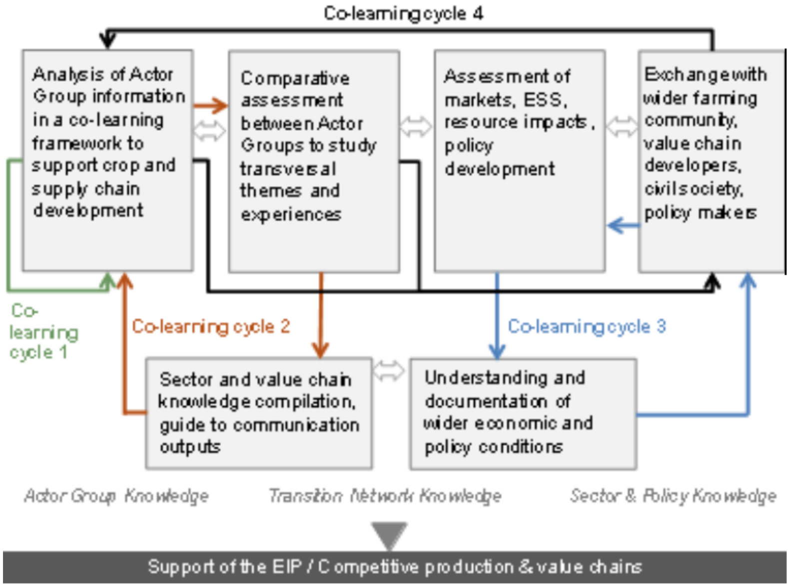
1 Introduction

Legumes Translated is a new thematic network in Horizon 2020. It supports the Agricultural European Innovation Partnership (EIP Agri) by linking research- and practice-based knowledge to support legume cropping and use. It is therefore in line with the recently announced European Protein Plan (European Commission 2018) that mentions a knowledge platform for protein crops. The overall goal is to support the production and use of grain legume crops in Europe as part of an overall change in protein sourcing and use (Donau Soja, 2017). The challenges that legumes crops can help address are well-documented: the need for more diversity in cropping with more crops that support pollinators; yield stagnation in cereal-dominated systems (e.g. Brisson et al., 2010; Watson et al., 2017); and a 29% deficit in tradable plant protein that is met by about 35 million tonnes of soybean equivalent imported from the Americas (Murphy-Bokern et al., 2017). This is a fundamental challenge to the resilience, acceptance and performance of our agri-food systems. There are indications that Europe is now on the cusp of a significant change manifest in the positive political response to the Donau Soja European Soya Declaration and the European Commission's work on Europe's protein balance. Thematic networks are a key element of the EIP Agri. funded from Horizon 2020. They complement both operational groups and Horizon 2020 research and innovation projects by compiling and validating existing knowledge and best practices and providing wider access to this knowledge with particular emphasis on trans-national border knowledge interaction. Legumes Translated has three underlying principles: empowerment of innovators through understanding; practice- and research-based sources of knowledge are mutually supportive; and cropping and farming system innovation must go hand-in-hand with corresponding value chain developments (especially in livestock).

2 Actor groups and transition networks: the primary source of practice-validated knowledge

The project concept is based on the networking of 15 existing groups of farmers and other innovators (actor groups) within an international framework provided by seven transition networks. These actor groups are already supported by public initiatives such as the German Plant Protein Strategy and private initiatives such as Donau Soja. The seven transition networks that they interact in are: Cool-season grain legumes; Soy; Food; Pigmeat; Poultry; Dairy and beef; and Aquaculture. These transition networks promote increased flow of practical information from actor groups between geographic areas with exchange occurring from southern Finland to Greece and from Ireland to Bulgaria. Supported by three analytical work packages, the transition networks enable exchange and rigorous knowledge synthesis and compilation at four levels: specific actor group farming systems; between related actor groups within seven networked technical areas of the agricultural sector (sub-networks called transition networks); exchange between research-based partners and the policy community; and between actor group-level knowledge and the policy community.



3 Results

Establishing and running an efficient thematic network is a complex task that must be completed in a relatively short project period. Supporting and benefiting from the 'bottom-up' multi-actor approach must be balanced by the use of a 'top-down' approach to analysis of information. Within the first six months, our actor groups have provided detailed information on their activities and ambitions and we have successfully established seven vibrant transition networks. Focus is essential for a three-year project and so we have already completed examples of our major outputs: practice notes/abstracts and videos. The synthesis of information from actor groups within the transition networks has identified four areas of demand for knowledge: the farm-level economic impact of introducing grain legumes into cropping systems; the nutritional and economic valuation of legumes for animal feed; knowledge exchange for soya production and use; and the testing/validation of environmental claims made corporate social responsibility schemes. The project will produce practice notes and abstracts, practice and development guides, and videos on a multi-lingual knowledge internet platform (The Legume Hub). This is an open publishing facility which is open to all interested in this innovation area.

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DiverIMPACTS European Conference on Crop Diversification September 18-21, 2019 Budapest, Hungary

Building and Fostering Trust as a Craft

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1 Introduction

Within the DiverImpacts (DI) project, three case studies are supported through the Reflexive Interactive Design (RIO, for its Dutch acronym) method, which is a methodology that has been developed to foster system change within (sustainable) transitions. Since the first adoption of the methodology, it has been applied in such diverse areas as livestock farming, water management, urban development and healthcare. Through applying the RIO method, it has been further developed, amongst others in regards to the role of visions within the interactive design method (Lissandrello & Grin, 2012) and the principles of structured design (Klerkx et.al., 2012; van den Kroonenberg & Siers, 1999). Within DI, we focus on the role of trust in the RIO projects. This paper presents preliminary insights on the intertwined relation of trust and collaborative learning, and thereby aims to feed into the further development of the RIO method.

2 Materials and Methods

In this methodological article, we discuss how trust should be regarded as an essential process that is intertwined with collaborative learning, and share what strategies are employed in order to establish and foster trust. RIO projects distinguish themselves from 'regular' collaborative learning contexts because of their explicit aim to foster structural change beyond their own network. We propose to regard trust building and -fostering as a 'craft', which entails an inextricable combination of tacit knowledge (Polanyi, 1958; Ybema et.al., 2009; Fischer, 2000), intuition and more formal strategies. In this article, we explore more specifically the role that project leaders play as 'spiders in the web' and the strategies they employ in order to establish a trust base within their networks. Through this analysis, we define lessons that contribute to the further development of the RIO method. Empirical data is used from three case studies, in Sweden, Belgium and Germany.

3 Results

This paper serves to share some tentative, more detailed insight into the strategies hitherto found to be employed within the three networks that are studied, enabling us to extract lessons that can inform both future research and future RIO projects. However, it should be noted that a heuristic framework is used, which implies that it is constantly adapted in concurrence with practical observations (Breeman, 2015). It explores specifically how 'doing' the RIO method in practice interacts with trust dynamics.

This can be seen already, perhaps especially, in the first phase focused on a needs analysis of the actors involved in the RIO networks. In this phase, the underlying values and beliefs of actors are center stage, informing the system design phase that follows. In identifying the needs and beliefs of these actors, the role of the project leader comes to the forefront. One of the central aims that is shared amongst the three case studies studied for this paper is to create a sense of ownership amongst the actors in the networks. Reasons that are mentioned for creating this ownership are amongst others 'ensuring a future for the activities after DiverImpacts' and 'ensuring that the project activities are useful for participants'. The project leaders each employ different strategies for creating such ownership. An important distinction to be made is whether the network still has to be built or is already existing. For example, in the Swedish case study the project builds upon an existing self-organized farmer group, and connects this group to other actors with an interest in local legume production and consumption. In the process of combining the group to a wider network, the project leader was frequently in touch with the different actors and focused on understanding their stake in the project while ensuring their commitment.

In the Belgian case study, the project revolves around establishing increased collaboration between organic livestock farmers and organic vegetable farmers. As the project is coordinated by the Flemish umbrella organization for the organic sector, most farmers are already familiar to the project leaders. However, the organic sector is traditionally organized according to type of farming, rather than on a regional basis.

Therefore, the project is organizing regional meet-ups where farmers can meet their neighboring farmers and explore possible collaborations such as land or manure exchange. In such regional meet-ups, the project leaders play a central role through facilitating the exchanges between actors.

Finally, in the German case study the connections between farmers and project leader started on a looser base. Therefore, the activities during the first year focused on interviews with farmers in the region in which their problems, as well as their wishes for the future of their farms, were identified. The insights gained from these interviews between project leader and farmers resulted in a re-framing of the project goals, to achieve an increased sense of connection and ownership amongst farmers. Whereas the project initially communicated primarily about contributing to water protection through diversification of crop rotations, whereas it later focused more on increased yield stability through these measures.

4 Discussion and Conclusions

Through the analysis conducted in this paper, we identify different dimensions on which trust interacts with a collaborative learning process. These dimensions include the temporal dimension of reaction and anticipation, as well as a distinction between interpersonal, interorganizational and societal dynamics that play into trusting (Koole, forthcoming). In addition to these dimensions of the 'object' of trust, different types of trust bases can be distinguished. In the literature on trust, a common division is made between affective trust, calculative trust and cognitive trust (Le Gall & Langley, 2015), or in other words, trust based on interaction or reflection, trust based on routine, and finally trust based on reason (Möllering, 2006). In practice, these different dimensions of trust are found to interact with each other.

From the different case study experiences, a picture is arising that demonstrates how the project leaders are constantly learning from the perspectives of stakeholders and adjusting project strategies to them, whilst maintaining overview about overall goals. That is a typical design activity, that also reflects the need for trust building amongst stakeholders, as well as between stakeholders and project leader. We will further enrich this analysis based on data on future activities. The twofold objective of the version to be presented in Budapest is to share with, and get feedback from, the wider community what we have learned hitherto in WP 2.3 on the dynamics of DI case studies, especially those that have adopted RIO.

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Knowledge Exchange in 'Plant Team' Cropping with On-Farm Participatory Research

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1 Introduction

On-farm validation is a crucial step in knowledge transfer from scientific trials to real-world farming systems. Field validation of diversification approaches in commercial settings allows the practicalities of new farming practices to be tested, their benefits and challenges to be demonstrated and the information to be used by farmers for decision-making. The Horizon 2020-funded project DIVERSify aims to optimise the performance of multi-species cropping systems, or 'plant teams', to promote within-crop diversity by understanding the plant traits and mechanisms that promote polyculture productivity. To achieve this goal, we have developed an approach that combines scientific trials conducted across pedo-climatic regions of Europe with tacit knowledge amongst communities of innovative practitioners who have unique expertise in growing and managing plant teams. At the heart of the project are 'participatory' farmers engaged to conduct on-farm trials of plant teams based on their existing experience and taking advantage of results from scientific trials. Farmers are partnered with research 'buddies' who advise on trial design and data collection so that robust indicators of plant team performance can be compared with standard practice. The objective of this study is to assess the outcomes of adopting this participatory approach focussing on results and experiences from the UK.

2 Materials and Methods

The mechanism for knowledge exchange between scientists and practitioners has been achieved using a two-step process for participatory research, described below.

2.1 Research farm trials: practitioner-to-scientist knowledge exchange

Experimental trials at small plot scale were conducted in 2017/2018 at the James Hutton Institute, UK, to test the performance of commercial cultivars of spring-sown cereal crops (wheat, barley, oat) and legume crops (faba bean, pea, lentil) selected from national recommended lists or other sources to cover a range of morphological, developmental, agronomic, yield and quality characteristics. Cereal and legume species were chosen following consultation with agricultural stakeholders, primarily farmers, both through local contacts and in national workshops conducted in 2017 across Europe (Pearce et al., 2018). The best-performing spring barley-pea and spring wheat-faba bean cultivars identified in the 2017 trials (see Karley et al., 2017), in terms of over-yielding and other indicators, were tested at large scale in 2018 at the institute's Centre for Sustainable Cropping long-term research platform. Each trial comprised a management treatment (conventional or integrated) and two replicate plots of each plant team treatment (crop monocultures or mixture) assigned at random to field or plot position. Spring barley (cv. Laureate) and pea (cv. Daytona) were sown in 3m x 120m plots and spring wheat (cv. Tybalt) and faba bean (cv. Boxer) were sown in 3m x 200m plots using a 3m Amazone AD/P Super/Amazone KG Power Harrow conventional drill or a John Deere 750A 3m direct drill. Sowing ratios were 40:60 for pea:barley and 50:50 for wheat:faba bean. Fertiliser was applied at sowing; the integrated treatment received *c.* 75% of the mineral fertiliser applied to the conventional treatment. Trials were monitored for crop development, canopy and individual plant characteristics, soil variables, pest and disease incidence and yield using standard protocols developed in the project.

2.2 Participatory farmer trials: scientist-to-practitioner knowledge exchange

Results from the plot-scale trials conducted in the UK and across Europe have been communicated to farmers at stakeholder events, through individual contact and in public outputs. Following initial contact in the national workshops, participatory farmers were invited in 2018 to trial plant teams of their choosing on their farms. To date, participatory farmers have been recruited in seven countries with six participatory farmer trials carried out in the UK using different plant teams. Trial design was specific to individual farm sites and evaluated the performance of spring barley-pea, wheat-bean, oilseed rape-bean, triticale-pea, fodder beet-clover-ryegrass or winter bean-wheat. Research partner 'buddies' worked with participatory farmers to collect data using a subset of DIVERSify standardised protocols. A communication plan guided contact between buddies and participatory farmers to establish the points of contact, flow of information and responsibilities of the buddies (Banfield-Zanin et al., 2018).

3 Results

3.1 Research farm trials

Over-yielding detected in small scale plot trials of barley-pea and wheat-faba bean plant teams in 2017 was detected at larger scales in 2018 under integrated management but was not observed consistently under conventional treatment. Other plant team effects included improved soil phosphorus availability with wheat-faba bean, particularly under conventional management, and aphid pest suppression on pea in pea-barley compared with monocultures (data not shown).

3.2 Participatory farmer trials

The performance of the five cereal-legume trials relative to the farmer's standard crop choice in monoculture, measured in terms of grain or biomass yield, indicated wide variation in plant team performance (Table 1) from under-yielding (<1) to over-yielding (>1). Other performance measures were collected depending on farmer motivation for plant team cropping; e.g. weed biomass was reduced in wheat-bean plant teams, but not in bean-oilseed rape, compared with bean monocultures. The farmers' own evaluations of their trials are currently being collated.

Table 1. Cereal-legume plant team performance in on-farm trials compared with the farmer's standard crop choice in monoculture.

Monoculture standard crop	Plant team partner crop	Plant team relative yield (= mixture/monoculture yield)
Pea	Triticale	1.08-1.40 (grain)
Winter bean	Wheat	2.98-3.22 (grain)
Spring bean	Wheat	4.2-4.6 (biomass)
Spring barley	Pea	1.0 (grain)
Spring bean	Oilseed rape	0.87-0.95 (grain)

4 Discussion and Conclusions

The two-step participatory approach devised in the DIVERSify project has facilitated knowledge exchange between scientists and farmers on best practice for plant team cropping. It has succeeded in i) quantifying plant team benefits in research trials relevant to farm settings, ii) transferring research findings on-farm and iii) enabling joint evaluation between farmers and buddies of plant teams in each farm system compared with standard practice. The results and experiences in the UK have highlighted improvements to the participatory approach that will be introduced through iterative development to optimise how learning from experimental and on-farm trials is communicated. Follow-on initiatives are ongoing to create a legacy in scientist-farmer collaboration and joint research in the UK.

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DiverIMPACTS
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The association Rheinische Ackerbohne e.V. - A contribution to the diversification through the revival of a traditional, nearly forgotten crop

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1 Introduction

The cultivation of faba beans has a long tradition in Germany. With the import of potatoes in the 17th century, faba bean production in Germany first disappeared from human nutrition and with the beginning of soya imports in the 1950s also from animal nutrition. Presently only less than 0.5% of the total acreage (2018: 54 000 ha) is cultivated with faba beans in Germany.

There are many benefits associated with cultivating faba beans. A central advantage of the cultivation is that they - like all legumes - in addition to the property as a protein source also provide numerous ecosystem services. For example, faba bean blooms in time of 8 weeks from May to June and therefore provides a habitat for insects. The faba bean itself does not require nitrogen fertilization due to its symbiotic N-fixation. Moreover, the provided nitrogen is available for the subsequent culture. The cultivation of faba beans improves soil structure because of its deep taproot. Finally, the use of pesticides in faba beans is significantly lower than is often found for cereals. That results in financial savings and ecological advantages.

These positive effects of legumes within the crop rotation are well known. However, the low market prices for faba beans discourages farmer from cultivating them. The small amounts of cultivation lead to a reduced market power of the producing farmers (in relation to the selling price) and thus the cultivation is reduced further. In order to break this negative spiral, it is necessary to create a funding structure that makes the cultivation of faba beans more economical. The support can be abolished if a functioning market structure has been established.

For this reason, there are support programs to promote legume research and the cultivation organized by the German Government. By using these programs the cultivation of e.g. faba beans in Germany could be increased from 17 300 ha in 2011 to 54 000 ha in 2018.

2 Materials and Methods

A case study approach was carried out.

3 Results

In January 2017, various actors (mainly farmers, the local cooperative, traders and other associations) allied in Rhineland to promote the cultivation of faba beans. They use subsidy programs to develop a market for legumes in the region by sales and quantity bundling. Using the subsidy program makes the cultivation of faba beans more economical for them. This period of economical viable cultivation should be used to re-establish faba beans and build up a value chain.

The association is not a producer group and does not distribute the faba beans themselves, but each member manages individually although marketing measures are carried out centrally by the association. 2 000 tons of faba beans are currently bundled by the association members each year, and the jointly produced quantity is sold to the agricultural trader. In this way, a reasonable price for the protein product is achieved.

In order to succeed the above-mentioned aims, the association advertises faba beans for the consumer. This is intended to satisfy the consumers demand for regional and GMO-free products and provide consumers an alternative to imported soy beans from overseas.
In order to catch attention and get in touch with the consumer, the association participates at public events and attends numerous agriculture-, or consumer-fairs, farm festivals and specialist conferences. In addition, the usability of the bean is described on the own website. Finally, field signs were developed that include information on the cultivation of faba beans, the utilisation possibilities and the ecosystem services provided by faba beans.

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The association also organizes the use of faba beans in animal feed. To increase the awareness of the association and to provide transparency and trust a logo was developed.

Figure 1. The logo of the association "Rheinsiche Ackerbohne e.V."

Association members use faba beans as animal feed. They are mixed with the feed of laying hens. The eggs are sold as GMO-free, regional products. Likewise, a dairy farmer feeds his cows with the beans and offers the milk. A regional butcher offers meat of pork, which was fed primarily with local faba beans. Furthermore, a beekeeper produces honey by placing his bee colonies in faba bean stocks. All these products bear the logo of the association "Rheinische Ackerbohne e.V." as recognition and unique feature. The marketing of the products takes place almost through direct marketing.

Another instrument for getting in direct contact with the consumer is the newly developed faba bean bread (40% faba beans and 60% spelt). It is characterized by a low content of carbohydrates and gluten as well as high protein content. It is currently distributed in five different bakery chains.

4 Discussion and Conclusions

The association "Rheinische Ackerbohne e.V." raised a value chain with faba beans. The main objective of establishing an active market for those products in the region has not been achieved yet. The association members who cultivate faba beans are on the right track. Such cooperation can help to establish legume cultivation permanently.

The cultivation of faba beans offers a wide range of advantages and benefits on the one hand within the crop rotation and on the other hand for the ecosystem. Furthermore, cultivation and processing of the protein plant is a sustainable way to reduce the import dependency of protein feed. The political conditions in Europe currently support the cultivation of grain legumes. Farmers use this promotion to build up market structures for domestically cultivated faba beans.

The aim of the association "Rheinische Ackerbohne e.V." is to establish an active and operational market for local produced faba beans. It is the duty of all members of farmers and traders and advisors to consider whether the activities of the association are transferable to other regions.

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Lessons from co-innovation process for increasing grain legume production and consumption in Southern Sweden

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1 Introduction

Over the last 50-60 years, agriculture has fulfilled the policy objectives of Sweden and of many European countries by contributing to national self-sufficiency in food and low food price. However, the big contribution of agriculture to loss of biodiversity, degradation of resources (water, air, soil), consumption of non–renewable resources, and to climate change has been highlighted by the Millennium Ecosystem Assessment report (2005). The increase in demand of meat in Sweden (and in Europe) led to intensive livestock farming systems, which further encouraged the development and rapid expansion of soybean production in South America at the expense of disturbing/destroying the social, cultural and ecological systems. Furthermore, methane emission from the livestock ruminants contributes to global warming.

The recently published EAT-Lancet report (2019), concluded that a diet rich in plant based foods and fewer animal source foods confers both improved health and environmental benefits. However, the per capita consumption of grain legumes in Sweden in 2012 was only about 2.0 kg/yr, compared to 27 kg recommended by the EAT-Lancet report. Production and marketing of Swedish grain legumes for food is at a very infancy stage, and the products are not easily, and affordably available to consumers, despite the rapidly growing demand for plant based protein (in 2017, about 30% Swedish youth prefers plant-based food, according to Nordic Council of Ministers). Grain legumes can fix atmospheric nitrogen and reduce external inputs such as fertilisers, and can increase crop diversity in cereal dominated cropping systems in Sweden. This case study (CS) aims to rapidly increase the production and consumption of grain legumes in Sweden by exploiting its agronomic, environmental and health benefits, as well as tap/create new opportunities such as local businesses and social interactions, through a co-innovation approach by linking actors on several levels in the food system.

2 Materials and Methods

The CS team consists of farmers, advisors, researchers, food expert, processors, wholesalers and retailers of grain legumes in Sweden. A consumer and nature protection organisation also actively contributes to the CS. The study focuses on grain legumes for human consumption. The CS follows the framework of farming systems research in which various actors in the food system actively participates in 'step-by-step' procedures of innovation, and in implementing them.

As the co-innovation process involves new approaches, diverse local actors took part in a co-innovation workshop to design an innovative crop diversification practise by incorporating several legumes into a reference organic arable crop rotation, which is currently tested in field in Sweden (as part of the DiverIMPACTS field experiments). The actors designed the crop rotation from the environmental, economic, practical/technological and marketing perspectives.

Several workshops and field visits are/will be organised during the 5-year project period (2017-2022) to help the CS team identify several challenges, opportunities and actions and, through rigorous discussions and analyses, achieve the overall objective. A four-step participatory exercise was conducted to devise action plans for the CS; Step 1: three paper sticky notes were handed to all participants, and in each note, one action/measure must be suggested. In Step 2, the note is passed on to the participant sitting next to him/her, who deepens and improves the suggested idea/action plan. In Step 3, the participants place the notes on the CS time-line and present to everybody. In Step 4, the case study leader and monitor structure, analyse, condense, digitalise and implement the action plans.

Furthermore, numerous campaigns and *'food jam'* (an event where participants pays a small fee and prepares different legume dishes in small groups, and share the food with all the participants at the end) have been organised in various events and fairs to promote (awareness about the taste of) Swedish legumes to consumers. Similar events are planned to be carried out in schools, municipal kitchens and big fairs. Dissemination through public media (newspaper, radio, television, magazines) will take place in the coming months.

3 Results and Discussion

The first co-innovation workshop generated both optimism, as well as hesitation among the participants about new practises of diversification in time and space, such as intercropping cash crops, using multispecies cover crops, new crops such as lentils and lupines and high frequency of legumes within the rotation. Some farmers decided not to take part in the CS further, as they lacked interest in new grain legumes, have unsuitable soil types in their farms or have insufficient time to get involved in co-innovation process. However, many farmers were willing to increase their production of legumes, and considered the learning process for growing and marketing new legumes as a stimulating challenge.

Important challenges to fulfilling CS objectives were identified by the CS team in the first two co-innovation workshops: a) lack of machines for sorting (if intercropped), drying and cleaning the new legumes, b) inadequate shops and buyers for 'special' local products, c) very few grain legume producers in Sweden, hesitation to grow new legumes, risk of legume diseases if legumes are frequent in crop rotations, low and variable yield, and uncertain price of local legumes d) lack of communication between different actors about benefits, challenges, opportunities and experiences, and last but not the least, e) abundant very cheap imported legumes in the market.

Action plans, developed from the participatory workshop, adopted until the time of writing this article have been received well by the CS participants as well as by the society/consumers. This is evident from the enthusiasm showed by the participants in the legume growing and drying workshops, and in the *food jam* held at the Naturskyddsföreningen (Swedish Society for Nature Conservation) annual meeting, which was attended by about 150-200 participants.

An important step at the initial co-innovation phase was to create a sense of belonging for all the actors in the CS, as the expectations, roles, views, contribution, actions were not clear, and the participants had diverse backgrounds and goals. In addition, despite, the presence of almost all actors (producers, researchers, advisor, downstream value chain) in the CS team, it was difficult to find an entry point (whether to start with addressing concerns from producers or value-chain actors or consumers) to achieve the objectives. The numerous workshops, and an exchanged visit to United Kingdom's DiverIMPACTS case study, have sharpened the focus of CS, identified roles of each actors, energised them and (there seemed to be an) increase collaboration among the CS participants to take collective actions, and even prepared for potential establishment of new legume value chain.

4 Conclusions

Despite the initial hurdles in tackling the heterogeneous actors and issues, the co-innovation processes have led to designing a new diversified cropping systems, identified important barriers and bottlenecks at the production, post-harvest, marketing, and policy levels of grain legumes, and in formulating goals and motivation for collective implementation among the participants.

Actions plans taken up have been successful so far, and more outreach activities via events and fairs, connecting producers and processors with food industry and municipal schools and canteens, outlets (super markets, university student library, gathering places, etc) will follow in the next 2-3 years. It is envisaged that in 10 years' time, most Swedish consumers will enjoy the taste of locally produced legumes, which will be easily affordable and available, often, in their meals.

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SESSION 5. ENHANCING AGROSYSTEM RESILIENCE AND PERFORMANCES BY CROP DIVERSIFICATION

Chairs: Erik Steen Jensen (Swedish University of Agricultural Sciences, Sweden),
Jorge Álvaro-Fuentes (CSIC, Spain)

ORAL PRESENTATIONS

- Syppre: better reconciliation of global and local issues through innovative and diversified cropping systems
  Speaker: Paul Tauvel, ITB, France
- Diversified arable cropping systems and management in selected European regions have positive effects on crop production and soil organic carbon
  Speaker: Claudia Di Bene, CREA, Italy
- Does diversity affect dynamics of agricultural system facing perturbations?
  Speaker: Manon Dardonville, INRA, France
- Does cropping system diversification with legumes lead to higher yield stability? Diverging evidence from long-term experiments across Europe
  Speaker: Moritz Reckling, ZALF, Germany
- Co-design and multicriteria assessment of low-input cropping systems in the South-West of France: an 8-years experimentation with farmers
  Speaker: Lionel Alletto, Chambre régionale d'agriculture Occitanie, France
- Combining temporal and spatial diversification to improve economic, environmental and social performances in European cropping systems
  Speaker: Loïc Viguier, INRA, France

POSTER

- Sunflower crop profile in the Republic of Moldova
  Presenter: Maria Duca, State University "Dimitrie Cantemir", Moldova

DiverIMPACTS European Conference on Crop Diversification September 18-21, 2019 Budapest, Hungary

Syppre: better reconciliation of global and local issues through innovative and diversified cropping systems

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1 Introduction

Agriculture must succeed in reconciling productivity, economic profitability and environmental protection. This requires a shift towards new production systems, based on both ecological intensification and technicological innovations, adapted to local conditions and manageable by farmers. To address this issue, the French technical institutes on arable crops, Arvalis Institut du Végétal, Terres Inovia and ITB launched in 2014 the collaborative project "Syppre : Building together innovative cropping systems for tomorrow", which involves National and regional stakeholders.

The project includes: (i) an observatory of current cropping systems, (ii) experimentation on innovative cropping systems (three of which being part of the H2020 DiverIMPACTS project) and (iii) groups of farmers engaged in the redesign of their farming systems. These complementary activities are currently implemented in five main crop production areas representative of a diversity of French arable crops. Based on system experiments results and on interactions with farmers' networks, Syppre's main goals are to disseminate technical references and to produce tools in order to support farmers in the evolution of their own cropping systems.

The presentation aims: (i) to briefly describe the five cropping systems and how diversification schemes have been designed to fulfil their objectives, (ii) to share their performance indicators during the first three years of experiments in terms of productivity, economic results and environmental sustainability (iii) and to discuss the strengths and weaknesses of these strategies relying on cropping systems diversification to meet local and global challenges.

2 Materials and Methods

The five crop production areas where the cropping systems were co-designed and tested are: PIC (Picardie, northern France, deep loamy soils, industrial productions); CHAM (Champagne, chalky soils, industrial productions); BER (Berry, central France, shallow clay-limestone, arable winter crops); LAU (Lauragais region, southern France, clay-limestone, arable crops) and BEA (Bearn, southern France, humic soils, maize single-crop farming). At each location, two cropping systems were co-designed with local farmers and advisors using "de novo" methodology (Toqué et al., 2015), and tested: (i) a control system representative of local crop rotation conducted with optimised cultural practices, and (ii) an innovative system aiming to meet local and global challenges. Global objectives were common to the five situations and local objectives were defined with regional stakeholders. They have been translated into relevant indicators (Guillaumin et al., 2007) and objectives. For each case, crop diversification was used as one of the main agronomic levers to meet the challenges.

Every year, a diagnosis is being conducted to compare the performances of the systems to the initial goals. It is based on a confrontation between foreseen decision-making rules and real practices on the platforms. To do so, an agronomic diagnosis using observations and measurements was used to determine main factors affecting crop yield A multi-criteria assessment that includes pesticides use indicators, mineral nitrogen supply, economic and environmental indicators isalso performed (Jouy et al., 2018). This assessment is being done by using the French tool Systerre®.

3 Results

After three years of experiments, first conclusions were drawn on each experimental platform. This abstract focuses only on the results of the CHAM platform (cf. Figure 1), the results of the other platforms will be presented during the conference. Introduction of pulses as intercrops and/or main crops enabled to reduce mineral nitrogen supply by 38% in 2017 and 20% in 2018, compared to the control system. Combining with reduction of soil tillage, greenhouse gases emissions decreased by 26% and 17% respectively. Energy consumption was reduced by 17% and 12%. Economic results, measured through the direct margin, drastically differed from one year to another: +31% in 2017 and -20% in 2018. More time will be required to get a better evaluation of the economic impact of these new cropping systems. First results were less favorable on other criteria. So far, the innovative cropping system has not led to an increase in productivity or to a significant decrease in the use of pesticides. Consequently, strategies have been adapted in 2018: sunflower was replaced by hemp, mechanical weeding was reinforced and the cereals herbicide program was adapted.

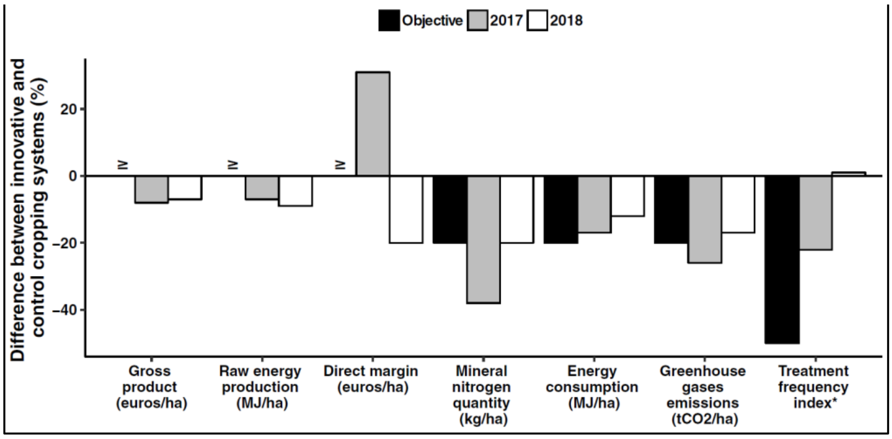

Figure 1. Results of the main indicators for CHAM platform

** Innovative system treatment frequency index values are compared to a regional reference and not to the control system values*

4 Discussion and Conclusions

The assessment of the systems after three years of experiment gave a first overview of the potential to reach global and local objectives thanks to innovative practices. It also enabled to identify potential benefits of crop diversification but also technical barriers to overcome. The LAU and BEA platforms are examples where diversification does not lead to a decrease in the use of pesticides. Moreover, combining different objectives could also be very problematic on all platforms: for instance, managing erosion issues in LAU using cover crops lead to increase the use of herbicides which was inconsistent with the aim of reducing treatment frequency index. It might also make it difficult the anticipated adaptation in case of ban of glyphosate use.

Regarding these first conclusions, adjustments have been made in the systems. For instance, it was decided in Picardie to redesign the innovative cropping system because of poor economic results. Indeed, the extension of the rotation of the innovative system was accompanied by a less frequent return of potatoes, which has a much higher profitability than other crops. In this case, diversification had a direct negative impact on profitability. Two options are thus being explored to redesign this system: introducing a second potato or multiple cropping in order to increase the gross products.

Beyond that, development of innovations could be expected from promising systems that could be deployed at a bigger scale. For example, integration of pulses as main crops without specific market opportunities tends to decrease economic results because of low productivity. Development of more productive varieties, more resistant to pests and better adapted to local conditions would be a good lever to improve the sustainability of innovative cropping systems.

However, this first evaluation could not take into account cumulative effects, neither evaluate the robustness of these cropping systems. A long-term vision is also essential and must rely upon adapted indicators such as organic matter, physical and biological soil fertility, and economic studies.

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Diversified arable cropping systems and management schemes in selected European regions have positive effects on crop production and soil organic carbon

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1 Introduction

Traditional arable cropping systems in the EU have been progressively simplified to monocropping systems, with high external inputs through mineral and organic fertilizers, pesticides and conventional tillage (CT). Thus, various crop diversification strategies such as crop rotation, intercropping and multiple cropping, as well as low-input management practices have been promoted to sustain crop productivity while maintaining environmental quality and ecosystem services. Actually, European arable area has high opportunities for sustainable intensification through crop rotation, conservation tillage (minimum (MT) or no-tillage (NT)) and fertilization management. It has been also argued that diversification of production systems can lead to better food security (Scherer et al., 2018) and economic sustainability of farms (de Roest et al., 2018), since it contributes to natural pest control, pollination, nutrient recycling, soil structure and fertility conservation, carbon sequestration, and water provision.

In the Diverfarming project (www.diverfarming.eu), the preliminary objective was to identify, with an exhaustive literature review, the best crop diversification systems and farming practices to be tested and validated in the field experiments to be planned in the different European pedoclimatic regions. Understanding the expected effects of diversified cropping systems and management options on the resilience and sustainability of agroecosystems in different regions, may promote the adoption of appropriate practices and help to select a suitable method for each production system and environment, thus improving farm management and increasing revenues.

2 Materials and Methods

We conducted a data-analysis to evaluate the expected effects of the existing alternatives for crop diversification and environmentally-sound farming management for arable crops in four selected European pedoclimatic regions (Atlantic, Boreal and Mediterranean North and South), and typical cropping systems (fodder grains, leys and mixtures, autumn-winter and spring-summer cereals). The dataset included site-specific environmental data (e.g. mean annual temperature and rainfall), soil tillage (e.g. no-tillage, minimum and conventional tillage), fertilization management (none, mineral, mixed, organic), cropping system (monoculture, rotation, intercropping, multiple cropping), crop production e.g. grain in cereals and above ground biomass in fodder crops (CP), soil organic carbon (SOC) concentration at the end of the experiment, and soil texture group according to USDA classification. Data included in the analysis depended on the following general criteria: study period (at least one full year), only field experiments (no laboratory or pot experiments), and neither studies specific for GHGs emissions, soil biological and physical parameters, meta-analyses nor modelling studies were considered. Moreover, studies providing SOC content by soil layers under tillage management were also considered. The final selected comparisons were 1165 from a total of 80 references.

The diversified (Div) and the control (Cont) treatments of each experiment were evaluated based on the percentage change of the considered response variable, i.e. CP, and SOC. Since we used the ratio between the difference (Div – Cont) and the Cont, we could eliminate the differences due to the different CP levels and SOC analytical methods among studies (Eqs. 1-2):

$$\text{Percentage change (CP)} = 100 \times (CP_{Div} - CP_{Cont}) / CP_{Cont} \quad \text{(Eq. 1)}$$

$$\text{Percentage change (SOC)} = 100 \times (SOC_{Div} - SOC_{Cont}) / SOC_{Cont} \quad \text{(Eq. 2)}$$

Changes of CP and SOC were analyzed evaluating the effects of crop diversification, tillage and fertilization management, and further by environmental (e.g. climate) or soil parameters (e.g. texture). Data were represented by Box-Whisker plots (central point means, and 95% confidence interval CI). Responses were considered significantly different if their 95% CIs did not overlap, and significantly different from the controls if the 95% CIs did not overlap with zero.

3 Results

Compared to monoculture, diversified cropping systems with longer crop rotations (at least 3 years) significantly increased CP by 12%, while the 2-years rotations showed a not-significant 5% increase. CP for intercropping were 11% higher compared to monoculture, though not statistically different. The average effect on CP of multiple cropping was 1%, close to zero (-0.4%) in the Mediterranean region while ranged from -4.3% to 12.6% in the Boreal region (average 3.9%).

SOC increased by 13% as average in diversified systems compared with monoculture, and the introduction of legume crops in the rotations significantly increased SOC by 13%. Average SOC increases were 11% higher in semiarid conditions than in humid and sub-humid climates (about 3%).

In relation to conservation tillage, CP was 12% higher in NT compared with CT, and was more effective on CP in silty clay loam soils and in arid and semi-arid climates. In addition, NT was more effective in increasing SOC than MT. Significant SOC increases by conservation tillage management were found with organic and mixed fertilization (27 and 5% respectively) and crop rotations (5%).

Results by soil layers showed an average SOC increase ranging from 14 to 45% in the top 15 cm with conservation tillage management compared to conventional deep tillage, while SOC decreased by about 10% as average in deeper soil layers below 15 cm.

In relation to fertilization management, organic fertilization with manure or slurry increased CP (37-40%), and mineral fertilization was particularly effective with the introduction of cover crops (56%), combined with crop residues (24%) or with manure and crop residues (41%). Furthermore, CP increased with crop residue incorporation (39%) or mulching under conservation tillage (39%) and longer crop rotations (39%). Compared to the control treatment with mineral fertilization, organic fertilization showed the highest and significant SOC increases (25%). Fertilization average effect on SOC was higher for cereal crops in the Mediterranean region (about 25%) compared to fodder crops in the Atlantic and Boreal areas (about 10%), and in loamy textures (about 23%).

4 Discussion and Conclusions

In our data-analysis, longer crop rotations resulted in higher CP compared to monoculture. Intercropping was mainly adopted in the humid conditions of the Atlantic and Boreal regions and showed a general lower effect on CP compared to traditional rotations. Results also showed the need of improvements in the management of multiple cropping systems, as indicated by Bedoussac and Justes (2010). In general, results point to the direction that conversion from the traditional monocropping systems, with intensive tillage and mineral fertilization, to alternative systems based on cropping diversification through the use of crop rotations, no-tillage and organic fertilization results in a better crop performance and in the accrual of soil C.

Diversification with longer rotations, NT and organic fertilization management increased both CP and SOC in European arable systems. Notwithstanding, crop diversification and environmentally-sound farm management strategies are often negatively perceived by farmers for a possible decrease in yields and economic benefits that are often coupled with higher machinery investments. Globally, regional differences related to climate and soil texture specific responses should be considered to target local measures to improve soil management.

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Does diversity affect dynamics of agricultural system facing perturbations?

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1 Introduction

Agricultural systems are increasingly facing climatic and economic disturbances while they have to deal with food security, economic viability and environment quality issues. Several conceptual frameworks have been developed to analyze dynamics of such systems: resilience, vulnerability, robustness etc. However, there is still a challenge to propose operational methods and indicators to characterize dynamics of agricultural systems facing disturbance(s) and to identify system's properties that drive this dynamic.

Diversity in its various forms is commonly accepted as a strong determinant of resilience in agriculture. Benefits are supposed to arise from functional and spatiotemporal complementarity and redundancy. However, empirical evidences are scarce when analyzing positive effect of diversity on resilience. [1] provide systematic review of climate resilience of integrated agricultural system (i.e. diversified systems). It reveals supportive but not conclusive evidence on positive diversity role in resilience. Observed variability can be explained by specificities of agricultural systems: gradually artificialized (selected species, inputs) and driven by stakeholders from farm to regional and supra levels.

In this communication, we will present results of a systematic review of scientific studies assessing quantitatively the dynamics of agricultural systems in terms of vulnerability, resilience, robustness and other related concepts, hereafter VRR.

2 Materials and Methods

A generic request on Web of Science and a systematic sorting by co-occurrence of terms (with Vosviewer) enabled us to identify 37 papers dealing quantitatively with VRR of agricultural systems, in temperate zones, at different organizational levels: from field and farming system to food-chains and food systems. We analyzed results of each study through detailed characterization of VRR *of what* (the studied system: type of production and organization level), *to what* (hazards), *when* and *where* (spatiotemporal resolution and extend), *of which attribute(s)* (performance(s) to maintain) and *due to which property(ies)* (drivers explaining the observed dynamics of the attribute). This structured analysis enabled us to identify key diversity drivers of agriculture systems dynamics. When comparable, we synthetize studies results according to organization levels (plot, farm and territory), type of production (grassland or crop), system performance attribute and perturbation studied.

3 Results

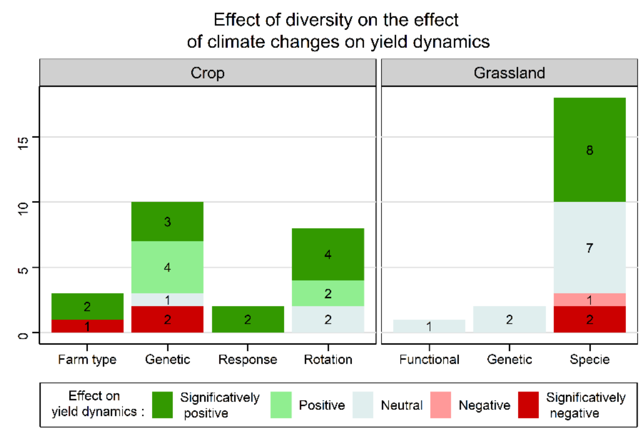

Figure 1. For crop and grassland at plot, farm and territory organization levels, effect of diversity (rotation diversity, farm type diversity, genetic (cultivar) diversity, response diversity, species diversity, genetic diversity and functional diversity) on the effect of climate change over studied indicators of yield dynamics: high level, high resistance, high or low risk of exceeding given threshold, increasing trend and low variability. Climate change is described as high, increasing trend and variable temperature or low, decreasing trend and variable precipitation. Light grey means no effect. Green/red means favorable/unfavorable effects of disturbed climate i.e. a lower/higher sensitivity of systems. Deep red/green represents significant results (at least p-value<0.1) and light red/green represent results where no statistical test is allowed by the method used.

A great majority of studies analyze effects of climate change on yield dynamics. They use a large range of dynamics indicators providing information on level, resistance, risk of exceeding given threshold, trend or variability of yields.

For grasslands, authors study mainly effects of taxonomic diversity in terms of specie (86%) and genetic (10%). For crop production systems, studies focus on effects of diversity of rotation at plot or farm level and farm type, cultivar or response (e.g. farm type, yield variability) at territory level. Our analysis shows that in only 38% of results there is a positive effect of diversity on dynamics of grassland yield considering climate change. In contrast,74% of results shows positive effect of diversity on dynamics of crop yield (Figure 1).

In grasslands, at plot/field level, diversity of grassland species enhances levels of biomass produced when climate perturbation occurs [2]–[5]. Then, interestingly, and contrary to literature hypothesis, diversity of grassland species and root functional diversity doesn't [2], [6], [7] or negatively impact recovery ratio of productivity [3], typically use as indicator of resilience. Furthermore, variability, resistance and trend of yield is changeably affected by diversity of grassland species depending upon frequencies of climate perturbations and presence of legume or grass species [2].

In crop production system, at plot/field and farm system level, within farm biodiversity (i.e. taxonomic diversity) has a positive effect on level and dynamics of crop yield: high yield, low variability, low recovery time, positive trend [8], [9]. Particular negative response is explained by specificities of rice production (a composition effect) [10]. Besides, some authors show positive effect of farm type diversity in size and intensity of production on reduction of variability of yield when high temperatures occur [11].

4 Discussion and Conclusions

Our review highlights that majority of studies focus on field level, taxonomic diversity, yield performance and climate change. Diversity has variable effects on dynamics of agricultural systems. Effects differ from grassland to crop. Variability of diversity effect could be explained by composition effect (abundance of some species), i.e. in dynamics of biomass production (recovery after drought for example). Additional researches are needed on the role of associated diversity driven by agricultural practices and landscape configuration [12], [13]. Furthermore, research community has to go further than yield-centered studies and to address effect of diversity on dynamics of economic (by offering range of market opportunities), agronomic (by improving biological process [14]), or ecological (ecosystem services and biodiversity *per se*) performances.

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Does cropping system diversification with legumes lead to higher yield stability? Diverging evidence from long-term experiments across Europe

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1 Introduction

In the face of climate change and to achieve global food security, the resilience of agricultural systems is gaining increasing attention, and is often considered as important as their productivity (Olesen et al., 2011). Temporal yield stability is one indicator of the economic resilience of cropping systems and its analyses have become more important as a decrease in yield stability has been observed for different crops at regional and global scale (Döring and Reckling, 2018). The temporal and spatial diversification of cropping systems with legumes, perennial crops, cover crops and intercrops can be expected to increase crop yield stability and offers an adaptation strategy to the increased climate variability (Liu et al., 2019).

The objectives of this study were to assess the effect of cropping system diversification strategies on yield stability, through (i) integration of perennial leys with and without legumes, (ii) increasing proportion (length, *i.e.* number of years) of the perennial grass-clover leys relative to the entire crop rotation, (iii) varying the order in which crops are positioned in the rotation, (iv) integration of grain legumes and (v) integration of cover crops during fallow periods.

2 Materials and Methods

For the analysis of yield stability, we used yield data of different time periods between 1971 and 2017 of winter wheat, durum wheat and oat from five long-term field experiments from Sweden (Lanna, Stenstugu and Säby), North-East of Scotland (Tulloch) and Southern France (Auzeville). The five sites are characterized by contrasting bio-physical conditions in terms of soil and weather conditions.

Several yield stability indicators were calculated to quantify yield stability considering different concepts of stability i.e. the coefficient of variation (CV), Power Law Residuals (POLAR) (Döring et al., 2015) and Finlay, Wilkinson regression analyses (FW) and the probability of one system outperforming another system (Piepho, 1998).

3 Results

The results showed that cropping systems incorporating perennial grass-clover leys in the Swedish LTEs outperformed systems without leys in terms of winter wheat and oat yields in 60-94% of the cases on average across the sites and depending on the nitrogen fertilizer application rate. Systems with pure grass leys outperformed systems without leys in only 55-80% of the cases. The FW regression analyses showed that oat grown in a cropping system with perennial clover-grass ley and no N fertilization had significantly higher yields in low- and high-yielding years compared to oat grown in the cropping systems with only a grass ley or without a ley (Table 1). The CV and POLAR did not indicate any significant differences in yield stability between the cropping systems.

The yield stability of oat in the Scottish LTE did not differ if oat was grown after a 4-year or a 3-year ley. Oat yields were 33% higher when following directly after the ley compared to oat grown two years later in the crop sequence. The CV and POLAR values indicated a greater stability for the first oat (CV 21%) compared to the second oat (CV 37%) but differences were not significant.

Table 1. Mean grain yield of oat (Mg DM/ha), CV values (%), Finlay-Wilkinson (FW) regression coefficient *bi* and POLAR coefficients for each cropping system (A = with perennial grass-clover ley, B = with perennial grass ley and C = without perennial ley) with no N fertilization at the two Swedish sites Lanna and Stenstugu.

Cropping system	Lanna				Stenstugu			
	Grain yield	CV	FW b_i	POLAR	Grain yield	CV	FW b_i	POLAR
A	1.9	31	1.1 a	0.01	2.0	29	1.09 a	-0.07
B	1.7	36	1.0 a	0.06	1.7	36	1.07 a	0.06
C	1.4	32	0.8 b	-0.11	1.3	33	0.79 b	-0.13

Durum wheat grown in a cropping system with grain legumes in southern France had a significantly higher FW regression coefficient compared to a cropping system without grain legumes and yields tended to be particularly high in low-yielding years. Diversification with cover crops in the French LTE using data from 2005-2016 did not affect yield stability of durum wheat significantly.

4 Discussion and Conclusions

We found that cropping system diversification with legumes can increase the productivity in LTEs across Europe, while the effects of diversification on yield stability were inconsistent. St-Martin et al. (2017) also found that winter wheat in more and less diverse cropping systems led to equally stable yields. Spring wheat in a 'crop-livestock' system with grass-clover and grain legumes tended to perform better in favourable years relative to the less diverse system (St-Martin et al., 2017). In another study, a lentil-oilseed sequence had the lowest variation in yield and was most suitable for high-yielding environments compared with fallow- and wheat–oilseed sequences (Liu et al., 2019). Our FW analyses also point towards a better performance of diversified systems with legumes in high-yielding years compared to systems without legumes.

We conclude that diversification with legumes increase yield of other crops in the rotation but we have not been able to show that the measures investigated have a consistent impact on yield stability. A higher level of diversification could be required in time and space to achieve both, higher yields and increased yield stability.

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Co-design and multicriteria assessment of low-input cropping systems in the South-West of France: a 8-years experimentation with farmers

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1 Introduction

Food production in the last decades has been greatly increased thanks to intensification of agriculture but this intensification also led to numerous undesirable environmental impacts such as biodiversity loss, soil degradation, and soil, water, air, and food contamination by pesticides (Foley *et al.*, 2005; MEA, 2005). Moreover, in many cases, economical performances of intensive cropping systems (CS) decreased that weakens the sustainability of farms. In the South-West of France, two main traditional CS could be identified: a rainfed durum wheat-sunflower CS and a maize monoculture CS (mainly irrigated). The main objective of this study was to evaluate the sustainability of CS designed as alternatives of these two traditional CS that aimed at reducing the negative externalities of agriculture while answering specific objectives of the involved farmers.

Table 1. Main characteristics of the 8 farms involved in the study. B: barley; CS: carrot seed; DW: durum wheat; FB: Fababean; M: maize; MS: maize seed; RS: rapeseed; SB: soybean; SG: sorghum; SF: sunflower; SW: soft wheat.

Site (department number)	Soil type	Initial CS	Alternative CS
Farm 1 (09)	Silt – Clay silt	MS monoculture	MS → MS → SF → SW → SB → SW
Farm 2 (31)	Silty with coarse elements, hydromorphic	M monoculture	M → SW → SB
Farm 3 (65)	Silt with coarse elements	M monoculture	M → SF → SW → SB → SW
Farm 4 (65)	Silt with coarse elements	M monoculture	M → SB → SW
Farm 5 (31)	Silt with coarse elements, hydromorphic	M → SW	M → SW → CS → SW → RS → SW
Farm 6 (31)	Calcareous clay on hillsides	DW → SF	DW → SF → SW → SG
Farm 7 (46)	Calcareous clay on hillsides	RS → SW → B	RS → SW → SF → B
Farm 8 (81)	Calcareous clay on hillsides	DW → SF → SW → SF	DW → SG → SB → SW → SF → FB → SW → SF

2 Materials and methods

Workshops, mixing farmers, advisers and scientists, were organized in 2009 and 2010 in order to (i) identify strengths and weaknesses of initial CS; (ii) design alternative CS (based on formalized decision rules) in order to answer to common and specific objectives; (iii) define/choose the indicators to monitor the CS performances and, after an *ex-ante* assessment (iv) experiment and perform an *ex-post* evaluation of the designed CS for each involved farm (Papy, 2001; Debaeke *et al.*, 2009). A 8-farms network was involved in this 8-years study (2010-2017) (Table 1). The main indicators chosen to monitor performances are mentioned in Table 2.

Table 2. List of selected indicators for cropping system performance assessment.

Dimension	Criteria	Indicator
Economic	Profitability	Semi net margin (SNM) at rotation level (€/ha)
Economic	Weed management	Weed abundance in the field
Economic	Dependency on external inputs	Input use efficiency
Economic	Productivity	Energetic yield (MJ)
Environmental	Water quality (pesticide)	Treatment Frequency Index (TFI)
Environmental	Water quality (pesticide)	I-phy
Environmental	Water quality (pesticide)	Number of toxic pesticides for aquatic systems
Environmental	Water quality (nitrate)	Nitrogen indicator (NI)
Environmental	Water quantity	Irrigation amount (m^3/ha)
Environmental	Soil quality	Organic matter indicator (IMO)
Environmental	Soil quality	Length of bare soil period (%)
Environmental	Fossil energy	Total fuel consumption at CS level (MJ/ha)
Environmental	Climate change mitigation	GHG emission (equivalent t CO_2/ha)
Social	Farmers' quality of life	Labor time (h/ha)
Social	Farmers' quality of life	Workload distribution (h/ha/month)
Social	Famer and public health	Number of pesticide applications

Furthermore, in order to test the robustness of cropping systems, 8 crop price scenarii, chosen over the period 2007-2014, were applied and a comparison between the economic performances of the initial CS and the alternative CS was made.

3 Results and discussion

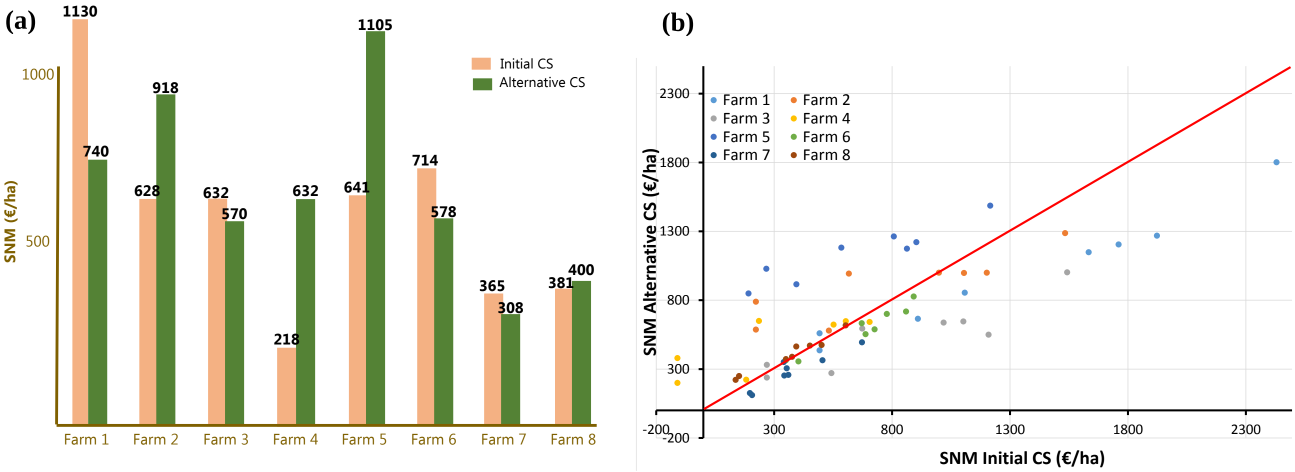

Figure 1. Semi net margin (a) and robustness toward crop price fluctuations (b) of initial and alternative CS.

Crop diversification was found to enhance CS economical performances if associated with rigorous control of the mechanization loads (Fig.1a). In most cases, diversification led to a better distribution of workload during the year allowing the development of high added value production (such a vegetables with direct selling). Selected indicators illustrated that diversification could lead to lower environmental impacts (Table 3), except if seed production (with high pesticide use) was integrated in the CS. For the project DiverIMPACTS, further investigations are performed with economical stakeholders to increase economical performances of diversified CS. In parallel, a multicriteria assessment (using the indicator list of DiverIMPACTS) of the initial (mainly maize monoculture) and diversified CS of the 20 farms involved in the Case Study 5 has started and should strengthen conclusions on the effects of crop diversification on the sustainability of South-West of France farms.

Table 3. Multicriteria assessment of alternative CS (selected indicators from the list of Table 2)

	SNM	TFI	NI	GHG	Labor time	Farmer satisfaction
Farm 1	-35%	-39 %	+43%	-21 %	-67 %	↘SNM
Farm 2	+46%	-62%	0%	0%	-72%	↘TFI; ↗SNM; ↘Labor time + Conservation agriculture
Farm 3	-10%	-16%	0%	-17%	-37%	↘Labor time + diversification in vegetable production
Farm 4	+189%	+25%	+156%	-62%	-45%	↘Labor time + Conservation agriculture; better weed management
Farm 5	+72%	+71%	+15%	-17%	0%	↗TFI (seed contract); ↗SNM
Farm 6	-20%	-48%	+32%	+24%	+25%	Better weed management
Farm 7	-15%	+10%	+24%	-30%	0%	Better weed management; low SNM
Farm 8	+5%	-43%	+47%	-43%	+10%	↗Labor time; Better weed management

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DiverIMPACTS
European Conference on Crop Diversification
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Budapest, Hungary

Combining temporal and spatial diversification to improve economic, environmental and social performances in European cropping systems

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1 Introduction

The simplification of European agri-food systems has started with the green revolution of the 1960s. Driven by food market globalization and output-based subsidies, the range of cultivated species grown in Europe has considerably dropped leading to a simplification and homogenisation of landscapes. In addition, the excessive use of synthetic inputs has led to strong adverse impacts on the environment. Among them are chemical pollution, soil degradation, biodiversity loss and important emissions of greenhouse gas (GHG) which contribute to climate change which is recognized as "one of the greatest challenges to food security" especially through increased climate variability leading to yield instability. Therefore, European cropping systems must evolve to combine high food production and low ecological footprints. One way to tackle this objective is to re-diversify agri-food systems in both time (rotation scale) and space (field scale). Several diversification practices 1) rotation extension 2) intercropping (i.e. the simultaneous growth of two or more crops on the same land), 3) contiguous cash crops (i.e. the growth of two or more cash crops on the same land and year and 4) multiple-services cover crops (i.e. the growth of a non-harvested crop after a cash crop) have proved to be efficient in increasing yield and yield stability, with reduced inputs. These diversification practices are currently marginally used in Europe, in both conventional and organic systems, even if the latter tend to have longer rotation than the first. There is an important lack of knowledge on the effect of combining these diversification practices (space + temporal) on cropping systems performances, which partially explain their marginalisation. The objective of this work is to compare the economic, environmental and social performances of low diversified cropping systems (references, REF) to that of cropping systems combining diversification practices (DIV), using an ex ante assessment. We hypothesized that combining spatial and temporal diversification with reduced inputs improve performances of cropping systems.

2 Materials and Methods

10 field experiments (FE) from the DiverIMPACTS project were considered for evaluation. All FE had their own REF whose practices corresponded to a typical local farm. Diversification strategies, for each FE, were co-designed with farmers, advisers and value-chains. For each FE, every cultivation operation (soil preparation, sowing, fertilisation, phytosanitary treatments, harvest and transport) planned was reported. For every operation, if needed, information about machinery (model, working performances), inputs (nature, price, dose used) and outputs (biomass, grain and straw yield) were also reported. Hypotheses were made on parameters such as yields and prices, according to local references or scientific literature, when needed. Multi-criteria analysis (MCA) of the performances of each FE was performed using SYSTERRE® developed by ACTA (www.diverimpacts.net/partners/acta-fr.html). This software calculates scientific-based indicators of performance from the exhaustive inventory of all the cultivation operations of a cropping system. The following indicators were chosen to assess the performances of cropping systems 1) Economic: Energetic Yield, Semi-net Margin; 2) Environmental: Nutrient balances, Amount of Active Ingredients, Primary Energy Consumption, Total GHG Emissions, and; 3) Social: Working load and Treatment Frequency Index (TFI).

3 Results

Three contrasted cases are given: a monoculture in conventional agriculture, a second in organic agriculture where the REF is already diversified, and a third in a classical rotation in arable conventional systems based on three crops (Table 1). The strategies of diversification in both time and space and their potential effects on different criteria are presented. The MCA shows positive effects on environmental indicators. Social

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indicators would indicate an increase of Work Load but decrease of TFI. Finally, the economic performance of DIV systems seems to be system-dependant with either reduction or increase of the Semi-net Margin.

Table 1. Overview of Multi-criteria assessment of the effects of crop diversification for three situations corresponding to three field experiments of DiverIMPACTS

Reference system (REF)	Diversified system (DIV)	Impacts of crop diversification
Silage Maize monoculture (conventional agriculture) (Netherlands)	Silage Maize + Sorhum Mixture of cover crops (Poaceae and Fabaceae)	Reduction of (1) Amount of Active Ingredients (-19%), (2) Primary Energy Consumption (-55%), (3) Total GHG Emissions (-31%), (4) Semi-net Margin (-52%). Increase of Working Load (+15%)
Silage maize Spring Barley Oilseed Rape Faba Bean Green Manure (organic agriculture) (Switzerland)	Silage maize + White clover Spring Barley + Pea Oilseed Rape + Lentil Faba Bean + Oat Green Manure	Reduction of Total GHG Emissions (-30%) Increase of Semi-net Margin (+9%) Similar Primary Energy Consumption and Working Load
Oilseed Rape Wheat Barley (conventional agriculture) (France)	Oilseed rape+legume/cover crop/grain maize/cover crop/sunflower/wheat/pea+wheat/cover crop/wheat/cover crop/barley/cover crop/lentil/durum wheat	Reduction of (1) GHG Emissions (-20%) (2) TFI (-50%), (3) Semi-net Margins (-10%)

Three contrasted cases are given: a monoculture in conventional agriculture, a second in organic agriculture where the REF is already diversified, and a third in a classical rotation in arable conventional systems based on three crops (Table 1). The strategies of diversification in both time and space and their potential effects on different criteria are presented. The MCA shows positive effects on environmental indicators. Social indicators would indicate an increase of Work Load but decrease of TFI. Finally, the economic performance of DIV systems seems to be system-dependent with either reduction or increase of the Semi-net Margin.

4 Discussion and Conclusions

These preliminary results suggest that diversification has a key role in the sustainable development of cropping systems and that even slight changes in their design could lead to major improvements of environmental performances. Careful attention should be paid to an increase in the work load in DIV systems since it could hinder farmers adoption of practices. Ongoing analyses of other FEs would suggest that diversification leads to a stabilisation or small improvement of economic performances. This work can become a tool to help (1) FE leaders and stakeholders to adapt their strategies and test other scenarii including an intensification of crop diversification to boost its effects, (2) farmers in their transition towards more diversified systems and (3) decision makers to support crop diversification in Europe.

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Sunflower crop profile in the Republic of Moldova

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1 Introduction

Since 1860 and to this day sunflower is the main source of edible vegetable oil in the Republic of Moldova. It is the third most cultivated crop after corn and wheat, having consistent planting areas in all geographical zones of the country [2]. Moldova's contribution to the global sunflower yield is 0.8-1.0%. Only in recent years the total sunflower production is around 600 thousand tons. According to the Food and Agriculture Organization of the United Nations (FAO), in 2014, sunflower seeds were the 2nd and oils were the 7th most exported crops and agricultural products in terms of value [3].

Long-term systemic research in Moldova has highlighted that sunflower can be grown successfully in correct crop rotation systems with wheat (or other cereals) and corn as an optimal predecessors and a minimum of a six-year rotation between successive sunflower crops. In order to ensure the aforementioned, the *sunflower* growing *areas* must not exceed the quota of 170 000 ha of the country's arable land [8].

However, in the past three decades, significant change has been implemented in farming due to the shift in the socio-economic and institutional environment in Moldova. Land reform, economic and infrastructural developments have shaped adaptive responses in sunflower production. The surface occupied with sunflower increased continuously, due to the increase of market demand for sunflower seeds and high crop tolerance to drought, which ensure the stability of production and the possibility to obtain stable annual income. During this period sunflower has been grown on approx. 260 000 - 380 000 ha, an area that exceeds the recommended limits by approximately 2.3 times [4, 5].

The impact of such developments on production remains mostly unexplored. Moreover, expansion of *area* planted with *sunflower* leads to the failure of crop rotation, increasing frequency and aggressiveness of various pathogens and inefficiency of long term strategy in managing insects, diseases and weeds, decrease of soil physical properties etc.

In this context, great interest is shown for a new approach to secure sustainable growth in Moldova's sunflower sector. In order to accomplish said task, the undertaken research was focused on the study of the current state of play of sunflower crop in farms.

2 Materials and Methods

A survey (face-to-face interview of farmers) was conducted in 78 localities, including 20 localities in 7 districts of *the northern region*, 22 localities in 8 districts of *the southern region* and 36 localities, 11 districts of *the central region.* Soil samples (0-30 cm arable layer) have been collected from each studied habitat. The analysis of principal soil parameters has been realized in the Republican Center of Applied Pedology of Moldova according to standardized methods as follows: available P_2O_5 and K_2O content [6]; humus content - $N\text{-}NO_3$, $N\text{-}NH_4$ [7].

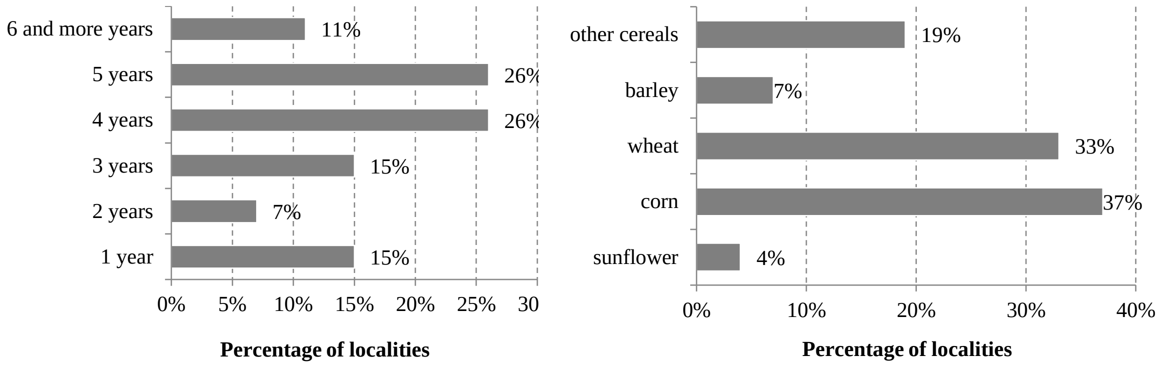
3 Results and Discussion

According to the obtained data, in most of the farms sunflower was preceded by winter wheat and other cereals (52%), corn (37%), in some cases barley (7%) and even by sunflower (4%) (Figure 1).

Unfortunately, the six-year rotation between successive sunflower crops was respected only in nine farms from the total of 78 interviewed. In the majority of cases (approx. 50%), sunflower was cultivated in 4 to 5-year rotation and in 37% of the farms the crop returned to the same field only after a 1 to 3-year rotation.

As a result of such intensive cultivation of sunflower, infection is accumulated and the potential for disease epidemics is on the rise [2, 5]. Sunflower is well known as a plant that absorbs a large quantity of mineral substances which depletes soil reserves. The aforementioned consideration enforces the idea that sunflower must return on the same field after a minimum six-year rotation.
In order to ensure profitability of sunflower production, it is necessary to maintain soil fertility. The analysis of the humus, nitrogen, phosphorus and potassium content were carried out and the soils have been grouped in six classes

according to the accepted classification [1]. Low and very low level of humus (1.4-2.8%) has been identified in the majority (63%) of the analyzed fields (Table 1). This parameter is the same or higher, at critical levels, (3.4%) only in 8 fields, which represent around 10% of the total analyzed fields. The same data shows that around 70% of the analyzed fields are characterized by soils with moderate nitrogen content. In 13% of them nitrogen content is low and only in 10% it is high.



A. **B.**

Figure 1. Rotation of sunflower in farms of Moldova
(A – Period of sunflower return to the same field; B – Predecessors of sunflower)

Regarding mobile phosphorus, 4% of all the fields are marked with low content of this element, 7% with medium and 46% of the total localities this value exceeded the media. Exchangeable potassium contents analysis has shown low values in 13% of fields and moderate in 33%. More than a half of analyzed fields (54%) are distinguished by higher than moderate content of exchangeable potassium.

Table 1. Percentage of localities with varying degrees of humus and macronutrient supply in soil

Soil characteristics	Very low	Low	Moderate	Relatively optimal	High	Very high
	Percentage of localities, %					
Humus content	17	46	30	7	-	-
Total nitrogen content	-	13	77	-	10	
Mobile phosphorus	7	40	7	20	16	10
Exchangeable potassium	3	10	33	30	17	7

Agrochemical research has shown that in most cases, soil is poorer in humus and nitrogen compared to the `90s [9].

4 Conclusions

According to survey results, due to the profitability of sunflower crop, many farmers abandoned the recommended long crop-rotation practices and follow current simplification and shortening trends of crop rotations. Considering the current state of play in Moldova, urgent measures are needed in order to restrict the use of pesticides/ fertilizers that ensure soil remediation and return to correct crop rotations. In this regard, continuous monitoring of the situation is needed. The basis of research programs has to be extended and information related to the benefits and feasibility of long term rotations has to be provided to farmers.

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SESSION 6. DIVERSIFICATION BENEFITS: THEIR ECONOMIC VALUE AND CARRY-OVER EFFECTS

Chairs: Stefano Canali (CREA, Italy),
Didier Stilmant (CRA-W, Belgium)

ORAL PRESENTATIONS

- Estimation of crop rotation effects based on farm accountancy data
  Speaker: Romaric Sodjahin, INRA, France
- On the economics of crop rotation diversification: pre crop, crop rotation and price effects
  Speaker: Alain Carpentier, INRA, France
- How to reconcile short-term and long-term objectives in agroforestry systems? An application of viability theory to mixed horticultural systems
  Speaker: Raphaël Paut, INRA, France
- Economic benefits of agro-ecological ecosystem services: consumers value diverse cropping systems
  Speaker: Heikki Lehtonen, Luke, Finland
- Finding and fastening the missing link: a novel method to estimate pre-crop values for previous and subsequent crop combinations
  Speaker: Pirjo Peltonen-Sainio, Luke, Finland
- Pre-cropping effects from grain legumes on wheat and oilseed rape: nitrogen fluxes and productivity
  Speaker: Anne Schneider, Terres Inovia, France
- Economic valuation of ecosystem services provided by crop diversification
  Speaker: Francisco Alcón, Universidad Politécnica de Cartagena, Spain

Estimation of crop rotation effects based on farm accountancy data

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1 Introduction

Crop rotation effects on yield levels and input uses are rarely investigated, probably because farmers' yields and production choices are rarely recorded simultaneously. Our objective is to estimate crop rotation effects on yields and input uses based on existing datasets, namely large panel datasets of farm accountancy data with cost accounting. Such datasets describe crop yields, acreages and input uses for a large sample of farms over a few years, but they lack information on farmers' crop sequence acreages. We propose two approaches to overcome this missing data issue. The first approach exploits the data collected by the European Commission, the yearly Integrated Administration and Control System (IACS) datasets. The second one relies on an original estimation procedure which allows recovering the observed crop sequence acreages while simultaneously estimating the underlying crop rotation effects. We also made use of expert knowledge information obtained from agricultural scientists and extension agents.

2 Materials and Methods

The two approaches we propose for estimating crop rotation effects are illustrated on an unbalanced panel accountancy dataset of 378 French farms located in the North and North-East of France and specialized in grain and industrial crop production from 2008 to 2014.

We are interested in the effects of the preceding crops on the yield and input use levels of the current crops. Both approaches rely on statistical models of yield and input uses. Namely, observed yield and input uses of a given crop are expressed as a weighted average of the unobserved crop yields and input uses at the crop sequence level, the weights being the shares of each preceding crops in the current crop acreage. Although our accountancy dataset contains information on acreages, yields and input uses for each farm of the sample, we have no information on their crop sequence acreages, which thus need to be recovered in order to estimate crop rotation effects.

In our first approach, we use the "RPG Explorer" software developed by Levavasseur et al. (2015) to recover approximate crop sequence acreages for farms located in the same geographical area as the farms in our sample. These crop sequence acreages are then matched to our sampled farms and directly used in the statistical models of yield and input uses for estimating the effects of previous crops. Importantly, the recovered crop sequence acreages show that farmers primarily select the "best" crop sequences (according to the views of the experts we have consulted), thereby demonstrating their accounting for crop rotation effects as well as their economic rationality. However this also implies that the effects of many crop sequences cannot be measured because farmers avoid using the "worst" sequences.

The second approach we propose assumes that farmers are economically rational when choosing their crop sequence acreages. This assumption enables us to "reconstruct" famers' crop sequence choices as functions of the crop rotation effects of interest along the estimation process of these effects. We define the crop rotation effect estimation problem as a mathematical programming with equilibrium constraints (MPEC) problem along the lines of Su and Judd (2012). This approach can be transposed to any farm accountancy dataset with cost accounting, regardless of the availability of potentially matching dataset on crop sequence acreages. It can also make use of expert knowledge such as ex ante rankings of the effects to be estimated or identified "forbidden crop sequences".

3 Results

Our results show that the crop sequence acreage shares that can be estimated based on the "reconstruction process" proposed in our second approach are close to those that are obtained from the IACS data in our first approach. Accordingly, the crop rotation effects on yield and input uses estimated with the two approaches are comparable.

The estimated crop rotation effects on yields generally conform to the view of the consulted experts. We notably find that, in terms of yield, straw cereals are among the worst preceding crops for straw cereals, cereals are good preceding crop for sugar beet, and in addition, alfalfa and peas are good preceding crops for wheat. The estimated crop rotation effects on input uses appear to be less convincing since they are often small and frequently at odds with experts' views. These contrasting results might be attributed to the fact that farmers "automatically" benefit from the effects of crop rotation on yields but may be reluctant to adjust their input uses to the effects of crop rotations on pest and weed populations, or on soil nutrient content. Yet, the acreages of some crop sequences are very small and some crops are produced by a limited number of sampled farms. This data configuration raises statistical identification issues for estimating the corresponding crop sequence effects that are still under investigation.

4 Discussion and Conclusions

The approaches that we propose for recovering crop rotation effects from cost accounting data seem to work well in practice and provide consistent results regarding the effects of crop rotation on yields. We are currently investigating the possibility to account for the confounding effects of soil and climate on yields and input uses. This will allows us to strengthen the interpretation of our empirical results, regarding crop rotation effects as well as their impacts on farmers' choices.

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On the economics of crop rotation diversification: pre crop, crop rotation and price effects

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1 Introduction

Adoption of diversified crop rotations by farmers primarily relies on economic criteria. The main objective of this article is to present a simple approach for analysing and comparing crop rotations from an economic viewpoint. This approach makes use of basic economic calculus, standard economic concepts (*e.g.*, margins and opportunity costs) as well as simple sensitivity analysis techniques. It mainly aims to address two questions. How to assess the economic value of diversified *versus* specialized cropping systems? How to uncover the main drivers of this economic value?

Extension agents or agricultural scientists may use this approach for demonstrating the interest of crop diversification to farmers. Agronomists may also find it useful for investigating the key drivers of the economic value of diversified cropping systems and, thereby, promoting or targeting their research efforts. Finally, economists and policy makers may obtain useful results for designing efficient public policy measures aimed to foster the adoption of diversified crop rotations.

The proposed approach builds on previous work on the valuation of pre crop effects and crop rotations (*e.g.*, Schilizzi and Pannell 2001; Hennessy 2006; Preissel *et al* 2015). It extends this work by emphasizing the effects of (input and output) prices and rotation lengths as well as by decomposing the economic benefit of diversifying crop rotations in three main components: the opportunity cost of diversification crops, the pre crop value of diversification crops and the long run value of crop rotation diversification.

2 Materials and Methods

The proposed approach can be applied with either experimental data or observed (*i.e.*, farm) data. It relies on crop input use and yield level data describing the technical performances of different crop rotations implemented in comparable settings. Price and cost data can be obtained from other sources.

The approach proceeds in three steps: (*a*) choosing relevant price ranges, (*b*) determining and decomposing the economic value of the diversification of crop rotations and (*c*) performing sensitivity analyses. The economic value of diversifying crop rotations significantly depends on chemical input and crop prices. Importantly, price series reveals trends, volatilities or regime changes that need to be considered when choosing suitable price ranges given the objectives of the analyst. We define the economic value of diversifying crop rotations as the difference in the crop rotation margins with and without the considered diversification crops. We then present a simple decomposition of this value. First, we decompose the value diversifying crop rotations into the sum of three components. (*i*) The opportunity cost of inserting the diversification crops in crop rotations basically compares the margins of the diversification crops and the other crops in the considered crop sequence. (*ii*) The value of the carry-over effects measures the economic value of the impacts of diversification crops on the production process of then next crops in the considered crop sequence. (*iii*) The long run value of crop rotation diversification measures the economic value of repeatedly implementing a diversified crop sequence on the state of the agro-ecosystem (*e.g.*, pest and weed pressures, soil properties).

Finally, we present simple sensitivity analysis exercises aimed to uncover the main drivers of the economic value of diversifying crop rotations. Performing these exercises enables the analyst to identify the crop or/and input prices that have the most significant impacts on the economic interest of "diversification crops" while it enables agronomists to uncover the technical components (*e.g.*, yield levels, pest pressure, nitrogen surplus) that should receive more attention or should be improved.

3 Results

As an illustrative example, we consider inserting protein pea in a rapeseed-wheat-wheat-barley rotation – in between the two wheats – using French data. We compute and analyse the economic value of protein pea as a diversification crop. Our primary data were produced from expert knowledge for the EcoPhyto R&D study aimed to assess the pesticide use reduction opportunities in the French agricultural production sector (Brunet *et al* 2009). These data were supplemented by results on pre crop effects and long run crop rotation effects found in the agronomic literature and by price data published by FranceAgrimer and the French ministry of agriculture.

Benchmark results were computed at the mean price levels over the 2013-2017 period for crops, fertilisers and fuel, at the 2017 price levels for the other inputs. Price means were considered for alleviating the effects of price variability. Recent prices were considered for accounting for price trends.

The economic value of protein pea as a diversification crop in the considered crop rotation is estimated at +12€/ha. The value of the carry-over effects of pea to the second wheat amounts to +33€/ha. It is mostly due to the yield effect evaluated at +24€/ha. The nitrogen surplus only amounts to 6€/ha. In the considered case, the 30€/ha saved when producing the second wheat is diluted along a five year crop sequence. The opportunity cost of inserting protein in the rotation amounts to –33€/ha. It offsets the benefits related to the carry-over effects. Inserting pea in the rotation appears costly as wheat is more profitable than pea (according to a static evaluation framework) and wheat production occurs less frequently in the rotation with pea. The long run effects of inserting pea in the rotation are estimated at +12€/ha and are due to herbicide savings. As discussed below, these long run effects are probably significantly underestimated. Sensitivity analyses show the value of inserting pea in the considered rotation significantly depends on nitrogen price but weakly depends on pesticide prices. This later effect is probably underestimated. Unsurprisingly, the value of pea in the rotation strongly depends on its price and yield. Increasing the yield of pea by 5% would turn the opportunity cost of inserting pea in the rotation into a benefit, from –27€/ha to +12€/ha. This would rise the value of pea from +12€/ha to +57€/ha.

4 Discussion and Conclusions

The approach that we propose for assessing the economic value of diversifying crop rotations is simple and intuitive. It can be very instructive for farmers, extension agents, economists and policy makers. Our application on protein as a typical diversification crop illustrates several points made in the literature. Opportunity costs of inserting diversification crops in standard crop sequences is often costly. This partly explains why farmers' crop rotations remain relatively short. Diversification crops are often less profitable, in a static sense, than major crops. The carry-over effects of typical diversification crops are well known and often well documented. Farmers' awareness of these effects is often questioned. Yet, two points related to these effects may explain farmers' reluctance to diversify their crop rotations. First, farmers automatically rip off the benefits of some of these effects (*e.g.*, direct yield effects) but they need to adjust their production choices for benefiting from others (*e.g.*, accept to reduce pesticide and fertilizer uses). Second, carry-over effects are short run effects the economic value of which is swamped along the length of the rotation. The long run effects of diversifying rotations are qualitatively well known but often poorly documented. As a result, their benefits are generally underestimated. This is unfortunate since their economic value may be large, through pesticide use saving in particular, as these effects yield benefits all along the crop rotation.

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How to reconcile short-term and long-term objectives in agroforestry systems? An application of viability theory to Mixed Horticultural Systems

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1 Introduction

The dual productive and environmental challenge that agriculture is facing has led to the emergence of new farming models based on agro-ecological paradigms (Altieri, 2004; Wezel et al., 2014). These systems are built on greater biological diversity that combines cultivated and natural elements within the agroecosystem. One of these systems, known as Mixed Horticultural Systems (MHS), corresponds to the intercropping of fruit trees and vegetables. This system is attracting a growing interest in Europe, especially among new farmers (Léger et al., 2018; Warlop, 2016). It represent a diversification strategy that goes further an increasing number of crops, since it add a functional diversity provided by trees. However, the management of MHS systems is particularly challenging for two main reasons. The first is linked to their complexity, since they add up the intrinsic difficulties of two very demanding systems -fruit trees and vegetables-. The second limitation is related to the fact that such systems involve, even more than for single-species systems, a need for prioritization and trade-offs between objectives and constraints. The simultaneous management of short-term market gardening and long-term orchard, with their own dynamics, can be very complex and jeopardize the long-term viability of the enterprise. The objective of the present study is therefore to provide a modelling framework for the analysis of agroforestry systems that combine annual and perennial crops.

2 Materials and Methods

In the present study, we rely on the framework of the Viability Theory (VT) to assess the management conditions that make it possible to conciliate long-term and short-term dynamics of vegetable and fruit trees. VT is a mathematical framework developed by Aubin (1991) that studies the evolution of dynamical systems under constraints. Its recent applications to natural resource management has proved to be particularly relevant in the fields of fisheries, silviculture or livestock (Sabatier et al., 2017). In the present study, we apply viability theory to explore different management strategies in MHS systems.

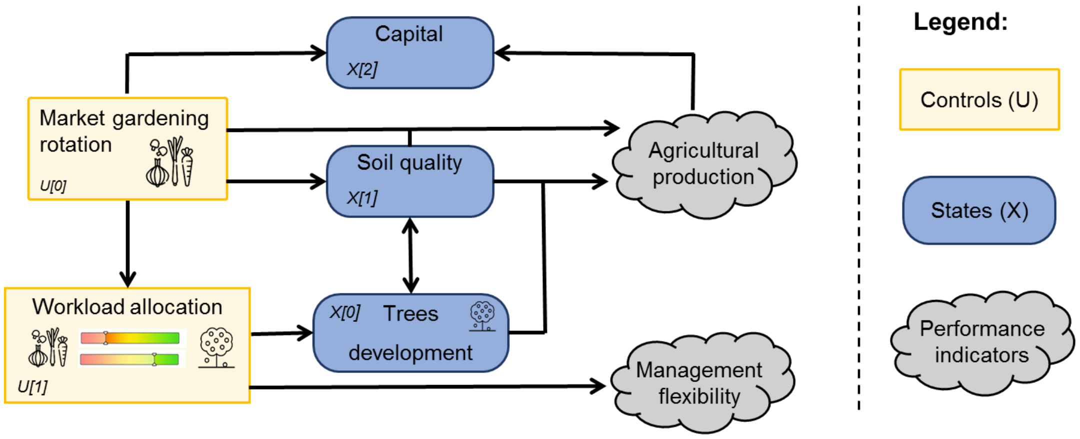

Figure 1. Conceptual model representation

This framework makes it possible to identify a set of viable management options that maintain the system within a set of constraints over time. It is based on states (X) and controls (U). States describe the agroecosystem and can vary over time (Figure 1). Controls represent the levers available for farmers to steer their cropping system, e.g. the choice of vegetables rotation or the workload allocation between fruit trees and market gardening. In our case study, we compare a short-term strategy aiming to promote vegetable production with a long-term strategy that gives priority to the establishment of fruit trees. To do so, we analyze the dynamics of MHS systems as a function of the workload allocation between the two component enterprises (fruit trees and vegetables).

3 Results

The Net Present Values (NPVs) showed that the short-term strategy (Figure 2a) obtained a greater annual economic profitability during the first years. Indeed in the early years, the costs of planting and operating fruit trees led to a decrease in NPV, but from the sixth year onwards, this loss was offset and the long term strategy (Figure 2b) became more effective. Besides, the cumulative NPVs over the whole period indicates that long-term strategy is globally more profitable, indicating that in the long run, a strategy favoring fruit trees establishment might be desirable.

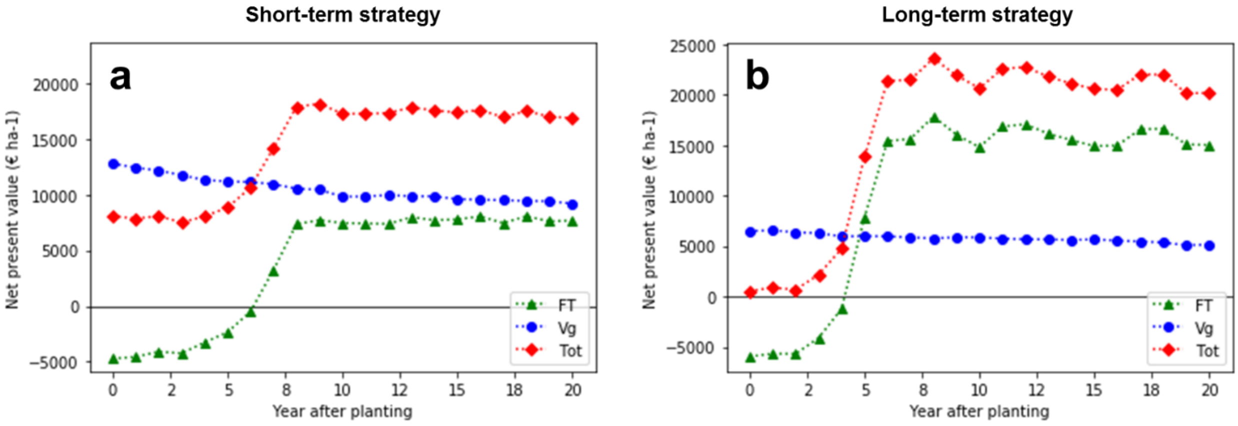

Figure 2. Evolution of fruit trees (FT), vegetables (Veg) and total (Tot) net present values of a simulated mixed horticultural system over time, as a function of two management strategies: (a) a short-term strategy favoring vegetables production over fruit trees growth; (b) a long-term strategy through the prioritization of fruit trees growth.

4 Discussion and Conclusions

Using this dynamic modelling approach based on viability algorithms, we simulated management decisions that respected the socio-ecological constraints of farmers. This makes it possible to identify optimal management strategies for both vegetables and fruit trees, and to assess their impact on the long-term dynamics of the system. Results showed that the strategy of promoting tree growth led to better long-term profitability. On the other hand, it requires for farmers being able to cope with several consecutive years of lower performance for trees establishment. The present work also points out the necessary trade-offs generated by the system's complexity (integrating the role of ecological and heuristic uncertainties). Besides, there is still little literature on system components dynamics (e.g. fruit trees-vegetables interactions) which were mainly hypothesized. This raises the need for further research on Mixed Horticultural Systems biological processes.

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Economic benefits of agro-ecological ecosystem services: consumers value diverse cropping systems

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1 Introduction

Diverfarming project seeks to solve current problems in conventional cropping systems through cropping diversification. Case studies analyse diversification of cropping systems in cereals and dairy feed production in the value chain of cheese production. The main environmental problems of agriculture in southern Finland, such nutrient leaching to watercourses and biodiversity loss, are related to cereals monocultures. Dairy and beef farms have been decreasing at a fast rate in southern and Finland while dairy and beef production are concentrating on other regions in Finland (OFS 2019). Cereal monocultures dominate in large parts of southern Finland despite many alternative crops available for diversification (Peltonen-Sainio et al., 2017). The aim of the non-market valuation of the diversification benefits concern the environmental benefits and perceived societal benefits of crop diversification as well as the perceived societal benefits of local cheese production.

2 Materials and Methods

The main idea of case studies is to analyse a change from cereal monocultures to diversified crop rotations in southern Finland. Cereal monocultural cropping (e.g. conventional cereal; barley-barley-rye-oats -rotation) is diversified with oilseed rape and catch crop, or with legumes and grass in the crop rotations. Monoculture of cultivation is thus broken and nutrient leaching, such as nitrogen and phosphorus leakages, are supposed to decrease. Soil structure and biodiversity are improved and soil organic matter will increase. The value chain of cheese includes also broader rural and cultural effects.

We used a stated preference method, contingent valuation, to measure benefits of shifting from monoculture to more diversified cropping system in cheese production and value chain. For the respondents two valuation scenarios were presented: first one focuses on Ecosystem services (ESs) realised on field and soil (decreasing greenhouse gas, more robust crop yield, field carbon accumulation, decreasing runoff leakages, and abundance of wildlife organisms). The second scenario introduced seven effects that are broader rural and cultural effects of cheese making (e.g. low-input production, more varied landscape, more jobs in rural areas and maintained tradition of cheese making). Third scenario combined both scenarios.

Two payment vehicles were used in the survey: extra cost of households' food expenditures (scenario 1-3) and a price increment on the current cheese price per kilogram in the last scenario (scenario 3). Multiple bounded dichotomous choice (MBDC) format was used that allows the respondent express their ambivalence (Welsh & Poe 1998). Respondent were given an identical set of 12 bids and for each bid they had five response categories to choose from 'Definitely pay', 'Possibly pay', 'Cannot say', 'Possibly not pay' and 'Definitely not pay'. Empirical survival function (decreasing yes-response probabilities with increasing bids) was calculated using non-parametric Turnbull estimates (Turnbull 1976, Haab & McConnell 2002) for the willingness to pay estimates. 600 responses were collected in January 2019, as a representative sample of the Finnish population.

3 Results

In our case we measured these non-market benefits in two ways: on one hand as additional cost for consumers' household expenditures, and on the other hand as an incremental cost in cheese price (euro per kg). Results indicate that 21% of consumers were not willing to pay anything to support more diverse cropping system. It seems that scenario1, with the ESs coming from diversified cropping system (effects from field and soil), was most highly valuated (increase in WTP 2.15 per month per household when respondent stated 'Definitely Yes'). At the broader value chain level the WTP was lower, 0.15 euro per month (scenario 2). Finally, in the case of the third scenario (including both previous scenarios 1-2) there was only a slight increase in WTP when adding scenario 2 on scenario 1, compared to scenario 2 (mean WTP 0.18€ household expenditures per month). When valuated through the price of cheese, mean for maximum WTP was 1.28€/kg, for those who stated 'Definitely yes'.

As Ready et al. (1995) showed ambivalence region is wide and in our study it is the wider the higher bids are offered (Figure 1). In our study the widest ambivalence region was obtained when offered price increase was 2.00 € per kg.

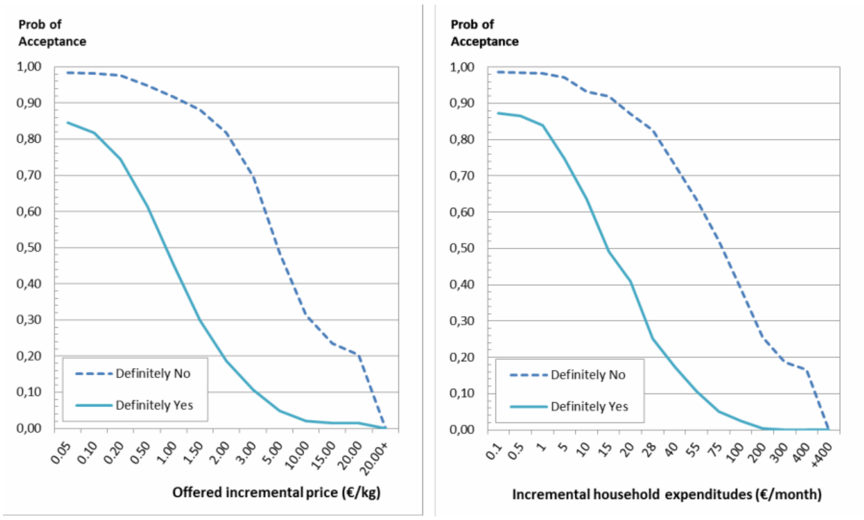

Figure 1. Distributions of Willingness to Pay.

4 Discussion and Conclusions

Estimating range of values, rather than one value, provides more abundant information for decision making.

Since the estimated survival functions (maximum WTP triggering no paying) decrease relatively slowly at bids 0-20 cent per kilogram or 0.1-1 euro per month), our results suggest that many of respondents appreciate ecosystem services and are willing to pay a little extra to get these ecosystem services (Figure 1). Especially higher WTP was stated for ESs from fields and soil. Identification and valuation of ecosystem services bundles may be useful to help decision makers account for multi-functionality of agro-food system and to better improve management on ecosystems services on a farm-level and develop appropriate policy measures.

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Finding and Fastening the Missing Link: A Novel Method to Estimate Pre-Crop Values for Previous and Subsequent Crop Combinations

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1 Introduction

Cereal-intensive crop rotations, such as cereal species monocultures and cereal monocultures as well as cereal rotations with one break crop within five years, dominate agricultural systems in Finland, while the share of fields with diverse crop rotations is <2% (Peltonen-Sainio et al. 2017). Monoculture rotation systems not only reduce biodiversity *per se*, but also lack resilience to the typical weather variability at high latitudes. Additionally, monocultural farming increases sustainability gap through e.g. abetting soil compaction and increasing dependency on crop protection. Thereby, it likely associates with declined soil carbon content and yield trends.

Farmers have intentions to diversify their crop rotations due to the manifold drawbacks that they have experienced with cereal monocultural rotations (Peltonen-Sainio et al. 2017). The area under some minor crops like faba bean (*Vicia faba* L.), oilseed rape (*Brassica napus* L.), pea (*Pisum sativum* L.) and caraway (*Carum carvi* L.) has expanded. Moreover, cultivation of later maturing primary crops and cultivars have shifted northwards, while novel crops like maize (*Zea mais* L.), winter oilseed rape and lupin (*Lupinus angustifolius* L.) have been taken into tentative testing by farmers. In addition to green-manuring crops and green-fallows, farmers have recently tested nursing crops, like alfalfa (*Medicago sativa* L.) and oilseed radish (*Raphanus sativus var. oleiformis* L.) to help soil to recover from damages. Though the changes in land use so far are marginal when compared to the arable land dominated by cereal monocultures, the currently existing potential for diversification is significant (Peltonen-Sainio and Jauhiainen 2019).

Pre-crop value is the measure that indicates the benefits of a previous crop for the subsequent one in crop sequencing. In order to further encourage farmers to take advantage of the existing diversification potential (Peltonen-Sainio and Jauhainen 2019), they need precise information about the pre-crop values for a high number of previous and subsequent crop combinations. Traditional field experiments are a valuable source of information, but they are very resource-intensive and hence, evaluate pre-crop values only for a limited number of previous and subsequent crop combinations. Therefore, we developed a method based on Normalized Difference Vegetation Index (NDVI) values derived from *Sentinel-2* to estimate pre-crop values (Peltonen-Sainio et al. 2019).

2 Materials and Methods

The NDVI values were derived from all available *Sentinel-2* imagery with less than 99% cloud cover from April to October in 2016 and 2017. The study area in South-Western Finland is covered by four tiles (34VEN, 34VEM, 34VFN, 34VFM) of the *Sentinel-2* tile system. Each tile has a size of 110×110 km with 10 km overlap. The 587 scenes were processed by using the method developed by FGI on the EODC platform (Earth Observation Data Center GmbH, Vienna, Austria). Data regarding crop species was linked with NDVI-values at field parcel scale. Our data comprised a total of 120,174 field parcels in 2016 and 118,116 in 2017. The study area was divided into four sub-areas. Mean NDVI-values for each crop at its most critical growth phase were compared to the sub-area specific 90th percentile of each crop within a year and thereby, an NDVI-gap was determined for each previous and subsequent crop combination available. The results were included only for ≥20 field parcels per crop combination. Pre-crop values were estimated for a high number of previous and subsequent crop combinations on farmers' fields by comparing the NDVI-gaps between crops that previously had the same crop growing on the field parcel (monotonous crop sequencing) and those that had a different one (Peltonen-Sainio et al. 2019).

3 Results

The pre-crops values provided by the novel method were available for a high number of previous and subsequent crop combinations. The availability of pre-crops varied depending on the following crop. In general, pre-crop values based on the estimation of NDVI-gaps indicated that often any other crop than the subsequent crop itself had positive pre-crop value. Rapeseed, grain legumes, sugar beet (*Beta vulgaris var. altissima* L.), potatoes (*Solanum tuberosum* L.) and special crops like caraway, linseed (*Linum usitatissiumum* L.) and oilseed radish were usually very beneficial pre-crops for spring cereals. Cereals had positive pre-crop effects on pea and rapeseed and also quite frequently for faba bean. Moreover, rapeseed and sugar beet had positive impacts on the growth of subsequent grain legumes. The developed method proved to work well in estimating pre-crop values at field parcel scale.

4 Discussion and Conclusions

The developed method based on data from *Sentinel-2* estimates pre-crop value for a high number of previous and subsequent crop combinations (Peltonen-Sainio et al. 2019). Pre-crop values ranged from +16% to -16% at most. They followed the general understanding and published results on the benefits of different crops as pre-crops, such as the positive effects of grain legumes and rapeseed as pre-crops for a number of following crops. Employing this novel method allows dynamic pre-crop values to be updated every year with new data. The developed method can be rapidly applied to different regions within a country as well as across countries and continents in order to estimate pre-crop values for relevant, region-dependent crop choices, provided that the data regarding crops is available at field parcel scale for each year. When more data for a wider range of years and beyond our test region will become available, a further understanding on the dependency of pre-crop values on growing conditions can be gained, which will further support the implementation of diversification actions by farmers. Hence, for the first time, a high number of previous and subsequent crop combinations originating from farmer's fields are available.

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DiverIMPACTS
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Pre-cropping effects from grain legumes on wheat and oilseed rape: nitrogen fluxes and productivity

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1 Introduction

In the current French arable cropping systems mainly based on cereals and oilseed rape (OSR), grain legume crops provide both a botanic diversification and nitrogen supply, thanks to their ability to fix atmospheric N_2. However, ecosystem services provided by legumes are not well characterised according to the given context, preventing them to be fully valued by a large number of farmers. For instance, the effects of legume crops on the performances of following crops rely usually i) on average estimates, ii) only for some couples of species, and iii) on fragmented data (Jeuffroy *et al.* 2015; Schneider *et al.*, 2017). And the major factors explaining the variability of these effects are not known. This prevents to forecast the crop system and adapted technical management which would have led to optimal services in a given context, such as enhanced production with lower charges.

In order to complement on-going analysis of a series of detailed traits in one location (Guinet 2016), Terres Inovia carries out trials on two locations to address the comparative characterisation of some services provided by grain legume crop to the following wheat or rape (or intercropped wheat).

2 Materials and Methods

Several trials were carried by partners of the UMT Alter'N[1]. The trials managed by the Technical Institute Terres Inovia aim at quantifying some services delivered by pea, faba bean, lentil crops compared with non-legume crop (wheat, rape) in two locations (« Berry » and « Grignon ») in different couple of years.

Several variables were analyzed: yield (quantity and quality), N fixed (%Ndfa, following 15N enrichment in the case of analytical trials), residual mineral soil nitrogen (at 3 dates), crop and grain nitrogen content, soil biological activity indicator (soil nematofauna), and, in one location, N2O emissions. Preceding crops on year n include non-legume crops (wheat and oil seed rape (OSR) in both locations), and legume species (winter pea and pea-wheat intercrop in both locations, winter faba bean and spring lentil only in Berry, spring faba bean and spring pea only in Grignon). Following crops on year n+1 include wheat and oilseed rape without N fertilisation (0N) or with a suboptimal N fertilisation (N1). The objectives of the first analysis are (i) characterize the service of the nitrogen fixation especially through the quantity of nitrogen issued from N fixation; (ii) compare the potential of modifying the yield of the following (or intercropped) crop.

3 Results

Three series of « preceding crops » (Berry16, Berry17 and Grignon17) and a single series of « following crop » (Berry17) of the analytical experiment have been used to analyse variables linked to ecosystem services of harvested grain legumes. Three types of services are here assessed:

3.1 Symbiotic nitrogen entry

Symbiotic fixation rates (%Ndfa) were high in Berry: about 75-80% for pea and lentil (versus 60-70%) and 90% for the faba bean (versus 70-80%). In Grignon, on the contrary, %Ndfa rates were particularly low for monospecific peas, about 40%, but remained higher for the intercropped pea (75%). There is a strong inter- and intraspecific variability is mainly explained by the quantity of fixed nitrogen (QNdfa) and the dry biomass(grains + stems) at harvest. Three groups can be distinguished and associated with three different

[1] *UMT ("Unité Mixte Technologique") is a partnership between a technical institute and research teams; Alter'N is the acronym for "To strengthen the strategic on-farm advice for cropping systems based on legume crops or organic fertilisers with low nitrogen losses and low dependency on synthetic fertilisers".* http://www.terresinovia.fr/umt-altern

situations Berry16, Berry17 and Grignon17. When pooling the data with the data from UMR Agroecology - Dijon (Guinet 2019), there is a correlation (Figure 1) between the harvest biomass and the quantity of nitrogen issued from symbiotic fixation. No particular relation between the %Ndfa and the residual soil mineral nitrogen content before or after winter was observed in trials (Terres Inovia) and in farmers' fields (Pelzer, personal communication).

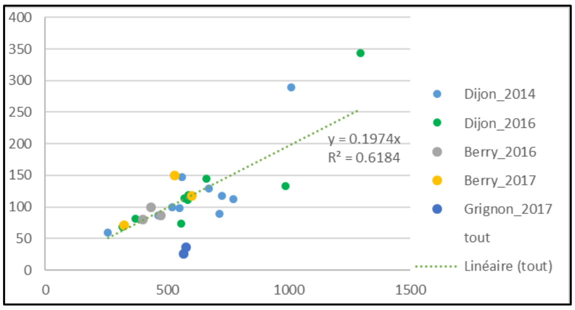

Figure 1. Relationship between the areal biomass at maturity (g/m2) on the x-axis and the quantity of nitrogen from symbiotic fixation (QNdfa) at maturity (kgN/ha) on the y-axis, on a series of situations.

3.2 Nitrogen absorption by the following crop

The service directly derived from the preceding effect of pea enables the following wheat to absorb from 59%N more than the wheat which follows a cereal and it leads to a rape which has absorbed 38% N more than rape crop which follows wheat. The trends confirm previous results of another trial (2009-10) in one location.

3.3 Yield level of the following crop

For the couples harvested in 2016 and 2017, the preceding crop in 2016 campaign has undergone by a normal growth during most of the crop cycle but by strong damages before harvest. The legume crop leads to higher non-fertilized wheat yields the following year compared to a wheat as preceding crop (*figure 2*) and the pea effect is significantly higher than the effect of lentil or pea-wheat association. The latter leads to higher yields of non-fertilized rape compared with faba bean, lentil or wheat, whereas the differences between the other preceding crops effects are not significant. There is a linear relation between the 0N wheat yield and the amount of nitrogen (QN) in crop residues of the preceding crops, but not for the 0N rape yields.

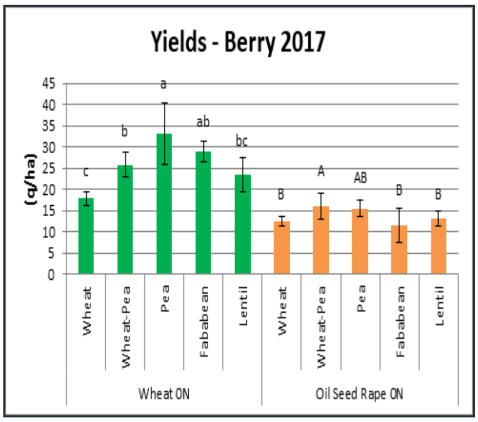

Figure 2. Average yields of non-fertilised wheat and non-fertilised OSR according to their previous crop on the Berry trial for the harvest 2017.

4 Discussion and Conclusions

These first series of results will be complemented with additional couples "year x location" and other related (dis-)services, including N leaching risks, GHG emission reduction, and also soil functioning through a soil bioindicator (Chauvin 2018). Pooling them with the results from the INRA partners' trials will enable us to consolidate the outputs and propose references for characterizing some key services related to the presence of grain legumes in cropping systems.

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Economic valuation of ecosystem services provided by crop diversification

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1 Introduction

Crop diversification is proposed as a sustainable way to address the social and environmental challenges agriculture is currently facing (Kleijn et al., 2009). It contributes to increase biodiversity (Olimpi & Philpott, 2018), improve soil structure (Hunt et al., 2019) and restore landscape (Redlich et al., 2018), which is translated into an improvement in agroecosystem resilience (Lin, 2011). Thus, crop diversification contributes to improve ecosystem services (ES) provided by agriculture, restoring agroecosystems functioning (MEA, 2005) and linking environmental conservation and human wellbeing to ensure agricultural sustainability.

Despite their contribution to human wellbeing, most ES provided by crop diversification are not market exchanged and their economic value are undetermined. The economic valuation of ES attempts to translate into monetary terms their social and environmental importance, focusing on their impact on human wellbeing. This value also reports a measure to unify the impacts of crop diversification in terms easily comprehended by stakeholders. Social demand for ES is usually estimated through non-market valuation techniques.

In this context, the aim of this work is to value the improvement of ES provision due to crop diversification practices. To this end, a case study, located in Murcia Region (South-East of Spain), has been used. This region is characterised by fruits and vegetable agriculture focused on monoculture with some environmental impacts associated such as biodiversity loss and soil and landscape degradations. Here, crop diversification could be employed to improve agroecosystem functioning.

2 Materials and Methods

A stated preference method, choice experiment (CE), has been applied for economic valuation. CE allows to analyse social preferences for different ES provided by agroecosystems. Biodiversity and four ES were considered for valuation: soil erosion and CO_2 balance as regulating services, and tradition and landscape appreciation as cultural services. Biodiversity was measured as the variety of both animal and plant species within the agroecosystem. Every attribute was composed by expected levels of diversified cropping systems in the study area and one level corresponding to a mono-cropping system (status quo- SQ). Additionally, a monetary attribute was used to know payment preferences for diversified cropping products. Specifically, the economic attribute referred to an increase in monthly expenditure per family due to the consumption of food derived from diversified crops.

The experimental design comprised the construction of the choice sets, which combined two diversification alternatives with the SQ alternative consisted in a monocrop. The final design consisted in 24 choice sets blocked in 4 groups, which were randomly distributed across the respondents. The households within the Murcia Region were selected as the target population, and 396 surveys were carried out. These data were collected between December 2018 and January 2019 through face-to-face interviews, using a stratified random sampling.

3 Results

Social demand for ES provided by crop diversification was modelled by a conditional logit model. The results show that all coefficients are significant, reflecting that respondents value all the ES provided by crop diversification at this design. The coefficient for status quo is negative, which means that society is not satisfied with mono-cropping environmental impacts. Monetary attribute is found to be negative as well, as an increase of familiar expenditure implies a reduction of respondent's utility. As expected, the coefficients associated to ES are positive, reflecting the higher utility respondents gain with the improvement of ES provision due to crop diversification. Thus, the highest utility levels would derive from a diversified cropping system that provide the best ES levels. The marginal rate of substitution among the coefficients of ES and the monetary attribute allows to capture the willingness to pay values (WTP) for improving ES provision. Specifically, the WTP for the change from high to low soil erosion was the most valued ES improvement (WTP of 17.76 €/month), followed by biodiversity increase and CO_2 balance (WTP of 16.52 and 16.30 €/month, respectively). Therefore, consumer surplus, which represents the highest level of ES and Biodiversity provided situation, reaches an increase of 60.82 €/month per family in food expenditure.

4 Discussion and Conclusions

To sum up, it was considered that society within the Murcia Region value the need of changing from the current situation and the positive contribution of crop diversification on ES provision. Thus, the present research contributes to broaden the knowledge of social perception about crop diversification. These results could be useful to be incorporated in a cost-benefit analysis in order to assess agricultural policies.

Acknowledgement

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SESSION 7. SOIL MICROBIAL FUNCTIONAL DIVERSITY ENHANCED BY CROPPING SYSTEM DIVERSIFICATION

Chairs: Sören Thiele-Bruhn (Trier University, Germany),
Raúl Zornoza (Universidad Politécnica de Cartagena, Spain)

ORAL PRESENTATIONS

- Effects of diversification on agricultural soil fungal biodiversity and community structures under Mediterranean conditions
  Speaker: Luigi Orrù, CREA, Italy
- Crop diversification - Implications on microbiologically mediated soil ecosystem services
  Speaker: Christoph Tebbe, Thünen Institute of Biodiversity, Germany
- Ecological service provided by cover crops on agroecosystem mycorrhization: the MA% indicator
  Speaker: Alessandra Trinchera, CREA, Italy
- Aromatic plants as intercrops in viticulture - Consequences for soil biology
  Speaker: Felix Dittrich, Trier University, Germany

POSTERS

- Biodynamic management with long rotations and multiple cropping contributes to high soil organic matter content, soil fertility and biodiversity compared to conventional systems
  Presenter: Raúl Zornoza, Universidad Politécnica de Cartagena, Spain
- Effects of pea intercropping on soils and physiological status of different wheat cultivars
  Presenter: Tünde Takács, Hungarian Academy of Sciences, Hungary
- Choosing a service plant or cover crop for enhancing soil microbial activity
  Presenter: Xavier Bousselin, Agroscope, Switzerland
- The potential role of 'elite rhizobia' to improve legume-inclusion in agri-food systems: a model approach using peas (*Pisum sativum* L.) and faba bean (*Vicia faba* L.).
  Presenter: Pete Iannetta, The James Hutton Institute, United Kingdom

Effects of diversification on agricultural soil fungal biodiversity and community structures under Mediterranean conditions

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1 Introduction

Metagenomic studies on soil fungi have enabled researchers to evaluate the real extent of diversity and the taxonomic structure of soil communities. However, soil is not a single environment but, according to the scale considered, it encompasses a range of different environments that can determine distinct fungal communities. This makes the interpretation of metagenomic data rather complex, especially when trying to identify the drivers of variability. Massive sequencing of fungal communities showed that climatic factors, followed by edaphic and spatial variables, constitute the best predictors of fungal richness and community composition at the global scale Tedersoo et al. (2014). In some case studies soil fungal biodiversity appeared to be affected by specific variables as the intensity of agricultural practices, or soil moisture. A few studies showed that the occurrence of keystone fungal taxa was best explained by a pool of variables (soil phosphorus levels, bulk density and mycorrhizal colonization) (Banerjee et al., 2018).

In this study the effects on fungal biodiversity of a diversified cropping system in a Mediterranean area were analysed. The aim was to explore fungal diversity and distribution in a farm where conventional monoculture was compared with a rotation system, in a long-term experiment. In addition to this, a tillage/no tillage contrast was also considered. The sampling scheme used, and the setting of some main environmental variables have been formulated in order to obtain a dataset capable of highlighting the effects of the different soil management onto fungal communities.

The research was performed in the framework of the Diverfarming project (EC H2020) whose aims are to assess the benefits and the drawbacks of diversified cropping systems under low-input agronomic practices.

2 Materials and Methods

The study site is a long-term field experiment that has been split in tillage and no-tillage management since 1995. To a continuous durum wheat cropping system (*Triticum turgidum* subsp. *durum* Desf.) a 2yr rotation with tick bean (*Vicia faba* L. var. minor) was introduced in 2009. The field site is in Apulia (Foggia, Southern Italy) where mean annual temperature and rainfall of 15.8 ºC and 529 mm respectively, are recorded. The contrasting plots (5 field replicates) where the following: conventional tillage with durum wheat monoculture, no tillage with durum wheat monoculture, no tillage with durum wheat/tick bean rotation, conventional tillage with durum wheat/tick bean rotation.

Total DNA was extracted from soil samples using a kit that allowed the extraction from 10g of sub-sample. The study targeted the Internal Transcribed Spacer regions. The UNITE/QIIME ITS reference OTUs were used for assigning taxonomy to ITS reads. QIIME software was used to measure alpha diversity across the sampled soils. The distances among fungal communities were visualized using a NonMetric Multidimensional Scaling (NMDS) ordination derived from a Bray-Curtis dissimilarity matrix. The correlation between the soil texture properties and the NMDS ordination was tested using the *envfit* function in the R package Vegan. The variables showing a significant correlation were plotted over the NMDS plot using the *ordisurf* function in the R package Vegan.

3 Results

The long-term field was dominated by Mortierellomycota (mean 68% of sequences), followed by Ascomycota (12.9%), Olpidiomycota (7.6%) Basidiomycota (4.3%) and Glomeromycota (1%). The ordination of samples based on fungal community composition using a Nonmetric Multidimensional scaling

(NMDS) technique showed that the contribution of the clay and silt environmental variables had a clear impact on the separation of tillage and no tillage groups (Figure 1).

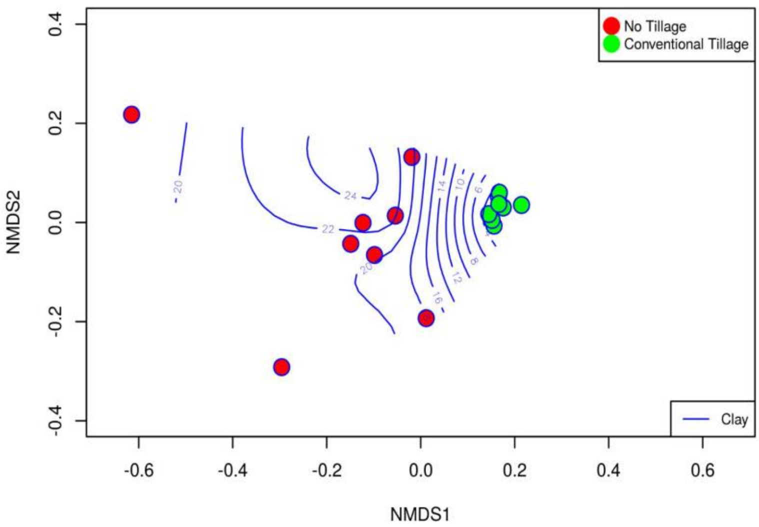

Figure 1. In the graph, samples were ordered based on community composition using a Nonmetric Multidimensional scaling (NMDS). To analyse the contribution of the clay environmental variable to the difference between the two groups, *ordisurf* function in Vegan was used to show the distribution of the clay variable displayed as isolines over the samples.

4 Discussion and Conclusions

The overall composition of the fungal communities at phylum level was similar to that reported from other studies, however our long-term field was dominated by Mortierellomycota. In particular, Mortierellomycota species were significantly more abundant in the plots where conventional tillage was used. Members of the genus *Mortierella* have been found to be abundantly represented in other Next Generation Sequencing (NGS) investigations of soil fungi, for example featuring amongst the top ten taxa in arable soils (Hartmann et al., 2014; Liu et al., 2015). Detheridge et al., 2016).

Statistically significant differences were found in the fungal communities associated to plots managed under conventional tillage and no tillage, independently of the use of rotated crops. A significant higher occurrence of Basidiomycota species was associated to the plot where both no-tillage and durum wheat and tick bean rotation was used. This plot was also characterised by the highest diversity (according to both Shannon and Simpson biodiversity indexes). The no-tillage plots showed 4 times more sequences in the Ascomycota phylum than the plots where conventional tillage was used, however this result was affected by a high spatial variability of Ascomycota's distribution across field replicates. A significant role of clay in defining the type of fungal community has been also highlighted although the difference in soil texture may have been, at least partially, determined in turn in the long-term by a strongly different type of ploughing.

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Crop diversification – Implications on microbiologically mediated soil ecosystem services

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1 Introduction

Cropping systems of the future should not ignore their impact on microbiologically mediated soil ecosystem services. Soil inhabiting microorganisms, which together form the soil microbiome, contribute to the decomposition of plant residues, the turnover of nitrogenous compounds, and the degradation of pesticides. Soil microorganisms can support plant growth by providing nitrogen or by mobilizing soil nutrients, but others may act as plant pathogens. Microbial activity has a direct impact on the production of greenhouse gases, the quality of ground water, and on crop yield. Despite this enormous importance for human and animal health as well as for the environment and agricultural productivity, farmers are typically not aware of microbiological activities of their soils. The soil microbiome is not specifically considered in agricultural management plans.

The difficulty of analyzing how cropping systems influence microbiologically mediated ecosystem services is mostly due to the complexity of the microbiomes and the ecological interactions through which microbial processes are controlled. The soil microbiome consists of *Bacteria*, *Archaea*, *Fungi*, and protists (unicellular eukaryotes), and each of these groups is present in most agricultural soils with high diversity. The groups interact within each other and also between each other, thereby forming networks which are affected by environmental changes and, thus, potentially susceptible to agricultural management.

Soils in agroecosystems can strongly differ in their physico-chemical composition along a range of spatial scales, from soil particle surfaces to landscape factors. Crops themselves affect the composition of the soil microbiome, e.g. by their root depositions in the rhizosphere. Because of their specific root architecture and composition of root exudates, each crop selects for a specifically structured microbiome. Consequently, diversified crop rotations should promote a higher microbial diversity in soil than monocultures. Ecological science postulates that higher biological diversity supports higher stability of an ecosystem and a higher efficiency in the utilization of substrates and the conversion of energy. For microbial communities in soil, the evidence supporting this ecological theory however is still scarce. As compared to mono-culture, diversified cropping systems including intercropping should promote higher microbial diversity and thus be beneficial for the agroecosystem. Beneficial traits could include a better control of soil microbial pathogens, a higher efficiency in mobilizing nutrients to plants, and releasing less greenhouse gases to the atmosphere.

Agroecosystems, being typically limited in nitrogen supply, receive large amounts of fertilizers, which serve as substrates for soil microbial communities. There are still new discoveries how soil microorganisms transform nitrogenous compounds and thereby affect the fate of nitrogen fertilizers. Nitrification, which requires oxygen, may enhance plant growth by conversion of ammonium to the more accessible nitrate, but it may also result in nitrogen losses especially early in the growing season when crop roots are not yet that abundant. Nitrification inhibitors may stabilize the nitrogen fertilizers in soil, but their efficiency could strongly depend on whether mineral or organic nitrogen is added. Nitrification can be done by *Bacteria*, but also by *Archaea*. At specific limiting oxygen levels, ammonium may be transformed in presence of nitrite to N_2 gas by the anammox process, which may cause a loss of nitrogen fertilizers. In the opposite direction, *Bacteria* and *Archaea* can fix (assimilate) atmospheric N_2 and thereby support plant growth, either as symbionts of legumes inside of the roots, or asymbiontically in the rhizosphere, or in presence of other carbon and energy rich soil compartments.

For each pathway, key enzymes and the corresponding genes which are involved in the microbial transformation of nitrogenous compounds have been identified. E.g., for bacterial and archaeal communities these include for nitrification the ammonium monoxygenase, for denitrification nitrite reductase, or for nitrogen fixation the nitrogenase. The respective genes are e.g. *amoA*, *nirS* or *nirK*, or the *nifH* genes, which can serve as indicators for process potentials when analyzing the soil metagenome. After extraction of total

DNA from soil, the genes can be quantified by real-time PCR (qPCR) or their diversity can be determined by PCR-amplicon DNA sequencing using high-throughput sequencing technologies. The latter approach allows the characterization of the organisms responsible for the selected functional potentials. This information can be useful to understand how cropping systems impact on the soil microbiome and how sustainable they are before adverse effects on ecosystem functions may emerge.

The EU project DiverIMPACTS offers to us a diversity of highly relevant field experiments to analyze the impact of cropping systems on the soil microbiome and their ecosystem services. As field site controlled variables we consider the implications of temporal and spatial diversification of cropping systems through rotation or multiple cropping.

2 Materials and Methods

In DiverIMPACTS, we selected experimental field sites which had already been established over years, located in Gembloux (Belgium), Lelystad (The Netherlands), and Hamerstorf (Germany). All sites consisted of replicated field plots in a randomized design in which different cropping systems and fertilization regimes were analyzed. Soil samples were taken at these sites after the growing season in September 2018 and before the season in March/April 2019, further samplings will take place at the end of the growing season in 2019 and before and after the season in 2020. All soil samples are characterized for their physicochemical properties and total DNA is extracted. This DNA, the soil metagenome, will be characterized after purification by molecular methods to assess the abundance of different microbial groups and functional potentials by means of quantitative qPCR. In order to identify the total diversity of the microbial communities and the diversity of microorganisms providing key functions in biogeochemical cycling of nitrogen, PCR products will also be sequenced utilizing Illumina MiSeq and the amplicons will be analyzed for the alpha- and beta-diversity of DNA sequence variants by appropriate bioinformatic and statistical tools. All quality filtered DNA sequences retrieved in this study will be deposited in publically accessible databases.

3 Results

The first samples of the DiverIMPACTS project were taken in September 2018. Physicochemical soil parameters were determined and total DNA extracted. First results indicated that some fertilization practices affected the soil pH values to a stronger degree than others. We suspect that this has consequences for changes in the soil microbiome, including some of the functional potentials. Total DNA was extracted from these soil samples to study the quantitative abundance of microbial genes as indicated above. An example is shown in Figure 1, where the abundance of *nifH* genes at the site in Hamerstorf, Germany, is shown. The abundance of this gene strongly declined with applying inorganic nitrogen fertilizer, while the addition of organic nitrogen sources maintained the quantitative levels seen in the soils not fertilized with nitrogen. This could mean that the additional carbon and energy supplied to the soil bacteria with the organic substrates is of high importance to maintain a nitrogen fixing capacity in the soils. Surprisingly, the results of this particular study also suggest that the diversified cropping caused the same response of *nifH* genes as the conventional system. At this stage it is not known whether the genes in both the control and the diversified systems come from the same bacteria or from totally different communities. These answers can be provided by sequencing of the *nifH* PCR amplified sequences, which we intend to do.

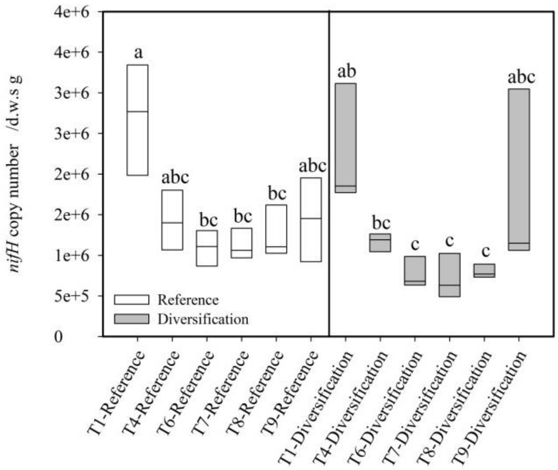

Figure 1. Effect of different fertilization treatments on the abundance of bacterial genes (*nifH*) encoding for the enzyme nitrogenase. This enzyme enables these organisms to fix molecular nitrogen (N_2) from the atmosphere – Comparison between a reference and diversified cropping system – Treatments: T1, no fertilization; T4: inorganic fertilizer, 150 kg N/ha; T6: 250 kg N/ha; T7: inorganic N, 140 kg/ha plus nitrification inhibitor; T8: inorganic N, 144 kg/ha; T9 organic N, 100kg/ha, plus inorganic, N 40 kg/ha.

4 Discussion and Conclusions

At this stage of our work for DiverIMPACTS, it is too early to present conclusions. The first results suggest that different qualities of fertilizers can have direct and indirect effects on the soil microbiome: (1) directly, as shown for nifH, by reducing the potential for nitrogen fixation with the addition of mineral nitrogen fertilizer, or (2) indirectly by ameliorating the effect in presence of organic fertilizers which supply addition carbon and energy to the microbiome. Another indirect effect is caused by a change of soil pH value.

In previous studies we could show that land use has a strong impact, independent of field site locations across Europe, on the structural diversity of soil microbial communities (Szoboszlay et al., 2017). We could also demonstrate that soil texture affects the microbial community composition (Hemkemeyer et al., 2018; Hemkemeyer at al., 2019) and that clay buffers the influence of environmental factors on the microbial community composition (Neumann et al., 2013). We therefore anticipate differences in the microbial community composition between the three sites, chosen for our DiverIMPACTS studies, but suspect that independent of their location, diversified cropping systems will support a higher microbial diversity than mono-culture and thereby contribute to the stabilization of ecosystem services.

Acknowledgements

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Ecological service provided by cover crops on agroecosystem mycorrhization: the MA% indicator

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1 Introduction

The introduction of winter-cereal cover crops (CC), such as wheat, spelt, barley, rye, etc. in organic vegetable rotation is a diversification strategy usually applied to avoid organic matter mineralization in bare soil and contain weeds before the vegetable transplanting (Ciaccia et al., 2015). However, many authors verified the ability of some CC, such as wheat or barley, to promote symbiosis with endomycorrhizal fungi, and particularly with arbuscular mycorrhizal fungi (AMF), a key agroecological service potentially provided by CC on belowground functional biodiversity (Costanzo and Barberi, 2014).

Up to now, many studies were performed in diversified agronomic systems, focused on the effect of AMF inoculation in promoting root mycorrhization of selected crop species. Few information is instead available on the effect of CC introduction on spontaneous plant mycorrhization in field by development of a common mycelial network among coexistent CC and weed species, being its formation observed only in forest ecosystems (Leake et al., 2004), and not in herbaceous ones. This research aims at quantifying the agroecological service provided by two different CC in terms of mycorrhizal colonization increase of coexisting plant species at field scale, by defining a new indicator, the Mycorrhizal colonization of the Agroecosystem (MA%).

2 Materials and Methods

In 2014 and 2015, at the MOVELTE (MOnsampolo VEgetables organic Long-Term field Experiment, CREA-OF in Monsampolo del Tronto, AP, Italy), in a four-years organic rotation and in a randomized block design (RBD) with three adjacent blocks (plot area: 3×6 m^2), the rye (*Secale cereale* L., RYE) and the spelt (*Triticum dicoccum* L., SPELT) were sown (250 kg ha^{-1}) as winter-cereal CC for managing weed. A not covered, unweeded plot was considered as reference control (CNT). In both the years and in all the treatments, at the rye full flowering and the spelt boot (end of April), the cover crop density (DCCi, pp×m^{-2}), the specific weed density (DWEEDi, pp×m^{-2}), the density of total weed species (DWEED-TOT, pp×m^{-2}), and the mycorrhizal colonization intensity (Mi%) of coexistent plant species (CC and five more abundant weed species: *Anagallis arvensis* L., *Polygonum aviculare* L., *Rumex crispus* L., *Stellaria media* L. and *Veronica persica* L.) were determined. After sampling roots from the field, the mycorrhizal colonization intensity (M%) of each plant species (CC and weeds) was determined by optical microscopy, while the external AMF hyphae were observed by Scanning Electron Microscopy (SEM). By joining DWEED-TOT, DWEEDi, and Mi% data of all considered species, we built a new indicator MA%, an aggregation function able to describe the contribution of each plant species to the mycorrhizal colonization of the agroecosystem (Trinchera et al., 2019).

3 Results

In 2014 and in 2015, among all considered weed species, the highest DWEEDi and Mi% were those of *Anagallis* both in CNT and in RYE and SPELT treatments. In 2014, under RYE, weed density was reduced, but considered weeds were less mycorrhized than in CNT. On the opposite, weeds were less contained by the SPELT, but their mycorrhization increased, if compared to that recorded in the CNT. In 2015, the higher CC-weed competition with respect to 2014 was testified by the significantly lower DWEEDi recorded for all weed species in RYE and SPELT systems respect to the CNT. On the contrary, the weed Mi% increased under cover crops, and particularly under SPELT. The MA% indicator, calculated in both the years, in 2014 showed a not significant effect of CC, while in 2015 the CC introduction increased significantly the MA%, being +270% under RYE and +120% under SPELT respect to the CNT (P=0.019, Figure 1-A). This relevant increase of MA% in cover cropped systems was due to the development of root mycelial network (→ external hyphae) among coexisting CC and weeds, observed in 2015 under RYE and, particularly, under SPELT (Figure 1-B).

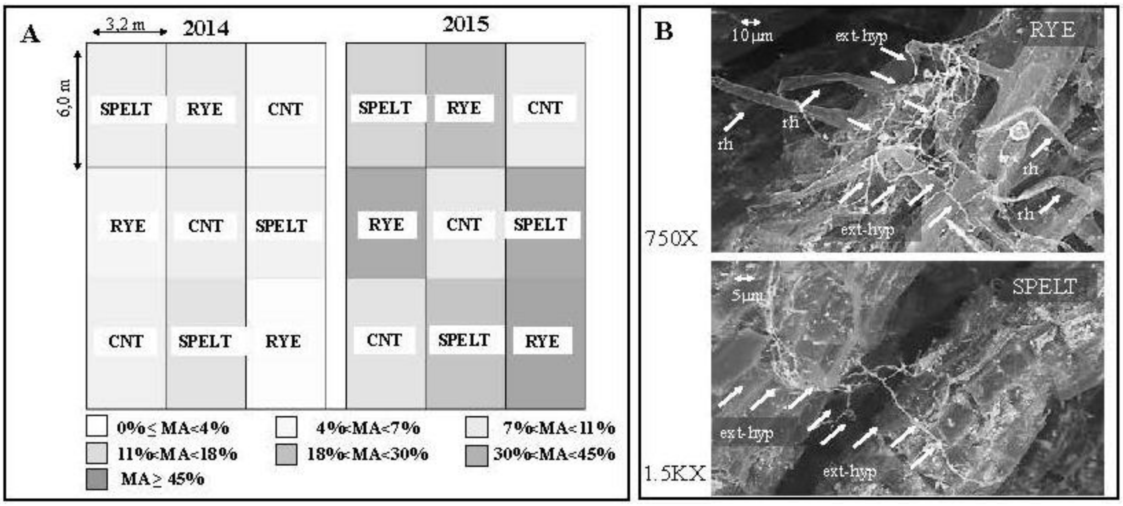

Figure 1. (A) Graphical representation of MA indicator in RYE and in SPELT cover cropped systems, compared to unweeded control (CNT). Increasing color scale is proportional to increasing % values. (B) SEM images of external mycelial network developed under RYE and SPELT in 2015 (rh = root hair; ext-hyp = external hyphae)

4 Discussion and Conclusions

In 2014, under high and not-well distributed rainfalls from November 2013 to April 2014 (786.4 mm, mainly in autumn), all cover cropped plots were highly infested and slightly mycorrhized, while in 2015 the regular rainfall (483.7 mm) and the registered highest average temperature in spring increased the CC-weed competition, the root mycorrhization playing a key-role in supporting water and nutrient uptake by coexisting plants.

The proposed MA% indicator is a performing descriptor of the agroecological service provided by the CC in boosting mycorrhization in a cover cropped system. While the ecological service played by rye consisted in increasing root mycorrhization in favour of its own ecological dominance, the spelt, effective in containing weeds, promoted the mycorrhization of some selected weeds by hyphal network formation, showing a potential, additional agroecological value for the maintenance of system biodiversity. Obtained results suggest to address future research to exploit the nutrient-mining properties of plant-soil organisms, by strengthening the mycorrhizal network development in organic agro- ecosystems.

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Aromatic plants as intercrops in viticulture – Consequences for soil biology

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1 Introduction

The area underneath vines is typically kept free of vegetation to avoid fungal diseases and competition on water, yet resulting in an increased risk of soil erosion and soil organic matter (SOM) depletion. Cover crops such as grasses and legumes have the potential to prevent soil from erosion or SOM depletion, however, they do not benefit to the value chain and may compete with vines or increase pest pressure. Alternatively, perennial aromatic herbs such as *Thymus vulgaris* and *Origanum vulgare* appear to be appropriate intercrops for vineyards, since they are economically valuable, adapted to the specific pedoclimate, have a low water demand and a low growing habitus, ideal to cover soil for erosion protection and weed suppression but with reduced competition with the vines. In addition, aromatic herbs are most likely host plants for arbuscular mycorrhiza and pollinators, and thus, potentially capable of increasing below- and aboveground biodiversity with subsequent provision of ecosystem services.

On the other hand, plant secondary metabolites (PSM) such as thymol and carvacrol (both found in *Thymus vulgaris* and *Origanum vulgare*) have been reported to show anti-microbial activity. Although these compounds are highly volatile, they are released to the soil ecosystem from plant litter and root exudates and may exert adverse effects on soil microbial biomass and activity. This could result in hampered soil functioning and fertility.

Our main objective is a comprehensive evaluation of possible effects of intercropping with aromatic herbs (as compared to control without vegetation) on soil biology and we hypothesize that:

i) microbial biomass and its activity is not hampered due to intercropping with aromatic plants

ii) arbuscular mycorrhiza fungal biomass is increased as intercrop root biomass increases

2 Materials and Methods

As part of the EU-funded research project Diverfarming, *Thymus vulgaris* and *Origanum vulgare* were planted underneath the vines of a steep slope vineyard in Wawern, Germany (Saar Valley) in May 2018. Vines without vegetation growing underneath served as a control. Regular soil sampling is carried out to monitor microbial soil properties such as microbial biomass (i.e. microbial biomass carbon after fumigation extraction) and its activity (i.e. exo- and endo-enzymes as well as basal respiration). Biomass of arbuscular mycorrhiza fungi is investigated using phospholipid analysis (PLFA).

In addition, a dose-response-experiment was conducted in the laboratory with spiking of thymol and carvacrol to the vineyard soil from the field experiment in order to evaluate the impact of PSM on microbial soil properties. In accordance with the field experiment, determination of selected indicators for microbial biomass (i.e. microbial biomass carbon after fumigation extraction) and its activity (i.e. dehydrogenase, phosphatase and basal respiration) was carried out after one day and one week of exposure. Data obtained from laboratory and field experiments will be comparatively assessed and presented.

3 Results

Due to severe drought after intercrop plantation in 2018, seedling establishment and growth was strongly limited. Results of microbial soil properties obtained from the field experiment were not altered after one season of growing aromatic plants. In the laboratory experiment, microbial soil parameters showed little or no effect after spiking with PSM regardless of exposure time.

4 Discussion and Conclusions

Limited growth of intercrops in the first year of the field experiment restricted possible impacts on plant-soil-microbe interactions. Therefore, we assume these impacts to become more pronounced as intercrop biomass increases over time. Missing significant effects on microbial soil properties in the laboratory experiment does not implicitly confirm our hypothesis that microbial biomass and its activity is not hampered due to intercropping with aromatic plants. The laboratory experiment rather suggests an in-depth assessment of aromatic plants' litter and the fate of PSM.

Biodynamic management with long rotations and multiple cropping contributes to high soil organic matter content, soil fertility and biodiversity compared to conventional systems.

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1 Introduction

Intensive conventional horticulture with high input management has a strong environmental impact, with negative effect on soil, air and water pollution, decreased biodiversity or greenhouse gas emissions. In this context, cropping systems with organic and biodynamic management are considered as a sustainable alternative to reduce the negative impact of the excessive use of mineral fertilizers and pesticides, with introduction of longer rotations and multiple cropping that can increase soil quality and biodiversity (Fliebach et al., 2007). Organic systems are related to higher carbon supply to soil, increasing soil structure, fertility and soil biodiversity, with decreased incidence of soil-borne diseases (Gattinger et al., 2013). These facts can contribute to climate change mitigation by soil carbon sequestration, reduced overall greenhouse gas emissions and promote soil diversity which is linked to solubilization of nutrients and plant resistance to diseases. Biodynamic agriculture is a system of organic agriculture based on a strong reduction of external inputs, use of compost and compost applications and other treatments based on plant extracts (Lotter, 2003). Hence, the aim of this study was to assess the influence of organic and biodynamic diversified cropping systems (long rotations and multiple cropping) compared to short rotations under conventional farming on soil physicochemical properties and on microbial biomass and diversity in cropping systems that have been adopted organic or biodynamic practices since nine years.

2 Materials and Methods

Three horticultural farms for each type of management system (conventional, organic and biodynamic) were selected in Cartagena countryside (SE Spain), with semiarid Mediterranean climate. They were selected close to each other to avoid climatic and soil variation and to allow the occurrence of the same crops. Organic and biodynamic farms converted in 2009 from previous conventional management. All farms apply multiple cropping (winter and summer crops) and rotations, but rotations in organic and biodynamic systems are longer, not repeating the same crop in three years. History of crops, fertilization, pesticides and soil management is recorded for the last 10 years. Crops cultivated were lettuce, cabbages, celery, broccoli, fennel, melon, watermelon, pumpkin, potatoes and maize. All farms are setup under drip fertigation. In the cycle 2017/2018, farms were grown with melon (*Cucumis melo*) in summer 2017 and leaf cabbage (*Brassica oleracea var. sabellica*) in winter 2018. Despite fertigation, organic farms also received sheep manure. Biodynamic farms received sheep compost and only compost tea as fertigation. Cover crops were used as green manure during no cultivation periods (*Avena sativa* and *Vicia sativa*). Harvest was carried out on 27/02/2018. Soil sampling was carried out on 22/02/2018, collecting three composite samples (coming from 5 different random points) per farm at 0-10 cm depth. Soil samples were sieved < 2 mm. For physicochemical properties soil was air-dried while for metagenomics soil was kept at -20ºC. DNA was extracted with DNeasy Power Soil Kit (Qiagen N.V.). To assess bacterial community structure, we amplified the variable region 16S and sequenced it by Ion Torrent Next Generation Sequencer (ThermoFisher Scientific). Data was analyzed with QIIME.

3 Results

Results showed that biodynamic system showed significantly highest values of soil organic carbon (7.1% compared to 5.5% in conventional and organic), total nitrogen (0.14% compared to 0.10 and 0.12 in conventional and organic) and available nutrients, such as potassium, copper or zinc. Physical properties such as bulk density (1.34 g cm^{-3}) were not affected by cropping system type. Biodynamic system also showed the highest content of total DNA (1503 ng g^{-1}) compared to organic (899 ng g^{-1}) and conventional (602 ng g^{-1}) systems, indicating higher microbial biomass. Microbial community in these systems showed differences at phylum and genus level. Biodynamic system showed lower number of genera than in the other systems (Fig. 1), and the chao1 diversity index (estimator based on abundance) showed higher values in biodynamic system (8000) than in the others (6500).

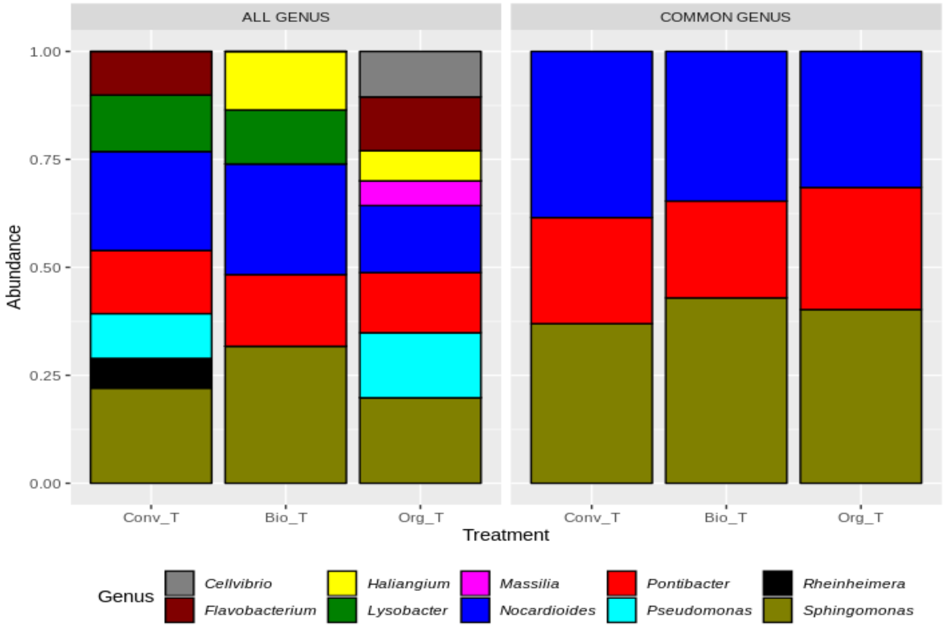

Figure 1. Relative abundance of all genera (A) and common genera (B) in all systems.

4 Discussion and Conclusions

Biodynamic systems resulted with soils with higher soil organic matter, soil fertility and microbial biomass when considering the first soil horizon of 0-10 cm. The higher organic matter inputs by addition of compost and compost tea has favoured the higher growth of microbial populations, which can increase the level of available nutrients in soil by processes of organic matter mineralization and solubilization of precipitated elements. Organic management showed, in terms of soil fertility, organic matter content and microbial diversity intermediated results between conventional and biodynamics systems, despite rotations and multiple cropping are very similar between both cropping systems. This may be due to the fact that biodynamic agriculture directly focuses on the increase of soil organic matter and microbial biodiversity, showing higher number and abundance of some microorganisms than the other systems. Cropping systems which contribute to enhance crop diversification and soil organic matter content are related to soil with higher fertility, microbial biomass and biodiversity, and reduced risks of pollution and increase the efficiency of soil as carbon sink.

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Effects of pea intercropping on soils and physiological status of different wheat cultivars

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1 Introduction

Soil microbial communities are key components of soil services in agroecosystems that impact quality and quantity of food production and the efficiency of cropping systems. Increasing of the biological diversity of soil microbiome is essential for improving the capacity of crops to adapt to fluctuating environmental conditions and to increase yields and yield stability in organic and low-input systems. The importance of mycorrhizal associations in host vitality and fitness has been proven in numerous reports. Efficiency of arbuscular mycorrhizal (AM) fungal community shows that compatibility of the mutualistic partners depends on their genotype, and due to the intra- and interspecific variability more possible partners are in race for the formation of the symbiosis, but the actual outcome of the colonization is also influenced by the environmental conditions.

2 Materials and Methods

In conventional and organic farming systems (Martonvásár, Hungary) the effect of winter wheat (*Triticum aestivum* L.) and pea (*Pisum sativum* L. 'Aviron') intercropping was investigated on the functional diversity of rhizosphere microorganisms and root colonization of soil indigenous AM fungi in relation to physiological parameters of wheat host. The plant vitality and fitness, the growth and *in situ* measured physiological (SPAD chlorophyll content in leaves and chlorophyll fluorescence) properties of three winter wheat genotypes (dwarf - intensive: Mv Nádor; robust - suitable for organic: Mv Kolompos; composite cross population: YQCCP) were examined in relation to wheat-pea intercropping (with or without pea). Furthermore, we investigated the influence of organic and conventional agronomic practices on the physico-chemical and microbiological properties of soils including the most important functional groups of the soil biota in agricultural ecosystems.

3 Results

The pH(KCl), AL-P2O5, total N values, AL-K2O and humus content of chernozem soils from organic farming were significantly higher compared to the conventional. However, the NO3--N were significantly lower in organic farming. Significant differences were not detected between the particle size distribution, AL-Ca and NH4-N. The wheat cultivars showed slightly effect on soil pH. At flowering phenophase of plants in the field, no differences were found in fluorescence induction parameters (Fv/Fm), shoot dry matter and AMF root colonization among samples originated from different managed soils and wheat-pea intercropping. AMF colonization in root of YQCCP wheat genotype was higher in organic farming soils, than in conventional soils. Intensity of AMF root colonization was poor in roots of wheat genotypes, while it was high in pea roots. The principal component analysis (PCA) of the microbial community-level physiological profiles (CLPP) generated by Biolog EcoPlate shown a slight separation of the organic and conventional samples. Soils with pea showed higher average catabolic response for organic acids while utilized polymers at a lower degree, than the samples without pea. SPAD showed a higher extent in conventional field, than in organic farming. Significant differences were found in P, K, Mg concentrations of cultivars. Pea caused a positive effect on SPAD, N-, P-, Cu-, Zn-, and K- content in wheat shoots.

4 Discussion and Conclusions

A multifactorial analysis was performed on the effects of different agricultural practices to check the physiological responses of wheat cultivars and the performance of indigenous soil microbial communities. Our data corroborated former results showing that organic management improved different parameters of soil quality, functionality of indigenous soil microbial populations. The pea intercropping improved the physiological and nutrient status of wheat and enzyme activities of soil microbial populations.

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Choosing a service plant or cover crop for enhancing soil microbial activity

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1 Introduction

Ecosystem services, such as nutrient cycling or biological control, may help to reduce the use of pesticides and chemical fertilizers (Zhang *et al.* 2007). A way to enhance ecosystem services is to increase agrobiodiversity (Altieri 1999). Thus, farmers can grow crops specifically to provide support or regulation services, such as cover crops (CC) sown between two cash crops (Schipanski *et al.*, 2014), or service plants (SP) grown within the cash crops (Verret *et al.*, 2017). According to the wanted services, several key traits were identified to select the species that can be used as CC or SP, such as morphological root and leaf traits or physiological such as nitrogen uptake (Tribouillois *et al.* 2016; Wendling *et al.* 2016; Dayoub *et al.* 2017). In additive intercrops, Lorin et al. (2016) suspected a positive effect of legumes used as SP on winter oilseed rape (WOSR) nitrogen status. In addition to the complementarity effect of nitrogen fixation, Drut (2018) also showed a positive impact of the legume, faba bean, intercropped with WOSR on rhizosphere microbial respiration. His results suggested that this microbial activity increase could explain facilitation processes for crop nitrogen nutrition. However, few studies investigated microbial respiration. They are limited to some crops (Zhou *et al.*, 2012; Drut, 2018) but did not compare a wide range of candidates plant species. We aimed to screen the species that could be associated as CC or SP in mixtures with a cash crop, in order to benefit from the microbial activity and enhance facilitation processes for crop productivity together with other targeted ecosystem services.

2 Materials and Methods

We conducted a two-month greenhouse experiment in Angers, France. Sixteen species used as SP and CC were tested (one species per pot, n=3): 4 Brassicaceae, 1 Polygonaceae, 1 Asteraceae and 11 Fabaceae and a control soil without plant. The plants were grown in 2 L pots filled with a neutral sandy soil well provided in P, K and Mg. At harvest, root and shoot biomasses were measured. The soil adherent to the roots was sampled for MicroResp^{TM} analysis (Campbell et al., 2003), a method for assessing the ability of soil microorganisms to metabolize C-substrates, used as an indicator of soil microbial activity in response to the root activity and rhizodeposition (Drut, 2018). The mineral nitrogen concentration was measured in the bulk soil.

3 Results

Mean total biomass (dry weight) ranged from 0.06 to 3.95 g among the sixteen species tested. The highest biomasses and the lowest mineral N concentrations of the soils were found for the Brassicaceae and faba bean. The lowest biomass concerned two species of Fabaceae (birdsfoot trefoil and white clover). Microbial respiration in the rhizosphere of faba bean was higher than that of the other species. Grass pea and WOSR were the two other species with higher microbial respiration, whereas lower intensities were found for most CC and PS species. CC and SP Fabaceae seem to be at least as variable as other species in term of effect on the rhizosphere microbial respiration.

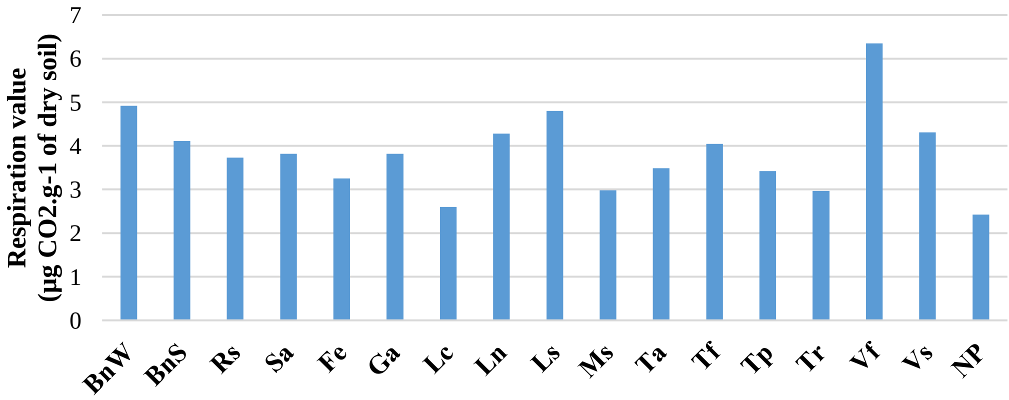

Figure 1. Soil MicroResp™ of two cash crops and fourteen species used as cover crops or service plants

The values are the average MicroResp™ measured with the fallowing substrates: water, arabinose, cellulose, glucose, trehalose, aspartate, butyric acid, glutamate, malate and phytate. Bars indicate standard deviation. In grey NP: no plant (control). In orange Brassicaceae BnW: *Brassica napus* L. (WOSR), BnS: *Brassica napus* L. (spring OSR), Rs: *Raphanus sativus* L., Sa: *Sinapis alba* L.. In purple Polygonaceae Fe: *Fagopyrum esculentum* Moench. In green Asteraceae Ga: *Guizotia abyssinica* (L.f.). In blue Fabaceae Cass., Ls: *Lathyrus sativus* L., Ln*: Lens nigricans* (M.Bieb.) Grdr., Lc: *Lotus corniculatus* L., Ms: *Medicago sativa* L., Ta: *Trifolium alexandrium* L., Tp : *T. pratense* L., Tr : *T. repens* L., Tf: *Trigonella foenum-graecum* L., Vf: *Vicia faba* L., Vs: *Vicia sativa* L.)

4 Discussion and Conclusions

In our study, we were able to separate plant species by the microbial metabolic response upon addition of 9 C-rich substrates commonly found in root exudates. Our results also shown high variation between the legume responses with a stimulation of microbial activity higher than the others for faba bean (Vf) and in a lesser extent grass pea (Ls). This suggests that the positive effect of legumes on microbial growth and activity due to favourable conditions into their rhizosphere can be mitigated according to the species considered. These variations in microbial metabolic profiles indicated that microorganisms in the rhizosphere might reflect differences in the amount and quality of plant rhizodeposition and N requirement of the plants (Brolsma et al., 2017). The potential of microbial activity will thus depend on the legume and influence the resulting priming effect that benefit to plant growth and their N acquisition. The impact of plant mixtures on rhizosphere microbial community is complex (Taschen et al., 2017) and can increase microbial respiration more than its individual components alone (Zhou et al., 2012). The benefits for cash crops induced by SP soil microbial activation for faba bean and grass pea need to be further investigated. It will allow to see if other SP species or SP species mixtures could also lead to an improvement of cash crop N nutrition. This preliminary work will help to design further experiments in order to investigate this field.

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The potential role of 'elite rhizobia' to improve legume-inclusion in agri-food systems: a model approach using peas (*Pisum sativum* L.) and faba bean (*Vicia faba* L.)

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1 Introduction

Commercially grown grain legumes in the British Isles, peas (*Pisum sativum* L.) and faba beans (*Vicia faba* L.), do not require any nitrogen (N) fertiliser (current UK Government and UK pulse growers – PGRO recommendations), as they can provide their own N needs *via* biological N fixation (BNF). They are nodulated spontaneously in UK soils by native *Rhizobium leguminosarum* bv. *viciae* (*Rlv*). Therefore, the need for rhizobial inoculants is generally ignored. However, these crops are characterised by yield instability, and one reason for this may be that there is a potential to that specific rhizobial strains may be applied as inoculants to improve growth, BNF and so grain yield. Thus, the BNF capacities of peas and faba beans cultivated in Maritime-Atlantic climates was assessed, and their symbiotic rhizobia genotypes characterised functionally and genetically.

2 Materials and Methods

The ^{15}N natural abundance technique (Unkovich, 2008) was applied to assess the proportion of air derived from air (%Ndfa), and BNF for pea and faba bean crops cultivated across the British Isles. In addition, a wide diversity of *Rhizobium leguminosarum* bv. *viciae* genotypes were isolated, and 145 representative strains were screened for their ability to promote growth of pea. Their "core-" (*rrs, recA* and *atpD*), nodulating- (*nodAD*) and nitrogen fixation- (*nifDH*) genes of these strains were also sequenced.

3 Results

BNF of pea and faba bean ranged from 100 to 350 kg ha^{-1} y^{-1} over the 4 y field-scale experimental rotation in East Scotland. The residual N left after grain harvest ranged from 30–90 kg ha^{-1} y^{-1}. For the tested pea and faba bean crops growing across the British Isles, we found that in all cases more than 80% of plant-N was Ndfa.

While all the strains tested nodulated pea, 20 significantly increased biomass compared to standard strains, and phylogenetic analysis of nodulation gene sequences (*nodA*, *nodD*) showed isolates were characterised as belonging to one of two distinct clades. Further analysis showed that *nif* genes appear as a good predictor of BNF capacity. However, these are not the only determinants, as some poor-performing strains on peas had similar *nifDH* genotypes to high-performing ones.

4 Discussion and Conclusions

This study has provided strong evidence that naturally occurring soil rhizobia are able to provide peas and faba with enough N through BNF to support high grain yields in locations which span the British Isles. Some of the isolates conferring high performance in *ex situ* biomass-gain trials, are now being tested in field for their potential as commercial inoculants.

The genomes of the potentially elite strains are currently being sequenced, as it is possible that deeper analysis of their whole genome might reveal additional and more reliable genetic markers for symbiotic performance (*c.f.* Young et al., 2006; Sanchez-Canizares et al., 2018).

Acknowledgments

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Session 8. Cropping system diversification to support biocontrol

Chairs: Jens Dauber (Thünen Institute of Biodiversity, Germany),
Didier Stilmant (CRA-W, Belgium)

ORAL PRESENTATIONS

- Influence of temporal diversification on aboveground arthropods
  Speaker: Michael Meyer, University of Münster, Germany
- Faba bean (*Vicia faba* L.) in wheat-dominated cropping systems: spill-over effects on densities and parasitism rates of vegetation dwelling natural pest control agents?
  Speaker: Katharina Schulz, Thünen Institute of Biodiversity, Germany
- Evaluating effects of cropping-systems diversification on biocontrol potential using Rapid Ecosystem Functions Assessment methods
  Speaker: Giovanni Antonio Puliga, Thünen Institute of Biodiversity, Germany
- Does crop diversification ensure mixed cropping systems health?
  Speaker: Marc Tchamitchian, INRA, France
- Biodiversity and regulatory ecosystem services in soybean (*Glycine max*) cropping systems
  Speaker: Daniel Alejandro Amthauer Gallardo, Thünen Institute Biodiversity, Germany

POSTERS

- Interactive effects of crop diversity and management on pollinators in a summer wheat-bean intercropping experiment
  Presenter: Jana Brandmeier, University of Münster, Germany
- Crop diversification in supporting beneficial arthropods - key traits and role of floral and extrafloral nectar
  Presenter: Minna Kosonen, Luke, Finland

Influence of temporal diversification on aboveground arthropods

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1 Introduction

Crop rotations are a widespread tool to reduce crop pests such as root-feeding insects, nematodes or deleterious microorganisms. The sequential cultivation of different crops and associated changes in physical and structural agroecosystem attributes breaks pest cycles. Crop rotations may lead to a decrease in pesticide or fertilizer use, increase yield and can therefore increase economic benefit (Struik and Bonciarelli, 1997, Bennett et al., 2012). Studies focusing on the influence of crop rotation effects on aboveground non-target organisms, mainly arthropods, are scarce and mechanisms are only poorly understood (O'Rourke et al., 2008), although these species may serve as food for higher trophic levels or provide ecosystem services as pollination or pest control.

2 Materials and Methods

To evaluate the impact of crop rotations and differences in temporal crop diversity on invertebrate communities, we conducted extensive sampling in a long-term crop rotation experiment close to the village of Harste (North of Göttingen, Lower Saxony, Germany). The design was a randomized complete blocks design with three blocks, on which five different crops (grain pea GP, sugar beet SB, silage maize SM, winter oilseed rape WR and winter wheat WW) were grown. The crops were either grown in monoculture or in sequences containing different numbers of involved crops (i.e. differently diverse crop rotations), which ranged to a maximum of a six-year-rotation that included four crops in total. Sampling was conducted on seven rotations and N=60 plots during the vegetation period from late April until harvest at the end of July 2016 using pitfall traps and pan traps. We calculated both activity density and species richness for each plot and sampling date but also for the whole season. To assess patterns averaged over time, we used GLMMs with location in the field as random factor.

3 Results

Arthropod activity density was differently affected by the currently grown crop. Namely winter oilseed rape had a positive effect on ground dwelling hunters, especially ground beetles of the Genus *Amara* (Analysis of deviance, GLMM; $p<0.001$, Figure 1 left column). Lower arthropod activity densities were obtained in crops providing simpler vegetation structure, such as maize or sugar beet. For spatially more mobile organisms, especially dipterans or hymenopterans, but also other beetle groups, we found no preference for a certain crop.

Unexpectedly, we observed responses of some taxa to the crop grown in previous years. Iso- and diplopods responded significantly positive to winter oilseed rape grown in the previous year ($p=0.006$) and even two years before ($p=0.013$), suggesting that these groups benefit from plant residuals left in the field. Also ground beetles were influenced by the crop grown in the previous year ($p=0.046$, Figure 1).

Temporal cropping system diversity, i.e. the number of different crops grown within a certain time span, had only negligible effects on activity density or showed contradictious results. Thus, our results indicate that crop identity may be more important than temporal crop diversity for arthropod activity density. The influence of currently grown crop or crop grown in previous years and temporal crop diversity on species richness was negligible. However, species composition between crops varied strongly.

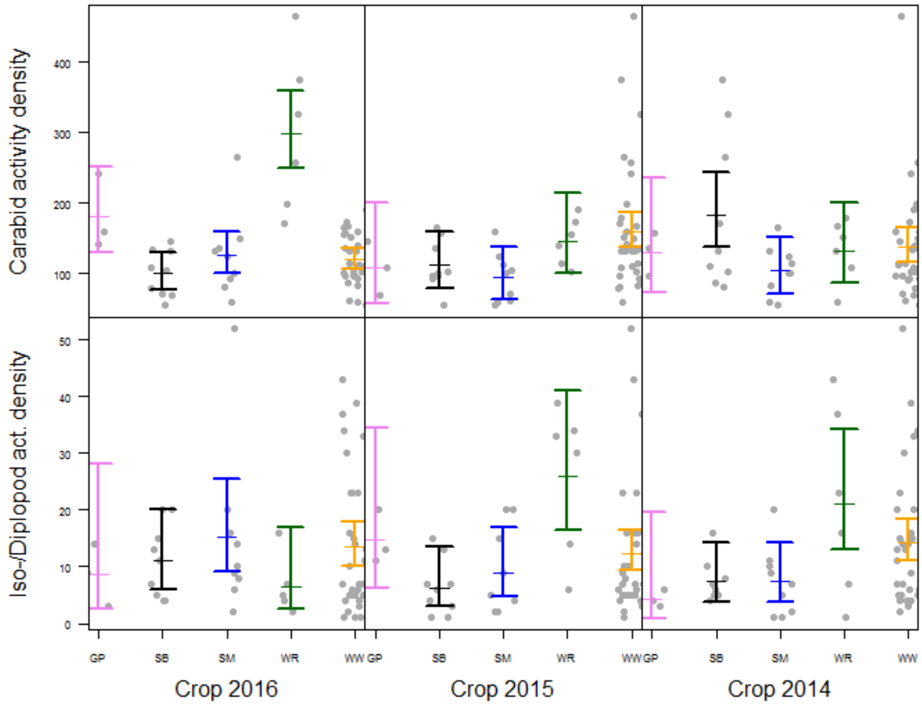

Figure 1. Effect of current crop (grown in year 2016, panels in left column) and preceding crops (grown in years 2015 and 2014, panels in middle and right column, respectively) on activity density of carabid beetles, and isopods and diplopods combined. All individual counts are based on data collected in 2016. Colors indicate individual crop species. Dots show the samples, bars show 95 percent confidence intervals around the mean (estimated from generalized linear mixed-effects models). Figure adapted from Meyer et al., 2019.

4 Discussion and Conclusions

Overall, our study demonstrates that crop identity and cropping system diversity shapes arthropod community structure. The "memory effect" in plots several years after cultivation of particular crops has only rarely been reported so far for aboveground species. However, there are several studies that were able to demonstrate an effect on soil fauna and microbiota and indirect effects on aboveground species (Kostenko et al., 2012). Memory effects of previously grown crops should be considered also in future analyses in different cropping systems. Our findings may also have implications for landscape-wide crop rotation effects with more complex spatiotemporal coupling. Crop rotations systems on a landscape scale are an annually changing mosaic-like pattern providing habitat for varying species. Therefore, if we manage to include more arthropod-beneficial crops in rotation systems, they may become a tool to increase insect biomass within our intensively managed agricultural landscape.

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Faba bean (*Vicia faba* L.) in wheat-dominated cropping systems: spill-over effects on densities and parasitism rates of vegetation dwelling natural pest control agents?

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1 Introduction

Agricultural landscapes in Germany are dominated by cereals, maize and oilseed rape. Legume crops such as faba bean (*Vicia faba* L.) have been under-represented for the past decades due to economic reasons, even though they diversify crop rotations and hence may have positive effects on biodiversity and ecosystem services. (Watson et al. 2017). Faba bean flowers and extrafloral nectaries may provide additional food resources not only for pollinators (Westphal, Steffan-Dewenter, and Tscharntke 2003) but also for hymenopteran parasitoids (Jamont, Crépellière, and Jaloux 2013). Also, hoverflies (Nuessly et al. 2004) and lacewings (for food spectrum in general see (Pappas, Broufas, and Koveos 2011)), whose predatory larvae are antagonists of numerous pest species, may benefit from additional nectar and pollen resources in the landscape. Hence, faba bean may act as a source habitat from which natural pest control agents move actively or passively into the neighbouring fields in the landscape. In the project RELEVANT (https://www.thuenen.de/en/bd/projects/relevant/) it was studied whether such spill-over effects are measurable in winter wheat adjacent to faba bean fields.

2 Materials and Methods

Densities of herbivores (Aphidae, *Oulema spec*.), predators (Syrphidae and Chrysopidae larvae), damage by *Oulema* spp (% of flag leaf area) and, as a measure of parasitism rate, parasitized aphids (mummies) were counted in 22 conventionally managed winter wheat fields in the federal state of Lower Saxony, Germany, from May to July 2018. Half of the fields were adjacent to faba bean fields (neighbour bean, nb) and, as a control, the other half was adjacent to winter wheat (neighbour winter wheat, nw). Both settings were grouped in three regions: I (nb=3, nw=2), II: (nb=2, nw=2), III: (nb=6, nw=7). Observation dates were adjusted as precisely as possible to the development stages of winter wheat in each field: flag leaf just visible to ear emergence (observation 1), flowering (observation 2), milk ripening (observation 3), early to late grain ripening (observation 4). This way it was possible to derive whether the economic injury level was reached or not during each walk. In the field, organisms were counted at three increasing distances to the neighbouring field (1m, 20m, 50m) along 50m transects parallel to the field border. Per transect, ten shoots were observed from the soil to the tip of the ear at five randomly chosen spots, i.e. on 150 shoots in total organisms were counted in each field per observation. In observation 4, ten ears per transect were harvested and dried in order to determine thousand seed mass. Analysis was carried out with RStudio Version 1.1.456. Effects of neighbouring crop on densities of focal organisms, on *Oulema* damage and on thousand seed mass were modelled in a general linear mixed effects model (glmmTMB package). Given that the location of the studied fields was dependent on ownership structures and farmer's management, the constitution of field borders differed throughout settings. Border structures were therefore considered in the analysis.

3 Results

At the current stage of analysis, the results show that in winter wheat fields adjacent to faba bean densities of Syrphids and Chrysopids were marginally significantly higher than in winter wheat fields adjacent to winter wheat, but only in observation 4 during winter wheat full ripening and senescence and faba bean full ripening. Herbivore densities and herbivore damage were not affected by the neighbouring faba bean field. Density of parasitized aphids was significantly higher in fields neighboured by faba bean than in fields neighboured by winter wheat, and parasitism rate increased earlier in the season here, precisely during faba bean flowering and winter wheat flowering to early milk ripening.

4 Discussion and Conclusions

The present study sheds first light on the potential effects of faba bean on vegetation dwelling natural pest control agents at landscape scale. Predators that feed on nectar and pollen as adults may benefit from adjacent faba bean fields late in the season, after faba bean flowering. Herbivore densities were not affected by the adjacent faba bean field though. A clearer faba bean effect was detected on parasitism. Total mummy density was higher in fields adjacent to faba bean, and while parasitism rates increased throughout the season in all fields, they started to increase earlier in fields adjacent to faba bean. Hence, during the crucial phase in which winter wheat is most susceptible towards pest damage (flowering to milk-ripening), parasitoid pressure on aphids was higher than in fields neighboured by wheat. It needs to be considered though, that the vegetative period in the year 2018 was characterized by high temperatures and droughts in Germany and that aphid densities were low in general in that year. Also, fields were intensely managed, and the effect of insecticide treatment remains to be discussed. Long-term studies are needed in order to understand the trends and effects demonstrated in the present study in the context of an entire crop-rotation with faba bean, which spreads over 5-6 years. Furthermore, research on within-field effects of faba bean is needed in order to understand effects of crop-diversification over time. A study on faba bean pre-crop effects on beneficial arthropods is in progress.

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Evaluating effects of cropping-systems diversification on biocontrol potential using Rapid Ecosystem Functions Assessment methods.

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1 Introduction

In agroecosystems, crop diversification plays a fundamental role in maintaining and regenerating biodiversity and ecosystem services, such as natural pest control. Spatial and temporal diversification of cropping systems can affect the abundance and diversity of epigaeic arthropods (generalist biocontrol agents) by providing alternative hosts and prey, food and refuges for overwintering (Altieri, 1999). Yet, little is known about how this translates into variations in the performance of natural enemies and efficiency of biological pest control. Therefore, the purpose of this study is to investigate the potential and resilience of biocontrol within the crops by applying a set of standardized field methods (Rapid Ecosystem Function Assessment, REFA, Meyer et al. 2015).

2 Materials and Methods

In summer 2018, three ecosystem services were investigated in 30 arable commercial fields in Lower Saxony, Germany (Case Study 3, DiverIMPACTS Project, https://www.diverimpacts.net/). The fields chosen are representative of 4 different cropping systems typical of the region, which differ from each other in terms of length of crop rotation and cultivation of catch crops. The cropping systems are: a) short rotation without catch crops (maize as main crop), b) short rotation with catch crops (maize as main crop), c) long rotation of several cereals without catch crops, d) long rotation of several cereals with catch crops. Differences in the cropping systems subsisted during the previous 9 years. Investigated ecosystem functions included invertebrate and vertebrate predation, seed predation and abundance and diversity of aboveground invertebrates. The removal of exposed standardized prey (Mealworms, *Tenebrio molitor*) was used to estimate predation by ground-dwelling invertebrate predators. Artificial caterpillars were used to estimate the predation rates by different predator groups, both invertebrate and vertebrate. Attack marks on caterpillar dummies were attributed to either arthropod, mammal, or bird predators based on the collection of images from Low et al. (2014). Seed predation was investigated by analysing the removal of three different seed species exposed on the ground. Finally, abundance and diversity of epigaeic arthropods were obtained by using barber traps exposed during the REFA sampling. The sampling was conducted over a period of 48 hours.

3 Results

Across all cropping systems, spiders contributed the highest share of total number of beneficial arthropods sampled, followed by carabids and ants. Both abundance and fresh weight of aboveground invertebrates showed similar trends, but only abundance was significantly higher in the fields with long rotation and catch crops compared to the other three cropping systems. Overall, the predation rates on caterpillar dummies were below 40% and did not differ between cropping systems. Based on the identification of the attack marks left in the dummies, arthropods and rodents were the main groups of predators, while only in one case an attack by birds was recorded. Predation rates on mealworms were lower in cropping systems with catch crops in particular in comparison to the system with short rotation dominated by maize. Finally, seeds were almost not predated at all in any of the treatments.

4 Discussion and Conclusions

In line with our expectations, our results highlight that a more diversified cropping system affects the abundance of ground-dwelling arthropods positively. Nevertheless, contrasting results on predation rates of mealworms, no differences in attack rates on artificial caterpillars and almost complete lack of seed predation, suggest that this may not necessarily translate in increased potential of biological control.

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Does crop diversification ensure mixed cropping systems health?

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1 Introduction

Agriculture specialization and intensification has led to a biodiversity loss in landscapes (Altieri & Nicholls, 2001) while this biodiversity fulfils several services in agroecosystems (Altieri 1999), which includes natural regulations of pest (Bianchi et al., 2006). In response to these negative statements, new cropping arrangements have emerged reintroducing ecological processes. Agroecology (Gliessman, 2001) is today's foremost paradigm used for the redesign of agriculture, promoting an integrated perspective of the interactions between natural ecological processes and human control on agroecosystems. Within this framework, agroforestry is a seducing way to combine agroecological principles and the necessity to maintain high level of land productivity (Eichhorn et al. 2006). Horticultural agroforestry, mixing fruit trees and vegetable crops on the same plot (MOMG, Mixed-Orchard-Market-Gardening) is gaining momentum as a diversification strategy to address both the consumer demand and ecological goals (Léger et al., 2018). These systems embed a high biological diversity, through the association of several crops at the same on time on the same plot, and through the large number of crops in rotation along time. Many of the farmers running such systems claim that the high diversity is a guarantee for the health of their systems, because of the regulation service it ensures.

The goal of this work was to assess the hypothesis that the high diversity of crops in these systems is linked to a decrease in pest pressure and crop damages.

2 Materials and Methods

To link system diversity with pest pressure and crop damages, we have chosen a statistical approach based on farm data obtained by a combination of surveys and satellite image analysis.

2.1 Surveys

Farmers running MOMG systems have been selected from the inventory achieved in France by the SMART project (Warlop, 2016), with two main criteria: exploring different soil and climate conditions and age of the MOMG which must be old enough to allow fruit production and enough past observations on the pest and disease occurrences. This led to select 20 farms with MOMG aged from 3 to 6 years (median 4.5, mode 5), covering the main regions where such systems are present. The farms and MOMG were described along several dimensions:

- Farm structure (area, area in MOMG, other productions…), [V, I]
- MOMG structure (age, area, specie and variety composition…), [V, I]
- MOMG cropping techniques (esp. rotations, inter-row management, genetic resistances …) [V, I]
- Managed landscape structure (mainly hedges, described by their length, degree of continuity, general state), in two successive buffers (close and farther), [V, S]
- Natural landscape structure (forests, woods, groves, isolated trees), with equivalent descriptors than for managed landscape structures, [V, S]
- System health over the last three years (diversity and pressure of the pests and diseases, observed frequency and importance of the damage to the crops, on the other hand. [I]

(V: observations gained during Visits, I: Interviews, S: Satellite image analysis).

2.2 Analysis

To analyse these data, we built a model according to the hypothesis that within the observed variables, some should be combined to characterise a more complex but not directly observable variable (also called latent variable), such as plant diversity effect or natural landscape effect on system health (Figure 1). The Partial-Least-Square-Path-Modelling statistical method then allowed to determine which and how the observed variables contributed to their associated latent variable, and the weight of the links between latent variables.

3 Results

The results show that the damages highly depend on the diversity of pests and diseases, but are negatively correlated to the management practices, especially to the choice of resistances. Protection treatments on the contrary have a positive impact on the overall damages, probably because they are too selective. The diversity of pests mainly depends on the managed landscape (through its sanitary and conservation state), on the crop diversity, on the inter-row management, and is negatively correlated to the crop rotation diversity. Overall, practices aiming at enriching the diversity combined with dense and healthy hedges favour a larger pests and diseases diversity, while the natural landscape elements tend to reduce it. Finally, the damages increase with the pests and diseases diversity, but can be controlled by targeted practices, especially the choice of crop resistances.

4 Discussion and Conclusions

These first results tend to invalidate the hypothesis that the increase of diversity in these horticultural agroforestry systems ensures the regulations and the system health, conversely to well established ecological principles (Ratnadas et al., 2012). They point out a certain fragility of these mixed systems, because their health mainly depend on one single practice, plant resistance choice. Further insight into the precise role of the structure of these systems on their capacity to ensure resource dilution, habitat for auxiliaries and on the effects of the practices on the auxiliary abundance are therefore needed.

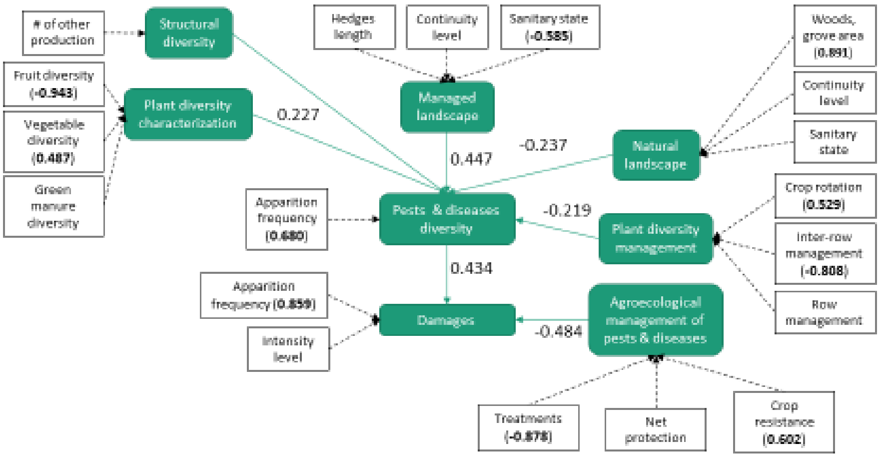

Figure 1. Explanatory model of the effects of MOMG characteristics on its health. Latent variables (round filled boxes) are statistically built from observed variables (square boxes). Values on the arrows represent the effect weight, values in the boxes represent the contribution of the observed variable to the latent variable building (only high values are presented).

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Biodiversity and regulatory ecosystem services in soybean (*Glycine max*) cropping systems

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1 Introduction

The soybean, belonging to the legume family (Fabaceae), plays a key role in many cropping systems and is today the most important oil seed crop, securing food and feed supply around the world. The area cropped with soybean worldwide has more than tripled from 37.5 million hectares in 1974 to around 117.5 million hectares in 2018. To date, Europe strongly depends on imported protein crops, mainly soybeans and soybean products, to feed livestock and for human consumption (Watson et al. 2017). This dependence has led to increased deforestation in soybean producing countries. Moreover, nutrient import resulted in a strong eutrophication of intensive European agroecosystems. To reduce this dependence and the environmental impacts, the EuropeanUnion (EU) encourages European farmers to grow more leguminous crops, such as soybean, faba bean (*Vicia faba*), pea (*Pisum sativum*) or lupin (e.g. *Lupinus albus*, *L. angustifolius* or *L. luteus*). Currently the EU and many of its members promote legume cropping with several programs.

Most legumes host rhizobium bacteria that fix nitrogen (N) and thus do not need N fertilizer. Many have deep and extensive root systems, produce large amounts of nitrogen rich crop residues and possess a flowering system that can facilitate insect pollination. Due to these key qualities, it is supposed that legumes offer numerous regulatory environmental services and effects on biodiversity: reduction of adverse N-emissions, mitigation of CO_2 emissions, better energy balance of cropping systems, soil fertility including improvement of nutrient mobilization from deeper soil layers as well as improvement of soil structure and porosity and provisioning of habitat and resources for fauna above- and belowground (Everwand et al. 2017). Nevertheless, to this time it is not established whether and to which extent soybean-based cropping systems offer regulatory ecosystem services or enhance biodiversity. This literature study aims to determine the effect of the soybean crop and its cropping systems i) on communities of plant, arthropods and birds, specifically their species richness, diversity, abundance and biomass; ii) on ecosystem services, such as pest control, pollination and soil fertility and iii) on management intensity, crop rotation and landscape parameters as drivers of biodiversity.

2 Materials and Methods

The literature survey yielded 60 studies, published between 1983 and 2018, which report on impacts of soybean cropping or soybeans in cropping systems on biodiversity in comparison to other crops or cropping systems without soybean. We excluded studies on fungi, soil meso-, and microorganisms and found 21 studies including plants, 40 studies including invertebrates and 6 studies including vertebrates, all of which were birds. The studied parameters were mainly abundance or biomass with 51 studies. Species richness or diversity and community composition were included in 29 and 23 studies, respectively. Effects on ecosystem services, such as pollination or pest control were investigated in 22 of the studies. Landscape effects were included in 23 of the studies. The geographic focus of the studies was on the American continent, with 38 studies from USA, 7 from Canada and 9 from Argentina. A comparison of different crops is shown in 35 studies and 49 studies compare different cropping systems.

3 Results

We found reports of potential benefits of soybean cropping on plants, pollinators, parasitoids and other natural pest control agents. Though weed species richness was the same, weed abundance and biomass were commonly higher in soy than in other crops. At the same time, soy, especially in low input systems, showed higher predator and herbivore insect species richness (Adams et al. 2017). Those, however, were in most studies also strongly influenced by landscape composition, field size, crop diversity and rotation, as well as management measures, such as tillage regime, fertilizer and pesticide inputs. Most studies show that biodiversity parameters are affected by crops or cropping sequences or management such as tillage, crop protection or fertilizer regime.

4 Discussion and Conclusions

We founded higher weed abundance and biomass but no higher diversity. It appears that the provided resources from soy cultivation to soil (nitrogen fixation and improved soil porosity) positively affects the agroecosystem but the plant diversity is already limited by the kind of artificial ecosystem itself and the agricultural management practices applied. We confirmed our assumption that arthropod richness and biomass is increased by soy cultivation, presumably through nutrient and protein rich foliar biomass.

We conclude that an assessment of potential biodiversity and ecosystem service effect of soybean in cropping systems cannot be founded on plant traits of soybean alone. Soil management and plant protection measures of the entire soybean-based crop rotation have to be taken into account as well as the structure of the landscape in which the respective cropping system is embedded.

Acknowledgments

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Interactive effects of crop diversity and management on pollinators in a summer wheat-bean intercropping experiment

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1 Introduction

More than 40 percent of Europe´s terrestrial land surface is dominated by agriculture (FAO 2015), with only low proportions of organic or low-intensity farming. Simultaneously we are facing drastic biodiversity declines, which are often affiliated to agricultural intensification (Stoate et al., 2009, Firbank et al., 2008). While organic or low-intensity farming promotes biodiversity (Garibaldi et al., 2014), it will likely never exceed a threshold of c. 20 per cent. Consequently, in order to promote large- scale agrobiodiversity, conservation across Europe will require measures targeting the heart of farming systems themselves. A promising alternative to growing crops in monocultures is intercropping, especially when it is extended not only to low intensity, where it is already widely used, but also to conventional farming systems. Several studies indicate advantages of intercropping, such as higher yield (Bedoussac & Justes, 2009) or promoting pollinators and pollination services by increasing floral diversity (Garibaldi et al., 2014). Nevertheless, this practice is not widespread in European conventional agriculture and thus knowledge regarding insects, a major component of terrestrial agriculture, in different farming systems is scarce. The ongoing loss of insects, especially flower visitors, may reduce ecosystem service provisioning and induce cascading effects across trophic levels (Hallmann et al., 2017). It is therefore necessary to improve the agricultural matrix itself by providing food resources and structurally rich habitats for flower visitors and insects in general, while simultaneously maintaining yield stability and agronomic efficiency.

The pan-European project "DIVERSify" aims to improve productivity and sustainability by increasing the spatial diversity of cropping systems. We set up a summer wheat-faba bean intercropping trial and manipulated management intensity (high vs. low management input) and cropping system diversity (monoculture vs. mixture) in a randomized complete blocks design (N=96 plots). The aim of our study was to find out if cropping system diversity affects pollinator abundance and diversity.

2 Materials and Methods

The experimental site was located in Münster, Germany. Four blocks, consisting of 96 plots, each 5x1,5 m, were sown with summer wheat (*Triticum aestivum* L.), and faba bean (*Vicia faba* L.) on April 23rd in 2018 with a sowing machine in monocultures and two types of mixtures with different sowing densities, one with a 50/50 and the other with a 75/25 legume-cereal ratio. Management input was assigned at random to blocks. One block was made of four rows. Two rows received no treatment (low input), the other two received one herbicide spray (4,4 l/ha Stomp Aqua with 455 g/l Pendimethalin as active agent) and nitrogen fertilizer (70 kg N/ha) as a solution of urea and ammonium nitrate (UAN) (high input). We recorded pollinator visits on three days for a total of 45 minutes per plot. Data were analyzed using the software package R (R Core Team (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/). Effects of crop diversity and management on pollinator abundance and diversity were analyzed using generalized linear mixed-effects models fit by penalized quasi-likelihood with block and management as random effects and (quasi-)poisson errors.

3 Results

There was a significant interaction between crop diversity and management on pollinator abundance (X^2=12.39, df=3, p=0.006; Figure 1a), as well as a significant main effect of crop diversity (X^2=94.54, df=3, p<0.001) and a non-significant effect of management (X^2=1.09, df=1, p=0.29). With increasing proportion of legumes in the mixtures pollinator abundance increased as well. Abundance was generally higher under low than under high management input, except for legume monocultures where high management showed highest abundance (Figure 1a). Similar to pollinator abundance, there was also a significant interaction between crop diversity and management on pollinator diversity (X^2=11.85, df=3, p=0.008, Figure 1b) as well as significant main effects of crop diversity (X^2=9.79, df=3, p=0.02) and management (X^2=12.12, df=1, p=0.0005). Pollinator diversity was maximized in 50/50 mixtures for low management input and in 75/25 mixtures for high management input (Figure 1b).

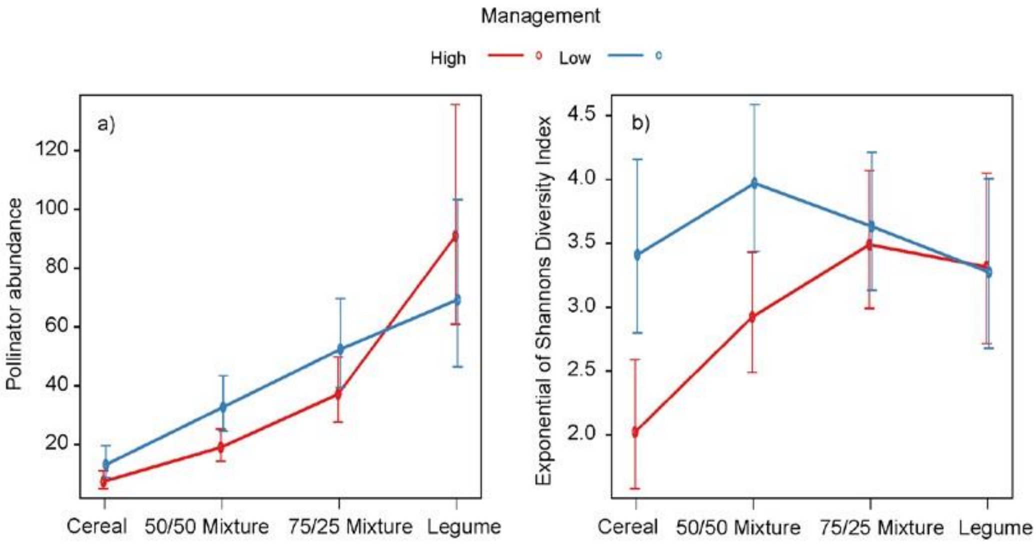

Figure 1. Model output for a generalized linear mixed-effects model fit by penalized quasi-likelihood on a) pollinator abundance and b) pollinator diversity (Exponential of Shannons Diversity Index) as a function of cropping system (Cereal = wheat monoculture, Legume = faba bean monoculture, 50/50 and 75/25 Mixture = faba bean-wheat mixtures) for high (red line) and low (blue line) management input. Bars are Standard Errors of the mean.

4 Discussion and Conclusions

In summary, cropping systems containing faba bean attracted more flower visitor taxa and individuals than cereal monocultures, showing that there is a positive effect of growing faba bean with summer wheat due to provisioning of nectar for insects. The interaction of cropping system and management input showed significant effects on abundance and diversity of flower visitors. Generally, low input plots attracted more flower visitor taxa and individuals than high input plots, likely due to a higher number of weed species to interact with. Only for legume monocultures the pattern was opposite. Here, the higher number of flowering faba bean plants lead to higher abundance and diversity in flower visitors on high input plots. Nevertheless, even in highly managed plots, summer wheat-faba bean mixtures showed higher pollinator abundance and diversity than wheat monocultures. Thus, legume-based intercropping and the accompanying diversification of agriculture can be seen as an important step to integrating conservation aspects into conventional food production systems.

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Crop diversification in supporting beneficial arthropods – key traits and role of floral and extrafloral nectar

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1 Introduction

Agroecosystem diversification can be pursued to strengthen certain natural processes, often termed ecosystem services, such as insect pollination and natural biological control. Circa 75 % of food crops benefit from insect pollination (Klein et al. 2007), while on average, 20-40 % of global crop yield is lost to insect pests or plant diseases annually (Chaplin-Kramer et al. 2011). It is thus imperative to seek for ways to strengthen and support natural beneficial arthropods in agroecosystems: their conservation and functional diversity is central for food production and preserving natural biodiversity. To potentiate this, we need to know better which agriculturally relevant crops and plant traits best support beneficial insect groups.

Various pollinating insects utilize floral nectar and pollen from agricultural and horticultural crops. Floral characteristics determine the attraction and availability of nectar to different groups and species of pollinators. Thus, floral traits are key in shaping crop-pollinator interactions. Some crop plants such as *Vicia* sp. produce also extrafloral nectar (EFN) which can attract for example ants and parasitoid wasps because of the carbohydrate-rich compositions (Marazzi et al. 2013). EFN acts as an alternative food source for herbivore natural enemies and could help strengthen natural biological control, a key ecosystem service involving arthropods. While floral nectar is available for a limited time only, EFN secretion can begin before blossoming and continues after flower senescence depending on the secreting species. Production of EFN could be an ecologically important trait for both pollinators and herbivore natural enemies.

Main objective of the work was to characterize common field crops for their specific traits of importance to supporting effective pollination and natural biological control in northern European agriculture. In addition, we aimed to describe the specific role of floral and extrafloral nectar provision and quality.

2 Materials and Methods

As part of an on-going research project LUMOTTU, we made an effort to characterize common field crops for their key traits important for pollination and natural biological control in Finland. This information can be used to design intercropping and to select effective agroecosystem service supporting crops. For this, ten crop species were selected: Faba bean (*Vicia faba* L.) cultivars Kontu and Sampo, buckwheat (*Fagopyrum esculentum*), oilseed rape (*Brassica napus* L.), turnip rape (*Brassica rapa* subsp. *oleifera*), phacelia (*Phacelia tanacetifolia*), mixture of two annual clover species (*Trifolium incarnatum* and *Trifolium resupinatum*), white lupin (*Lupinus albus*), common vetch (*Vicia sativa* L.) and hairy vetch (*Vicia villosa* Roth.). All the plant species are commonly used as field crops or for green manure in Finland.

The crops were compared for their traits based on earlier literature and are tested empirically using on- going two-year field plot experiments established in Mikkeli, Finland. The species were described for general floral characteristics, timing and length of flowering, number of flowers per acreage, and production and quality of floral and extrafloral nectar. In the field trials, the traits are assessed for each crop and linked to observations of natural arthropod group preference and activity in field at full flowering (assessed using trapping and visual observations).

3 Results

All the studied species secrete floral nectar, and faba bean and vetches also EFN that is produced by the stipules on the base of each leaf node. Based on literature survey, quality of floral and extrafloral nectar also show variation: for example sugar composition in extrafloral and floral nectar may be varying and this may affect ecologically utmost important interactions between plants and nectarivores (Blüthgen & Fiedler 2004).

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In first year field trial (2018), both *V. faba* cultivars had relatively short main flowering time, whereas *V. sativa* and *V. villosa* produced flowers for a longer time (Figure 1). The longest flowering period was observed for *F. esculentum*. Sugar content in floral nectar varied in the Faba bean cultivar from Sampo contained more varied sugars than cultivar Kontu. Extrafloral nectar contains mainly three sugars, glucose, fructose and sucrose whereas floral nectar contains several sugars in faba bean cultivars. In 2018, the most attractive plant species among main pollinator species such as *Apis mellifera* and bumblebees were *P. tanacetifolia* and *Trifolium* species. The oilseeds had a high incidence of herbivore species and their natural enemies.

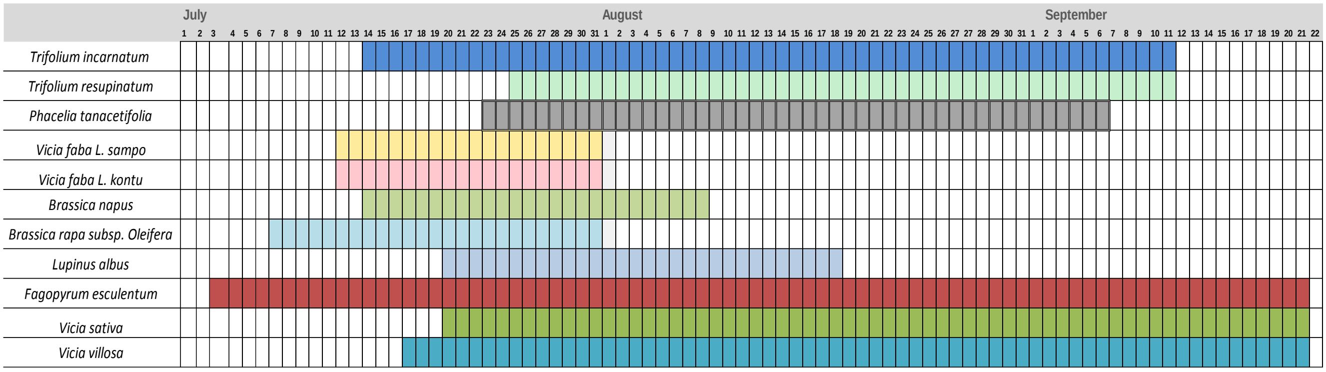

Figure 1 The flowering times in eleven plant species in Mikkeli, South-Savo, Finland 2018

4 Discussion and Conclusions

Based on literature survey and first year field trial results, the selected flowering crops show variation in floral characteristics, length and timing of flowering, and floral and extrafloral nectar. Their attractance for and hosting of key herbivore, predator, parasitoid and pollinator groups also varied in the first year field trial. By linking literature-based knowledge, ecological importance of crop traits and field studies to assess associated arthropod activity it will be possible to assess potential benefits of the crops in practice.

It seemed especially important that since the *Vicia* species produced EFN already before actual flowering time they can be important for many beneficial natural enemies already when the first EFN secreting stipules emerged. On the other hand, the long flowering time and easily accessible nectar of *F. esculentum* suggests it could offer good potential for supporting wide range of pollinator populations. We conclude that crop diversification strategies can be supported by gaining better knowledge of ecologically important specific crop traits, the temporal variability in their expression and the actual linkages proving their support for specific beneficial arthropod groups.

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SESSION 9. IMPACTS OF INTRODUCING SERVICE CROPS AND LEGUMES IN CROPPING SYSTEMS

Chairs: Frédéric Muel (Terres Inovia, France),
Elise Pelzer (INRA, France)

ORAL PRESENTATIONS

- Do tomorrow's diversified cropping systems need ley pastures?
  Speaker: Guillaume Martin, INRA, France
- Cropping diversification and N fertilization effects on soil greenhouse gas emissions in irrigated Mediterranean conditions
  Speaker: Jorge Álvaro-Fuentes, CSIC, Spain
- Diversifying irrigated rotations with cover crops in Mediterranean semi-arid regions: learnings from a long-term experiment
  Speaker: María Alonso-Ayuso, Universidad Politécnica de Madrid, Spain
- Multifunctional analysis of ecosystem services relative to the nitrogen fluxes provided by ten legume crops
  Speaker: Maé Guinet, INRA, France
- Agro-ecosystem services and drivers of variability in their delivery from legumes in European cropping systems: a systematic review
  Speaker: Dirk van Apeldoorn, Wageningen University & Research, The Netherlands
- Increasing cover crop benefits from the termination method choice in semi-arid Mediterranean regions
  Speaker: María Alonso-Ayuso, Universidad Politécnica de Madrid, Spain
- Diversity of perennial legume-grass mixture influences the delivery of ecosystem services in organic arable cropping systems
  Speaker: Nawa Raj Dhamala, Swedish University of Agricultural Sciences, Sweden

POSTERS

- Diversification of crop rotation by cover crops enhances ecosystem services.
  Presenter: Liina Talgre, Estonian University of Life Sciences, Estonia
- Energy gain from crop rotation depending on included crops
  Presenter: Madara Darguza, Latvia University of Life Sciences and Technologies, Latvia
- Mobilisation of functional properties of diverse legumes species at various scales in the CA-SYS Long Term Experimental Platform on Agroecology: expected services and prospects
  Presenter: Anne-Sophie Voisin, INRA, France
- Impact of agro-ecological service crops and their termination modes on Soil Mineral Nitrogen dynamic at spring crop implantation
  Presenter: Didier Stilmant, CRA-W, Belgium
- Can we expect reduced nitrous oxide emissions from soil in diversified cropping systems?
  Presenter: Roman Hüppi, ETH Zurich, Switzerland

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Do tomorrow's diversified cropping systems need ley pastures?

Guillaume Martin*±[1], Jean-Louis Durand[2], Michel Duru[1], François Gastal[3], Bernadette Julier[2], Isabelle Litrico[2], Gaëtan Louarn[2], Safia Médiène[4], Delphine Moreau[5], Muriel Valentin-Morison[4], Sandra Novak[3], Virginie Parnaudeau[6], Foteini Paschalidou[4], Françoise Vertès[6], Anne-Sophie Voisin[5], Pierre Cellier[7], Marie-Hélène Jeuffroy[4]

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1 Introduction

Specialized cropping systems are confronted to yield stagnation and appear sensitive to climate change. They rely on a large use of mineral fertilizers and pesticides that have negative impacts on the environment and on human health and can lead to impasses (e.g. resistance to pesticides). Diversified cropping systems could be more sustainable, as suggested by cropping system experiments. Ley pastures i.e. temporary pastures integrated in crop rotations and composed of grasses, legumes and/or other forbs grown for 1 to 5 years, are one of the strategies that may contribute to diversification, among others. The role of temporary ley pastures in cropping systems is currently being challenged by most future-oriented scenarios aiming to increase and secure the food production to feed the increasing world population while improving the sustainability of agriculture (Schader et al. 2015; Röös et al. 2017). Most of these scenarios converge towards a reduction of animal proteins in human diets of developed countries, and, as a consequence, a shift in livestock's role to using land unsuitable for food production. As arable land is no longer used for feed production, this suggests the reduction of ley pastures in cropping systems.

We argue that the scientific community underestimates the potential benefits offered by ley pastures in cropping systems. In this context, we aim to synthesize the potential benefits of their introduction in cropping systems and to raise the practical and research challenges related to the introduction of ley pastures in cropping systems.

2 Materials and Methods

To review the literature, our theoretical framework considers:

- the companion or following crop and management techniques implemented: the latter encompass the type of pasture (annual or pluriannual), the species sown (grass or legume species or mixtures), the way sowing is practiced (i.e. on a bare soil or through relay cropping), the way the pasture is used (grazing, mowing, living mulch for sowing a crop in the ley, crushing for green manuring or biomass for energy).

- the ecosystem services provided: besides producing fodder for livestock, ley pastures may provide multiple ecosystem services related to soil stability and erosion control, nutrient supply and recycling, climate regulation, soil water retention and purification, biological control of pests, and habitat provision for biodiversity conservation. If often mentioned, those services are seldom considered together nor quantified for ley pastures.

3 Results

In most situations, ley pastures provide ecosystem services when inserted in cropping systems, and decrease their negative impacts.

Limiting soil disturbance and favoring carbon input through the development of pluriannual plant covers such as ley pastures can largely contribute to improve soil structure and water retention capacity, and more globally to improve soil health, even more if associated with crop residues and animal manure returns. Ley pastures also act as a major factor to lower runoff and promote water infiltration and to protect soils with respect to water and wind erosion. Avoidance of soil erosion limits soil nutrient losses, particularly N and P. Moreover, both the biodiversity and activity of soil microorganisms that control a large part of C, N and P cycles are stimulated in less disturbed soils like ley pastures compared to soils with frequent tillage like crops. Beyond that, introduction of ley pastures in cropping systems can improve soil nutrient provision via 3 main levers: i) higher N inputs thanks to symbiotic fixation of legume species, ii) higher development of roots (compared to annual crops), higher root exudate secretion and higher development of soil microorganisms allowing desorption of P and K, and iii) large C inputs by grasses. Introduction of ley pastures in cropping systems also contributes to nutrient recycling especially in case pastures are grazed. At pasture destruction, a large part of the SOM is mineralized, leading to high C losses (as CO_2) and possibly to excess N mineralization that can generate high N losses. Carbon storage by pastures is one important lever to mitigate climate change but storage rate very much depends on their use which may counterbalance this positive effect. Ley pastures, by covering the soil during periods at risk for deep water contamination (winter in oceanic Western Europe), reduce N leaching through plant uptake of N and P and by limiting run-off and erosion. As pastures are usually not treated against pests, their occurrence in cropping systems results in lowering pesticides inputs. Moreover, an increase in soil organic carbon such as the one occurring during the ley pasture period improves the soil generic capacity to filter organic pesticides. Ley pastures provide particularly unfavorable growth conditions for weeds and therefore tend to affect the composition of the weed flora and reduce weed growth. They do not have a direct effect on pest populations and expansion of diseases but their indirect positive effect is proven in most cases except in the case of wireworms pullulation following pastures. Ley pastures do play a vital role in maintaining biodiversity in many cultivated areas since they provide over-wintering sites, feed resources, refuges and source populations for re-colonization of disturbed habitats. Finally, ley pastures provide feed resources in quantity and potentially of high quality for ruminant livestock.

4 Discussion and Conclusions

We claim the role and relative importance of ley pastures in tomorrow's cropping systems should be reconsidered through an ecologically-intensive lens bringing together new technologies and organizations at various levels. To benefit from ecosystem services provided by ley pastures in cropping systems while limiting their disservices to thresholds compatible with international commitments (e.g. greenhouse gas emissions) and/or political choices (e.g. feed/food competition for land use), defining a "safe operating space" is needed (Buckwell and Nadeu 2018; Rockström et al. 2009). It consists of identifying the lower boundaries defined by levels of ecosystem services which offer sufficient benefits, and the upper boundaries defined by the sustainable thresholds for the disservices. The practical questions are how to identify this safe operating space, and how to move cropping systems into this space. Presently, defining the safe operating space for ley pastures in cropping systems requires (i) to better quantify the ecosystem services bundles they provide, (ii) to address ley pasture management issues that may allow reducing disservices through better management or use of new technologies (e.g. new cultivars and species mixtures) and (iii) to identify acceptable societal compromises at different scales and translate them into policy decisions (regulation, incentives). A further step would involve assessing the side effects of scenarios including more ley pastures in cropping systems.

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Cropping diversification and N fertilization effects on soil greenhouse gas emissions in irrigated Mediterranean conditions

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1 Introduction

Global warming is one of the greatest societal and economic threats. The rise in atmospheric greenhouse gases (GHG) due to human-related activities is the principal reason for the increase in surface earth temperature observed over the last century. Agricultural activity contributes to the increase of atmospheric GHG concentration. Soil is a main emitter of GHG and certain agricultural management practices may foster the production and emission of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from soil to the atmosphere. Agricultural soils are key emitters of N_2O with more than 60% of the global N_2O emissions attributable to soils (Cayuela et al., 2017). In particular, nitrogen (N) fertilization and irrigation have been recognized as two practices which promote the production and emission of this gas from agricultural soils. Furthermore, soil CO_2 emission is derived from microbial and root plant respiration. Microbial-derived CO_2 is originated through the decomposition of organic compounds present in soils. Increasing rates of soil CO_2 emitted may indicate greater soil C decomposition rates and, hence, decreased potential for soil organic carbon sequestration and atmospheric carbon (C) removal. According to this, it is important to design and implement agricultural management practices that mitigate the production and emission of GHG from agricultural soils.

In irrigated areas of NE Spain, maize is the principal crop due to the favourable yield response of this crop to additions of N fertilizers and water (Franco-Luesma et al., 2019). This fact has driven the proliferation of maize monocropping as main cropping system in those areas. However, excessive use of fertilizers and irrigation water has promoted the appearance of environmental side-effects which must be quantified and mitigated.

The main aim of this study was to evaluate the contribution of cropping diversification and N fertilization on soil GHG emissions (CO_2, N_2O and CH_4) in an irrigated maize (*Zea mays* L.) experiment in Mediterranean conditions.

2 Materials and Methods

The study was conducted in the experimental farm of the Aula Dei Experimental Station, Zaragoza, Spain (41º 43´ N, 0º 48´ W, 225 masl). The climate is Mediterranean semiarid with annual mean air temperature of 14.1 ºC, annual precipitation of 298 mm and grass reference crop evapotranspiration (ETo) of 1243 mm. The soil is a clay loam classified as Typic Xerofluvent (Soil Survey Staff, 2014).

In October 2018, a 1 ha field was divided in two parts to establish and compare two different cropping systems: a pea (*Pisum sativum* L.)-maize system and a maize monoculture system. At the same time, within each cropping system three N fertilization levels were compared: control (unfertilized), medium and high N rates. The experimental design was a split-block design with three replicates per treatment and a plot size of 6 m x 25 m. Field pea was sown in October 2018 and maize after pea in late June 2019. In the maize monocropping field no action was performed until April 2019 when maize was planted. Pea crop was not N fertilized and differential N fertilization was performed in both maize systems (monocropping and maize after pea).

In November 2018, one polyvinyl chloride (PVC) ring (31.5 cm internal diameter) per plot was inserted 5 cm into the soil. Rings were only removed during harvest and tillage operations. Closed PVC chambers 20-cm height were used to sample air emitted from soil. During the fallow season of the maize monocropping (November-April), soil gas sampling frequency was once every three weeks, but after maize planting the sampling frequency was intensified to once a week. In the pea-maize system, gas sampling during the pea

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phase was performed once every two weeks and weekly in the maize phase. During irrigation and N fertilization applications, the sampling frequency was also intensified. Soil gas samples were analysed in an Agilent 7890B gas chromatograph equipped with a flame ionization detector (FID) for CO_2 and CH_4 (for CO_2, a methanizer ahead the FID detector was used) and an electron capture detector (ECD) for N_2O. Concomitant to soil gas sampling, soil temperature to 5 cm depth, and soil moisture and soil mineral N from the 0-5 cm layer were also measured.

3 Results

Soil CO_2 and N_2O fluxes from November 2018 to mid-April 2019 are shown in Figure 1. Average soil CO_2 flux was almost two-fold higher in the pea phase compared with the maize (fallow) phase (958 vs. 570 mg CO_2-C m^{-2} day^{-1}, respectively). Differences between both cropping systems increased particularly in March and kept steady in April.

Average soil N_2O flux was significantly higher in the maize (fallow) phase than in the pea phase (1.20 vs. 0.12 mg N_2O-N m^{-2} day^{-1}, respectively). Daily soil N_2O fluxes were similar until April when a prompt increase in soil N_2O fluxes was observed in the maize (fallow) plots.

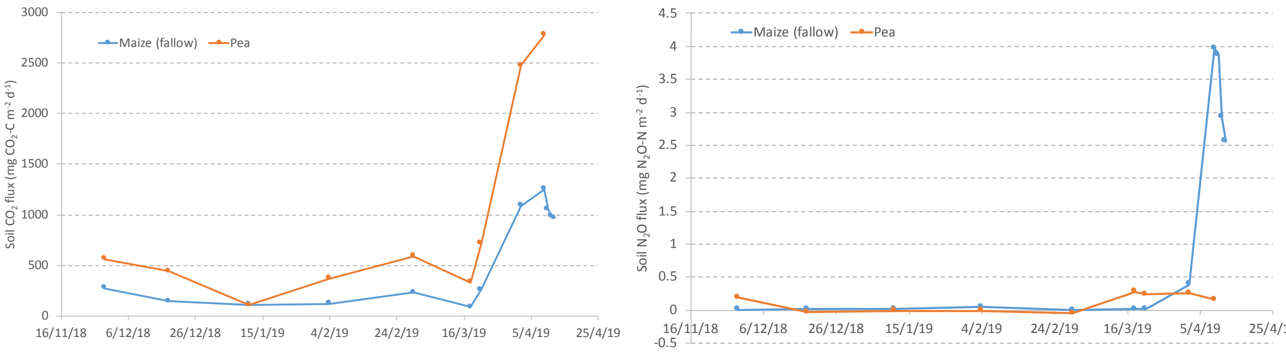

Figure 1. Soil CO_2 (left graph) and soil N_2O (rigth graph) fluxes as affected by diversification pea phase of a pea-maize cropping system and the fallow phase of a maize monocropping system in Mediterranean irrigated conditions.

4 Discussion and Conclusions

In both cropping systems, soil CO_2 fluxes increased particularly after the only irrigation applied over the season (mid-March). This increase in soil fluxes could be due to two factors. The first factor could be the irrigation effect on the crop growth (pea) and thus to the greater contribution of root respiration to the total CO_2 flux. Secondly, the increase in temperature during spring together with the addition of water could favour microbial-derived CO_2. In the maize-fallow season, in which no crop was grown, irrigation also increased soil CO_2 fluxes due to an increase of microbial activity. Soil N_2O fluxes in the pea season were steady and low compared with the maize (fallow) season. The prompt increase observed in soil N_2O fluxes in the maize (fallow) phase could be explained by the N fertilization event applied on the 8th of April favouring nitrification and denitrification processes and thus N_2O production and emission. These preliminary data showed that crop diversification might have a significant effect on soil GHG emissions in irrigated Mediterranean systems.

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Diversifying irrigated rotations with cover crops in Mediterranean semi-arid regions: learnings from a long-term experiment

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1 Introduction

In annual rotations, the traditional winter fallow can be replaced by cover crops (CCs) providing different ecosystem services (Tonitto et al. 2006; Lal, 2015), and diversifying agricultural systems.

While some of the reported benefits, as nitrate leaching reduction, may be observed in the short term, others require more time to be perceived. Thereby, soil restoration is a slow process and there is a need to find out the time required for CCs to have an effect on recovering soil functionality. Similarly, the result of introducing CCs for weed communities may take several years to manifest (Moonen and Barberi, 2004). Therefore, long-term experiments are very valuable to assess the impact of CC use. Besides, the use of modeling techniques is interesting to assess the impact of farming strategies under different spatial and temporal scenarios.

The evaluation of the CC performance under semi-arid conditions could promote the adoption of this agricultural practice in Mediterranean river basins, where the land degradation and low water quality are common problems.

2 Materials and Methods

The study was conducted in central Spain and consisted of a 10-year crop rotation, with or without a winter CC between consecutive summer cash crops. The two CC evaluated were barley (*Hordeum vulgare* L.) and vetch (*Vicia* sp. L.), and they were compared to a bare fallow as a control treatment. Every year, CCs were established in October and terminated in April. Cover crops were never fertilized or irrigated during their growing period. After termination, the main crops – maize (*Zea mays* L.) and sunflower (*Helianthus annuus* L.) - were sowed over the residues. Summer crops were irrigated every year, and received fertilizer depending on the year (García-González et al. 2018).

Each year, the biomass of CCs and main crops was measured at CC termination and harvest. The %C and %N were determined. From these values, the annual C and N input was calculated.

Every two years, soil samples were collected to determine soil organic C and N, water stability aggregates and particulate organic C. Infiltration was determined three times over the experiment. At the end of the trial, the inorganic N content was determined for barley and fallow plots down to 4m.

The long-term effect of CCs in weed suppression was assessed after 10 year of rotation. For that, soil samples were collected from each plot and seeds were extracted to evaluate the weed seedbank.

Besides, data coming from the field experiment were used to calibrate and validate a soil-water model (WAVE model, Water and Agrochemical in the soil and Vadose Environment, Vanclooster et al. 1996). Therefore, combining field data and modelling allowed the assessment of the CC impact on nitrate leaching under different soil and climate scenarios, including climate change conditions.

3 Results

Compared to the fallow, CCs promoted C sequestration at a rate of 180 kg C ha^{-1} year^{-1} and N retention at a rate of 13 kg N ha^{-1} year^{-1}. Differences between treatments on soil parameters were observed after 4 years of rotation. By the end of the experiment, barley showed the greatest water stable aggregates and highest infiltration rates. Barley reduced the inorganic N content in the soil profile compared to the fallow (García-González et al. 2018).

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The seedbank density and diversity did not differ between CC treatments, but differences were found for some species: *Xanthium* spp. density was higher in the fallow than in CCs. *Setaria* spp. density was greater in barley plots. Vetch had the highest density of *Lamium amplexicaule* L., and higher *Portulaca oleracea* L. and *Amaranthus* spp. than the fallow (Alonso-Ayuso et al. 2018a).

The calibration and validation of the WAVE model allowed the analysis of multiple scenarios. Cover crops reduced the nitrate leaching compared to the fallow, the largest reductions were observed in scenarios with conditions favouring large leaching periods. Under climate change scenarios, the differences in nitrate leaching between CCs and fallow would increase (Alonso-Ayuso et al. 2018b).

4 Discussion and Conclusions

Replacing the winter fallow by barley and vetch CCs contributed to enhance the soil quality in irrigated cropping systems while providing several ecosystem services as water quality preservation and the mitigation of climate change through C and N sequestration.

Although there were no differences in the weed seedbank density or diversity, the results indicated the relevant role of winter CCs in an integrated weed management tool, but warned that CCs are not expected to provide a complete control throughout the cash crop period.

The modelling experiment showed the relevance of CCs as a technique to reduce the nitrate leaching risk with respect to the fallow, and confirmed their potential role in the context of climate change adaptation.

Overall, this long-term experiment evidenced the importance of winter CCs in degraded soils under semi-arid Mediterranean conditions, whose implementation should be promoted.

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Multifunctional analysis of ecosystem services relative to the nitrogen fluxes provided by ten legume crops

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1 Introduction

In the context of agroecological transition, ecosystem services should be maximized to ensure agriculture production (Tibi and Therond, 2017). The provision of ecosystem services relies in particular on the reintroduction of spatial and temporal biodiversity (Isbell et al., 2011). Indeed, species diversity provides a variety of functions supporting ecosystem services. Legumes deliver unique and/or complementary functions to those of other groups of species. Specifically, they should play a key role in the provision of ecosystem services relative to nitrogen (N) fluxes when reintroduced in cropping systems mainly based on cereals. Indeed, legumes enable the production of protein-rich seeds. They also have the unique ability to establish a symbiosis with specific soil Rhizobium bacteria that leads to N accumulation during their growth through the symbiotic N_2 fixation process (Guinet et al., 2018). Legumes also supply N to the following crops through the mineralization of their N-rich residues (Angus et al., 2015). Nevertheless, some negative impacts can result from the introduction of legumes in cropping systems. Hence, their lower ability to retrieve soil inorganic N compared to cereals (Hauggaard-Nielsen et al., 2001) and the desynchronization between N supply by legume residues and the N demand of the following crop can lead to N losses by leaching during legumes growth cycle and/or after their harvest.

As a large diversity of grain legumes exist, an important issue is to characterize and distinguish them based on their ability to deliver functions supporting ecosystem services relative to nitrogen in order to assist the choice of legume species according to the expected objectives. However, the choice of grain legumes according to the provision of those ecosystem services remains difficult due to a lack of references for a diversity of species. The objectives of our study was i) to quantify N fluxes induced by legumes and to identify several explanatory plant traits of these N fluxes in order to establish the functional profiles of ten grain legume crops and ii) to better understand the synergy and trade-off between the different N fluxes and hence the explanatory plant traits.

2 Materials and Methods

Two field experiments lasting two years were carried at the INRA experimental site of Bretenière (Dijon, France) in 2014-2015 and 2016-2017. The first year (2014 and 2016), nine legumes were cultivated in absence of N fertilization: chickpea, common bean, common vetch, faba bean, lentil, lupin, Narbonne vetch, pea and soybean. In 2016, fenugreek was also cultivated. Seeds of the ten legumes were inoculated at sowing with species-specific strains of N_2-fixing bacteria to ensure symbiotic N_2 fixation. Two cereals were also sown as pre-crops for comparison with legumes. Legume and cereal seeds were harvested and residues were chopped and incorporated into the soil. No seeds were harvested for Narbonne vetch in 2014 and 2016 and for chickpea in 2016, due to climatic conditions unsuitable for seed production for these two species. The second year, winter wheat was sown in October as a following crop for each of the legume and cereal pre-crops, and was not supplied with N fertilization. Wheat was then harvested in July 2015 and 2017, respectively.

During the two year legume – wheat succession, five N fluxes were measured or estimated using the STICS model: 1) amount of N in harvested legume seeds, 2) amount of N derived from the air in legume shoots through the symbiotic N_2 fixation process, 3) amount of N derived from the soil in legume shoots through soil inorganic N uptake by the roots, 4) amount of N leached between legume harvest and wheat harvest, and 5) amount of N in the shoots of the following wheat. Legume plant traits considered as explanatory for these N fluxes were measured on legumes during the two field experiments or during a greenhouse experiment where the same ten legume species were cultivated in rhizotrons. For the ten legumes species, a redundancy analysis was performed using the five N fluxes as response variables and the plant traits as explanatory variables in order to study the link between the N fluxes and identify the most explanatory plant traits.

3 Results

Our results indicate that the amount of N in legume seeds and the amount of N derived from the air were positively correlated with four plant traits: legume shoot biomass, nitrogen harvest index (amount of seed N / total amount of shoot N), mean seed weight and seed N concentration. The two previous N flux were uncorrelated with the amount of N in the following wheat, which was negatively correlated with the legume residue C:N ratio. A clear antagonism between the amount of N leached after legume harvest and the amount of soil inorganic N retrieved by legumes was found. The latter N flux was positively associated with the root lateral expansion rate of legumes and the belowground nodule mass fraction (nodule biomass / belowground biomass).

Those profiles enabled to distinguish legumes with high ability to retrieve soil inorganic N during their growth cycle and with low N losses by leaching after their harvest (chickpea, common bean, and soybean) against species with low ability to retrieve soil inorganic N and with higher risks of N leaching (common vetch, faba bean, fenugreek, lentil, pea and Narbonne vetch). Yet, the latter legume species tended to induce higher amounts of N in the shoots of the following wheat in comparison to chickpea, common bean, and soybean. Finally, faba bean in 2016 and soybean in 2014 had the highest amounts of N derived from the air as well as the highest amounts of N in seeds compared to the other species.

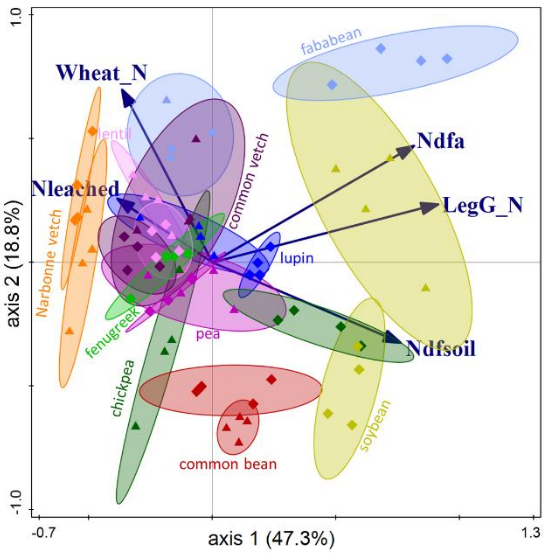

Fig. 1 Redundancy analysis (RDA) biplot of N fluxes and legume pre-crop treatments for the 2014-2015 experiment (▲) and the 2016-2017 experiment (◆). Ellipses show the 95% confidence interval associated with each legume pre-crop treatments in both experiments.
LegG_N: amount of N in harvested legume seeds; **Ndfa**: amount of N derived from the air; **Ndfsoil**: amount of N derived from the soil; **Nleached**: amount of N leached between legume harvest and wheat harvest; **Wheat_N**: amount of N in the shoots of the following wheat.

4 Discussion and Conclusions

Based on the simultaneous study of five N fluxes and several plant traits considered as determinant for the provision of the N fluxes, ten grain legume species were distinguished according to their functional profile. Hence, the characterization of grain legume species according to a combination of plant traits values enable to evaluate their potential abilities to deliver N functions and the resultant ecosystem services. Yet, negative impacts such as N leaching could be compensated by adequate agricultural practices such as legume-cereal mixture or the establishment of cover-crop during the fallow period. Lastly, variation within each legume species could be characterised in the future by measuring plant traits that were identify in this study, to select the right genotype in order to improve N transfers.

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Agro-ecosystem services and drivers of variability in their delivery from legumes in European cropping systems: a systematic review

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1 Introduction

The area of farmland under legume production in the European Union (EU) has steadily declined (with the notable exception of soya) in the last decades (FAOSTAT, 2018). Recently, it has been estimated that grain legumes occupy only 1.8% of arable land in the EU (Pelzer et al., 2017). This low percentage appears to indicate that despite the expected ecosystem service (ES) benefits of including legumes in cropping systems, various factors are dissuading farmers from doing so. Extension, policy, and marketing initiatives aimed at bolstering farmers' uptake of legume crops require sound scientific evidence of the role and benefits of legumes in sustainable farm management. Gaining an overview of what is already known about ES delivered by legume crops can both feed these knowledge needs and direct new research.

2 Materials and Methods

Here we present findings from a systematic literature review on ES delivered by legumes in European cropping systems, which we conducted in response to an observed lack of such a review. Additionally, we systematically identify and characterize drivers of variability in the delivery of ES, also previously missing from the literature. Following the Prisma method (Moher, Liberati, Tetzlaff, & Altman, 2009), we compiled a literature database containing 132 documents reporting on ES delivered by legume crops and legume-based cropping systems in the EU. We then collected meta-data from each document, including details such as experiment location and design, method of legume inclusion, crops studied, and ES measured. Analysis of the meta-data were done on the basis of descriptive statistics (e.g. counts and associations between study locations, crop combinations, and ES measured) to illuminate trends, themes, and gaps in the literature. We examined a random subset of the database literature (3-5 papers measuring each ES) and recorded the direction of the effect on ES delivery observed by the incorporation of legumes and the reported sources of variability in this delivery.

3 Results

Our analysis revealed that much of the literature is concentrated around a relatively small combination of possible ES, crops, legume inclusion methods, and experiment locations (Figure 1). Papers on production-related services (namely yield and produce quality) were the most prevalent, and these primarily reported on cereal—grain legume intercrop systems, with experiments located in five main countries (France, Denmark, United Kingdom, Switzerland, and Italy). Furthermore, we found that the services for which there are apparent knowledge gaps in the literature (namely pest, weed, and disease suppression) are the same services that farmers involved in a large, legume-focused EU research project (LegValue) indicated they needed information on in order to more successfully incorporate legumes into their cropping systems. Notably lacking from the literature were studies conducted at the farm, landscape, and regional scale which could provide insight into ES operating beyond the plot level, for instance pollination or services with cultural value.

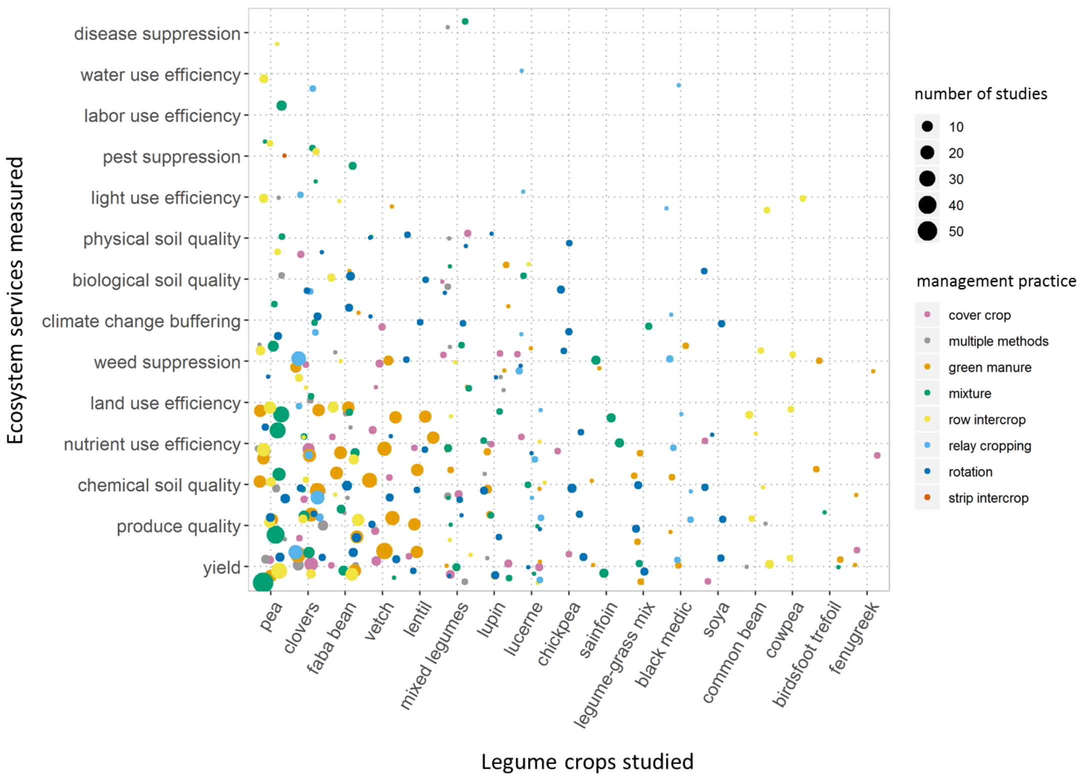

Figure 1. Matrix of associations observed in the literature database between legume species and ecosystem service measured. Dot color corresponds to the legume inclusion method (management practice) employed in the study. The larger the dot, the more studies on that combination.

A preliminary analysis of sources of variability showed that legumes can both enhance and detract from ES delivery, particularly for weed and disease suppression. This finding reinforces the need to focus research on these topics, as they are highly relevant for farmers considering new legume crops. Our survey of sources of variability also showed climate/environment, legume species and cultivar, and nitrogen fertilization (source, timing, and quantity) to be key drivers for many ES, indicating additional avenues for future research. Better understanding of sources of variability in ES delivery from legumes can be obtained through a quantitative meta-analysis of the literature in the database, for which an initial assessment identified 72 papers meeting inclusion criteria.

4 Discussion and Conclusions

The findings of this review point to an urgent need to extend and diversify research on ES from legumes to include those topics not yet well explored, rather than reinforcing known topic and context combinations. The apparent alignment between what farmers want to know and what is missing from the literature provides even more compelling stimulus to redirect research agendas and foster multi-actor engagement towards work that directly supports farmers in developing productive and sustainable legume-based cropping systems.

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Increasing cover crop benefits from the termination method choice in semi-arid Mediterranean regions

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1 Introduction

Winter cover crops (CCs) are considered an interesting tool to increase the sustainability of agroecosystems (Schipanski et al. 2014). Together with the species choice and the termination date, the CC termination method is a key management decision that can lead to differences in weed control, N dynamics or in the cash crop performance (Alonso-Ayuso et al. 2014).

The roller-crimping termination is an interesting practice that could be suitable for no-till systems and may lead to benefits in terms of weed suppression, soil quality increase or water conservation (Kornecki et al. 2009). In addition, it could be a way to reduce the use of burndown herbicides such as glyphosate. However, its termination efficiency has been reported to be challenging (Peigné et al. 2015); and its use and research in Mediterranean regions is still scarce.

2 Materials and Methods

A 3-year field experiment with a barley/vetch (*Hordeum vulgare* L. / *Vicia villosa* L.) CC mixture, followed by an irrigated corn (*Zea mays* L.) was performed in central Spain. Each year, the CC mixture was established in early October. Cover crops did not receive fertilizer or irrigation during their growing period.

The termination method and the weed post-emergence labors were the factors studied, using a split-plot randomized block design with 4 replications.

At mid April, the termination method took place and 3 treatments were studied: i) Roller-crimper pass; ii) Glyphosate application + roller-crimper, or iii) Mowing and incorporation.

Few days later, the corn was direct sowed. By May, the post-emergence treatments were established in the subplots: a) post-emergence herbicide, b) inter-row cultivator, c) post-emergence-herbicide + inter-row cultivator, d) without post-emergence treatment. The CC ground cover was monitored from October to April. Before the CC termination, the aboveground biomass was measured, and the C and N content determined.

In spring, the soil water content and soil temperature were measured in the topsoil layer. And the weed density and diversity were determined as well in each subplot. Regarding the cash crop performance, the corn N status was evaluated at flowering with an optical sensor, and at harvest the grain yield and N content were determined. Each experimental year, the N available use efficiency was calculated.

Besides, an energy consumption and an economic analysis were performed to evaluate the impact of the different CC management practices under other sustainability approaches.

3 Results

The CC termination with roller-crimper lengthened the period of soil covered during the cash crop cycle. Besides, the roller-crimper use increased the soil water conservation in spring, even in drought conditions, compared to the residue incorporation method. When combined with glyphosate, the roller-crimper decreased as well the soil temperature.

The use of roller-crimper showed to be less dependent on post-emergence weed labours than the incorporation method, to achieve a proper weed control and competitive grain yields.

The roller-crimper termination efficiency varied through the experiment depending on weather conditions. When the roller-crimper did not terminate properly the CC mixture, the post-emergence herbicide was essential to ensure high grain yields and grain quality values.

The CC managed with roller-crimper without glyphosate had the lower energy consumption values. However, the post-emergence herbicide was a key to get high energy productivity values.

In terms of costs, treatments including herbicides had greater economic costs in the rotation, but when the stochastic net benefits were calculated, the CC residue incorporation with the post-emergence treatments and the roller-crimper with glyphosate and post-emergence herbicide obtained the most positive results.

4 Discussion and Conclusions

Compared to the residue incorporation, the roller-crimper showed interesting environmental benefits as the enhancement of soil water conservation, the weed suppression or the energy consumption reduction, agreeing with other authors (Canali et al. 2013).

The main constraint of the roller-crimper was the low effectiveness for CC termination, that was solved by using glyphosate before passing the roller-crimper or a post-emergence herbicide application (Kornecki et al. 2009).

The CC termination effectiveness depended mainly on weather conditions, rather than on the CC phenological stage, being the regrowth risk high on wet springs. Thus, the results confirm the need to diversify the CC management strategies under semi-arid Mediterranean conditions. Due to the termination effectiveness, the use of the roller-crimper without herbicide support was riskier in terms of economic benefits, but when supported with herbicides, the roller-crimper achieved and stabilized favourable net benefits.

Overall, the fallow substitution by winter CCs is an interesting practice to diversify agroecosystems, and this work contributes to increase the understanding of the implications of the CC termination methods in semi-arid Mediterranean areas. The roller-crimper is a promising technique to increase the environmental sustainability, but more research is needed to design strategies that will maximize the potential and will solve the termination effectiveness challenge.

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Diversity of perennial legume-grass mixture influences the delivery of ecosystem services in organic arable cropping systems

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1 Introduction

Integration of perennial forage legume- and grass-based grasslands into arable cropping systems has demonstrated a great potential to enhance sustainable production and multifunctionality of agricultural systems (Lüscher *et al.*, 2014). However, cropping systems in Europe are largely dominated by cereals, and perennial crops are rarely included in intensive stockless cropping systems even though they may be highly valuable in a bio-based economy, e.g. for biorefining of proteins and sustainable production of bioenergy carriers (Jensen *et al.*, 2012). We performed a three-year field experiment with perennial forage legume and grass mixtures integrated in an organic arable cropping system, with the aim to determine how species choice and composition of perennial forage legumes and grasses, other than those commonly used in forage production, and cutting frequency would influence dynamics of biomass production, weed abundance and pre-crop value to a subsequent cereal crop.

2 Materials and Methods

The field experiment was carried out in an arable organic cropping system in Alnarp, Sweden (55°13′ N, 13°4′ E). The experiment was initiated in the spring 2010 by under-sowing four forage legume species; *Medicago sativa* (MS), *Melilotus officinalis* (MO), *Lotus corniculatus* (LC) and *Trifolium repens* (TR), and four grass species; *Phleum pratense* (PP), *Dactylis glomerata* (DG), *Festuca pratensis* (FP) and *Lolium perenne* (LP) as pure stands and mixtures of varied composition (Table 1) in oat (*Avena sativa*). The species mixtures were established in a replacement design, based on equal proportions relative to each species sowing density in pure stand. The oat was harvested in September 2010 and species mixtures were investigated in the first and second production years (2011 and 2012) under low (two cuts in both years) and high (four cuts in 2011 and three cuts in 2012) cutting frequencies. At each cut, above-ground biomass was manually sampled, sorted into legume, grass and unsown (weed) functional groups, dried at 60 ˚C and weighed. Finally, pre-crop value of the species and mixtures (without distinguishing between cutting frequencies) was determined in terms of grain yield of a subsequent spring wheat crop sown in spring 2013. The effects of species identity and mixture composition and cutting regime on measured variables was determined with analysis of variance (ANOVA) and TukeyHSD function in the R open source software.

3 Results

The total biomass yield, summed up for all cuts during the two years, was as high in mixtures as in the most productive legume or grass pure stand (Table 1). Weeds were suppressed in mixtures compared to most legume pure stands, especially under high cutting frequency. A six species mixture composed of three forage legumes and three grasses showed promising yield under both cutting strategies, reflecting a positive effect of diverse legume-grass mixtures in utilizing above-and below-ground resources. The species mixtures appeared to be more tolerant to high cutting frequency, especially when compared to pure stands of legumes (except LC). Yields of subsequent spring wheat ranged from 4 to 6 t grain ha^{-1} yr^{-1} (Table 1). Pure stands of legumes had higher pre-crop value to spring wheat than pure stands of grass and legume-grass mixtures, with the highest grain yield after pure stand of LC. The MS+PP, LC+PP and the four species mixture also showed a good pre-crop effect, comparable to most legume pure stands (with the exception of LC).

Table 1. Total biomass yield and weed biomass in pure and mixed stands of legumes and grasses in a two-year sequence (sum of all cuts in 2011 and 2012), and grain yield of subsequent spring wheat in 2013. Values are means of four replicates. Within each column, values followed by the same letter are not significantly different ($p<0.05$)

Species composition	Biomass production (ton DM ha^{-1})		Weed biomass (ton DM ha^{-1})		Wheat grain yield (ton ha^{-1})
	2 cuts/yr	3 or 4 cuts/yr	2 cuts/yr	3 or 4 cuts/yr	
Legume pure stands					
Medicago sativa (MS)	18.3 def	11.5 acd	1.9 ab	5.2 de	5.2 bcde
Melilotus officinalis (MO)	6.7 a	7.4 a	5.0 c	5.5 e	5.5 cde
Lotus corniculatus (LC)	14.2 cde	12.8 bcd	2.7 abc	3.6 bcde	6.2 e
Trifolium repens (TR)	6.9 ab	9.1 ac	4.2 bc	3.9 cde	5.7 de
Grass pure stands					
Phleum pratense (PP)	13.1 cd	13.9 bcd	2.8 abc	3.2 abcde	4.3 ab
Dactylis glomerata (DG)	12.8 bcd	13.0 bcd	0.3 a	0.7 a	4.2 a
Festuca pratensis (FP)	13.9 cde	13.5 bcd	1.9 ab	2.5 abcd	4.6 abc
Lolium perenne (LP)	11.6 abc	12.9 bcd	1.3 ab	1.9 abc	4.6 abc
Mixtures					
MS + DG	19.2 ef	16.1 bd	0.2 a	0.4 a	4.8 abcd
MS + PP	21.2 f	16.1 bd	0.8 a	1.9 abc	5.1 abcd
MO + PP	14.8 cde	14.3 bd	1.4 ab	1.8 abc	4.6 abc
LC + PP	17.4 cdef	16.8 b	1.7 ab	1.8 abc	5.0 abcd
TR + PP	16.4 cdef	16.0 bd	1.6 ab	1.6 abc	4.9 abcd
MO + MS + DG + PP	18.7 def	16.0 bd	1.6 ab	2.2 abc	5.0 abcd
MO + MS + TR + DG + FP + PP	19.2 ef	17.7 b	0.6 a	0.8 ab	4.4 ab
LC + MO + MS + TR + DG + FP + LP + PP	17.4 cdef	16.1 bd	0.6 a	0.7 a	4.7 abcd

4 Discussion and conclusions

Species mixtures had different effects on the evaluated ecosystem services, with the advantage of species diversity for biomass production and weed reduction being most pronounced in the six-species legume-grass mixture under both cutting strategies. However, when considering the pre-crop value, the two- four- and eight-species mixtures appeared more promising. This is an important insight about tradeoffs between different ecosystem services that need to be considered when designing diversified forage mixtures as multifunctional components of arable cropping systems. The study also highlights possibilities to optimize plant diversity for soil fertility build-up via legume N_2 fixation, resource-efficient biomass production, and weed reduction. These findings are in line with principles of agroecology, *e.g.* promoting crop diversity and multifunctionality while considering synergies and tradeoffs between different ecosystem services provided by diverse legume-grass mixtures in arable organic cropping systems.

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Diversification of crop rotation by cover crops enhances ecosystem services

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1 Introduction

Cover crops are seen as a solution to provide a number of ecosystem services and increase biodiversity. In crop rotations winter cover crops protect the soil from loss of nutrients, build the soil organic matter when ploughed into the soil and promote N recycling in the soil-plant system (Blanco-Canqui et al., 2015). Winter cover crops can inhibit weeds (Madsen et al., 2016) and diseases (Larkin and Griffin, 2007). They support beneficial soil organisms (de Cima et al., 2016) and natural enemies of pests (Kruus et al. 2012).

Improving soil properties with winter cover crops is essential and it is necessary to find and develop technologies that support them. To assess the effects of winter cover crops and their combination with composted manure on soil quality, weeds and beneficial soil organisms, in 2008 at Estonian University of Life Sciences an experiment was started.

2 Materials and Methods

The influence of different cropping systems on soil quality, weeds and beneficial soil organisms was investigated within a five-field crop rotation (barley undersown with red clover, red clover, winter wheat, pea, potato) in three organic and two conventional cropping systems. The system Org 0 followed the rotation. In organic systems Org I and Org II winter cover crops were used as follows: mixture of winter oilseed turnip (*Brassica napus* ssp. *oleifera* var. *biennis*) and winter rye (*Secale cereale* L.) before pea; winter oilseed turnip before potato and winter rye before barley. In Org II system composted cattle manure was also applied (for cereals 10 t ha^{-1} and for potato 20 t ha^{-1}). The two conventional systems were without winter cover crops: Conv I without fertilizers and Conv II with mineral fertilizers (all the crops received 25 kg ha^{-1} P and 95 kg ha^{-1} K; winter wheat and potato 150 kg ha^{-1} N, barley undersown with red clover 120 kg ha^{-1} N and pea 20 kg ha^{-1} N). Both conventional systems were treated with herbicides, insecticides and fungicides. The experiment was established in four replications, each plot (60 m^2) situated in a systematic block design. Organic (Org) and conventional (Conv) plots were separated with an 18 m long section of mixed grasses.

3 Results and discussion

Cropping systems were influencing the soil properties as important ecosystem services (Table 1). Although Org 0 and Conv I are both control systems, in organic system the organic carbon content (C_{org}) was on average 13 percent higher ($p< 0.05$) than in conventional system, where pesticides were used. In conventional system the synthetic pesticides inhibit the soil processes and cause the lower biological activity. In Org I and II systems the winter cover crops in crop rotation increase the biomass and activity of earthworms and soil microorganisms. The results show that the microbial hydrolytic activity (FDA) was higher in organic systems due to the higher amount of incorporated biomass from winter cover crops and weed biomass. The highest FDA was measured in system Org II because in addition to cover crops also composted manure was used. On average, the highest number and biomass of earthworms and collembola was also monitored in the Org II and it was significantly lower in both conventional systems.

Due to beneficial soil organisms, the organic compounds were decomposed and converted into plant-available nutrients. It improved the chemical and physical properties of the soil. In organic systems, total nitrogen, calcium, phosphorus and magnesium content were significantly higher compared to conventional systems. The highest content of nutritional elements was achieved in Org II system, where winter cover crops in combination with composted cattle manure were used (Table 1).

Mineral fertilizers, especially nitrogen, contributed to the soil acidification in the conventional systems. In organic systems, due to the effects of winter crops, soil pH increased. Our results showed that the soil pH $_{KCl}$ varied from 5.57 in Conv II system to 6.05 in systems with cover crops (Table 1).

Our earlier results (de Cima et al., 2015; de Cima et al., 2016) showed that winter cover crops improve the soil physical properties; soil structure and infiltration and by decreasing the soil bulk density.

Additionally, winter cover crops and manure increased the activity of ground beetles (natural enemies of pests) in organic systems. In our experiment the number of species of ground beetles was higher in organic systems with winter cover crops, compared to the conventional systems. This is partly due to the better wintering conditions for beetles offered by winter cover crops.

Table 1. Average soil properties of different cropping systems during 2013–2017

Soil properties	Cropping systems				
	Org 0	Org I	Org II	Conv I	Conv II
pH	5.95c	6.05d	6.04d	5.77b	5.57a
C_{org} ,%	1.51c	1.55cd	1.59d	1.31a	1.43b
N_{tot} ,%	0.124c	0.130cd	0.131d	0.100a	0.108b
P (mg kg^{-1})	108.7bc	107.8bc	111.2c	93.2a	102.5b
K (mg kg^{-1})	115.7b	116.3b	125.8c	105.5a	127.5c
Ca (mg kg^{-1})	1475b	1517bc	1563c	1276a	1217a
Mg (mg kg^{-1})	166.4b	179.7b	203.9c	106.9a	122.7a
FDA*(µg fluorescein g^{-1} soil h^{-1} in oven dry soil)	55.4c	57.0d	60.0e	48.5a	53.8b

Means followed by a different letters indicate the significant influence ($P < 0.05$) of cropping systems (Tukey test). * – average of 2012–2014.

4 Conclusions

It is possible to conclude that winter cover crops in crop rotation, especially in combination with composted manure, have a several beneficial effect on the ecosystem services: increased functional biodiversity (soil biological activity, natural enemies of pests) and improved soil properties.

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Energy Gain from Crop Rotation Depending on Included Crops

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1 Introduction

In Europe, half of arable land is sown by cereals, and the crop diversification is small. Higher cereal yields can be obtained by carrying out elementary agrotechnical measures, like appropriate soil tillage method and crop diversification in rotation helping to limit harmful organisms. Different field crops included in crop rotation can be compared by energy gain per ha from harvested yield, which can be determined using the energetic value (MJ kg^{-1}) of each included crop and yield of above ground biomass (t ha^{-1}). The aim of this paper was to compare the gained energy yields depending on different crop rotation schemes and soil tillage treatments.

2 Materials and Methods

The study was based on two season data (2016/2017 and 2017/2018) from two factorial long-term trials started in 2009 at the Research and Study farm 'Peterlauki' of Latvia University Life Sciences and Technologies (56° 30.658′ N and 23° 41.580′ E), in which two soil tillage methods (traditional and reduced) and three crop rotation schemes were included: (1) repeated wheat (*Triticum aestivum*) sowings (W–W), (2) oilseed rape (*Brassica napus* ssp. *oleifera*)–wheat–wheat (OR–W–W – two different variants each year), (3) faba bean (*Vicia faba*)–wheat–oilseed rape–barley (*Hordeum vulgare*) (FB–W–OR–B – three different variants each year). Meteorological situation in season 2016/2017 was satisfactory, but it was overly wet in the start of season 2017/2018; conversely, the amount of precipitation was extremely low and temperature extremely high, if compared with long term observations, in the spring / summer period in 2018. Only two years preliminary data for this paper was used. Yield of winter wheat, spring barley and spring faba bean was harvested by direct combining, but that of winter oilseed rape was detected from sample-sheet analysis. Yields of grain or seeds and straw were calculated as 100% dry matter (DM) yields. Straw yield was calculated from grain to straw ratio, which was obtained from sample-sheet analysis. Harvest index (HI) was calculated as a relationship between grain and the total aboveground biomass yield. Gross energetic value (MJ kg^{-1} of dry matter) was detected according to LVS EN ISO 18125:2017 for grain or seeds and straw. Energetic value of dry matter yield was used to calculate energy yield per ha (GJ ha^{-1}). Multi-way ANOVA was used for mathematical data processing with four investigated factors: year, crop rotation, forecrop and soil tillage. Research was financed by the Ministry of Agriculture of Latvia project „Influence of minimal soil tillage on its fertility maintenance, development and distribution of pests as well as crops' yield and quality in resowings" and the LLU project Z33.

3 Results

The highest grain and straw yields (t ha^{-1}) from studied crops in rotations were gained from winter wheat. Crop diversification in rotations (2) and (3) led to an increase of winter wheat grain yield, if compared to continuous wheat sowings. Multi-way ANOVA showed that winter wheat grain DM yields in two-year period were influenced by crop rotation ($p<0.001$) and forecrop ($p=0.017$), also straw DM yields were influenced by both the mentioned factors (crop rotation, $p<0.001$; forecrop, $p=0.033$) and the year ($p<0.001$). Average grain DM yield per all variants of wheat was 6.0 t ha^{-1} in 2017, and 5.3 t ha^{-1} in 2018, but average straw yields were 7.9 t ha^{-1} in 2017, and 5.1 t ha^{-1} in 2018. An average HI of wheat differed significantly ($p<0.001$) between years: it was 0.44 in 2017, and 0.51 in 2018. Hot summer of 2018 led to shorter stems and lower straw yield. Barley grain yield was 5.5 t ha^{-1} in 2017, and 2.7 t ha^{-1} in 2018, HI varied from 0.42 in 2017, to 0.46 in 2018. Yield of winter oilseed rape did not differ significantly between years – on average 2.5 t ha^{-1}; HI was on average 0.33. Faba bean yield, obtained only in 2018, was 2.2 t ha^{-1}; HI was 0.46.

When comparing the energetic values of the different crops included in studied rotations, it was found that higher energetic value was demonstrated by oilseed rape seeds (on average 27.9 MJ kg^{-1}). Similar values were detected for wheat and barley grains – 16.8 and 16.7 MJ kg^{-1} on average per both years, respectively.

Energetic value of faba bean seeds was 16.3 MJ kg^{-1} in 2018. Mathematically lower energetic values were obtained in 2018, if compared to 2017: by 1.1 MJ kg^{-1} lower for oilseed rape, 2.1 MJ kg^{-1} lower for wheat, and 1.7 MJ kg^{-1} lower for barley.

The energy yields (GJ ha^{-1}) calculated from energetic values and crop above ground biomass yield were directly related to crop grain or seed and straw yield. Total energy yield from two-year period was influenced by crop rotation scheme ($p<0.001$), forecrop ($p<0.001$) and year ($p<0.001$). Average energy yields differed significantly ($p<0.001$) also between years. It was by 35% lower in 2018 (139.5 GJ ha^{-1}) than in 2017 (216.6 GJ ha^{-1}). Higher average energy gain in 2018 was obtained from rotation (2), but the lowest from rotation (3). Wheat did not grow in rotation (3) plots in 2018 (yields of other three crops included in rotation were obtained), so it decreased the average yield for that rotation. However, if the total energy yield (from grain and straw) from each crop rotation two-year period was compared then the highest results were gained from four-crop rotation (3) period –**W–OR**– (437.6 GJ ha^{-1}), and from crop rotation (2) period –**W–W** (428.0 GJ ha^{-1}). Higher energy yields were gained in 2017, when wheat in rotation (3) and (2) had a yield increasing impact from forecrop: in rotation (3) from winter wheat sown after faba bean, and in the rotation (2), when wheat was grown after oilseed rape. A positive impact of oilseed rape on the second year wheat yield was also found in rotation (2) in 2018. In the mentioned cases, the energy yield increased due to crop diversification in rotation, because wheat yields in rotation (2) and (3) were higher than annual wheat yields in repeated wheat sowing (rotation (1)). Lower energy yields were calculated in 2018 in four-crop-rotation (3) period –**B–FB**– where spring crops were sown (barley and faba bean), because of drought at the earlier growth stages for spring crops –development of mentioned crops was disturbed, and it led to low grain and straw yield. Two year energy yield in rotation period –B–**FB**– was 289.3 GJ ha^{-1} (faba bean's energy yield was 76.8 GJ ha^{-1} in 2018), and from rotation period –OR–**B**– was 246.4 GJ ha^{-1} (barley's energy yield was 99.9 GJ ha^{-1} in 2018). Average two-year energy yield in repeated winter wheat sowings (crop rotation (1)) was 369.4 GJ ha^{-1}. Soil tillage method ($p=0.068$) did not affect energy yields. The study will be continued to get results from full crop rotation cycle, and even from several cycles in future.

4 Discussion and Conclusions

The energy gain from crop rotation in this study depended mostly on crop above ground biomass yield and calorific value of grain or seed and straw. In every case, crop diversification in rotation and use of non-cereal forecrop (oilseed rape or faba bean) for wheat showed an improvement of yield, if compared to wheat as forecrop. In Canada, similar conclusion was drawn that significant increase of energy output from crop rotations with similar included plants was obtained through the diversification of plants in rotation (Zentner *et al.*, 2004). Increase of total energy yield is possible by crop diversification and, in optimal conditions, of growth and development. Crop diversification can create benefits for the following plant if cereals are grown in rotation with oil crops and pulses, if compared with growing in monoculture (Darguza, Gaile, 2018). Differences of energy yields obtained from the whole crop rotation depending on soil tillage variant was not found in this research, and also other researchers did not mention them (Nagy *et al.*, 2000; Strašil, Vach, & Smutný, 2015); the effect of soil tillage differs between soil types and conditions during tillage (Darguza, Gaile, 2018).

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Mobilisation of functional properties of diverse legumes species at various scales in the CA-SYS Long Term Experimental Platform on Agroecology: expected services and prospects.

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1 Introduction

The sustainability of current European cropping systems is threatened by the massive use of synthetic inputs over the last decade and their negative impacts on environment and health. As an alternative towards multi-performant and sustainable agricultural systems, the agroecology principles are to value the ecosystemic services delivered by enlarged planned and natural biodiversity to sustain regulation and support services for agricultural production. Maximizing the biological functions provided by biodiversity requires to profoundly re-design agricultural systems, considering the management of both cropping systems within cultivated fields and their surrounding semi-natural habitats. Legume species have a major role to play, due to specific biological properties compared to other major crops (Voisin et al, 2014).

2 Materials and Methods

INRA has recently set up an ambitious long-term Agroecological System Experiment platform CA-SYS (www.inra.fr/plateforme-casys_eng/) that covers 125 ha near Dijon (France). It tests several prototypes of pesticide-free agroecological systems using cropped and wild biodiversity as mean to produce, targeting multi-performance from an agronomic, economic, environmental and social point of view. These new agroecological systems include fields of the four tested cropping systems and their interactions with adjacent semi-natural habitats in the landscape. The spatio-temporal arrangement of fields and semi-natural habitats will be managed through a coherent strategy, implemented to meet specific goals over time.

Four cropping systems combining a large diversity of farming practices were recently co-designed with a vast array of actors (farmers, extensions, researchers) to explore two main agricultural ways (with two different prototypes for each way) : i) no-plowing and cover crop based-systems inspired from conservation agriculture; ii) tillage and cover crop-based systems inspired from organic agriculture. These two options require to finely tune and manage biodiversity, across time (through crop rotations), and space (with species or variety mixtures), both within fields and their margins. All systems were designed to maximise the use of biological processes to halt pesticides and to drastically reduce the dependency to nitrogen and water.

3 Results

Legumes have a specific role to play in the delivery of the expected services: due to their specific ability to fix dinitrogen in symbiosis with soil bacteria, they have the unique ability to produce protein-rich seeds or forage, and to provide biological nitrogen to cropping systems. The mineralisation of their nitrogen-rich crop residues and the specificity of their rhizosphere also improve nitrogen cycling and provide mineral nitrogen to the soil, thereby limiting the need of external inputs for the other crops in rotations. One of the tillage-based system of CA-SYS targeting auto-fertility will not be fertilized with exogenous mineral inputs. Still, the cropping system has to be finely managed to limit potential losses and pollution linked to their shallow root system and to this surplus of N mineralisation. Especially, spatial and temporal arrangement with other crops should target a better synchronization between this nitrogen supply and other plant needs and ability to retrieve it.

As legumes are minor crops in current cropping systems, their development also contributes to the diversification of botanic groups, which contributes to break the biological cycle of pests and diseases frequently encountered in simplified cropping systems, and therefore to their regulation. Nevertheless, increasing the proportion of legumes in the rotation may increase their specific pests and diseases, which will have to be overcome and/or regulated in the tested systems. As dicotyledonous plants with flowers often rich in nectar, legumes are major plants contributing to nourishing and sheltering insects and pollinators both within fields and in semi-natural habitats.

The introduction of legumes in the CA-SYS platform was designed to value those specific properties, using a wide array of species, either in pure stand, in mixtures, as companion or cover crop or permanent cover in semi-naturel habitats (see Figure 1).

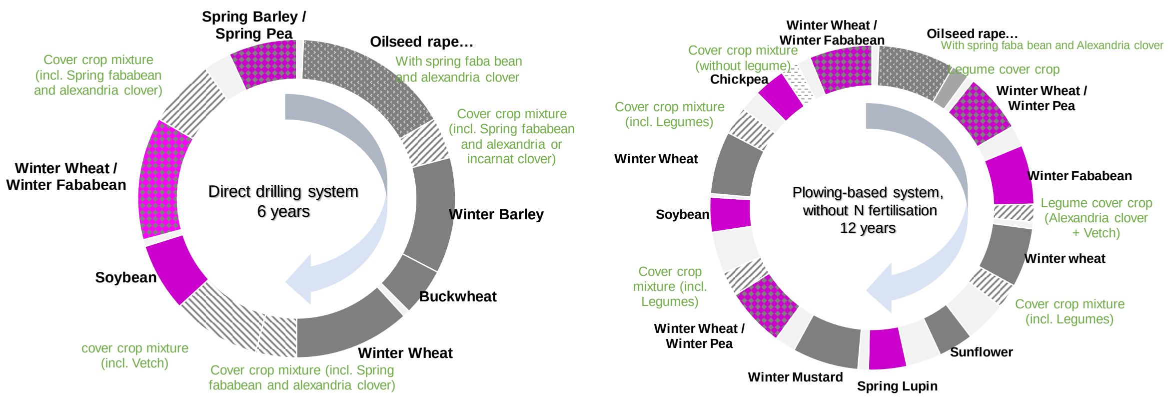

Figure1. Diversity of legume crop introduced in the cropping systems of the CA-SYS plate-form. Crop succession of a direct drilling system (left) and of a plowing-based system (right)

4 Discussion and Conclusions

New prospects linked to the development of more legumes in agroecological systems will also be raised, concerning: i) the management of their biological functions (and/or limitations) ii) methodologies and tools for the evaluation of their expected services and impacts, iii) breeding new varieties adapted to agroecological conditions. Embedded factorial experiments within the four systems tested will help in a better understanding of specific questions, such as the enhancement of beneficial plant-microbe interactions specific to or stimulated by legumes.

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DiverIMPACTS
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Impact of agro-ecological service crops and their termination modes on Soil Mineral Nitrogen dynamic at spring crop implantation

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1 Introduction

In Western Europe, winter fallow could last 9 months, for example between a winter wheat and a cabbage crop. On bare soil, the risks of erosion and nitrogen leaching are high. The introduction of winter cover crop or agro-ecological service crop (ASC) could deliver several benefits to the environment and the agricultural system. Indeed, ASC can improve the vegetable production in term of nitrogen recycling following ASC termination and input of atmospheric nitrogen by legumes in the ASC mixture.

2 Materials and Methods

During the winter 2016 - 2017, as part of the organic SOILVEG project, the performances of three ASC covers were compared in Wallonia (Belgium): pure barley (C), a mix of 70% barley and 30% pea (C7/P3) and a mix of 50% barley and 50% pea (C5/P5). Each ASC was destroyed by three termination modes: (1) chopped and incorporated like green manure (GM), (2) chopped and no-incorporated (CNI) and (3) flattened by roller-crimping (RC). The experimental design was a split-plot with the ASC factor as main plots and the ASC termination factor as sub-plots with four replications. An additional treatment was included in each block as a control with a bare soil (BS) during ASC season and tillage before plantation after several rotary harrow tillages aiming to control weeds. The cash crop following these ASC was red cabbage.

The ASCs were sowed on September 15th 2016. The termination dates differed between treatments: GM on May 5th, CNI on May 23nd and RC on May 31st 2017. Cabbage was planted on May 31st and harvested on October 25th and 26th. Cabbages were fertilized, with 60 kg ha^{-1} of nitrogen and 33 kg ha^{-1} of phosphorous, in all modalities, at the plantation, with commercial organic fertilizer. The fertilization rate was based on the residual soil N content in BS plots and the cabbage needs. Soil was sampled to evaluate soil mineral nitrogen (SMN) and water content to 30 cm depth before plantation and each month till the harvest of the main crop.

3 Results

ASCs reduced soil nitrogen and water availability by uptake for succeeding cabbage compared with BS. From the beginning of spring to June 2017, the SMN in BS were significantly higher than in GM, CNI and RC modalities (Figure 1).

The increase of the proportion of legume in the ASC increased, but not significantly, the SMN on June 12th 2017, at red cabbage implantation period, only under GM modality, where the C5/P5 presented an additional 11 kg N ha^{-1} in comparison to the two other ASC covers (C5/P5: 40 kg N ha^{-1}, C7/P3: 29 kg N ha^{-1}, C : 29 kg N ha^{-1}) (Figure 2).

The ASC occurrence and management mode impacted nitrogen and soil water availability at cabbage plantation, where SMN content of GM plots were significantly higher than CNI and RC plots (Figure 2). This difference is reflected significantly, among other, by aboveground cabbage biomass of 9, 5, 4 and 15 10^3 kg dry matter ha^{-1} for GM, CNI, RC and BS treatments respectively.

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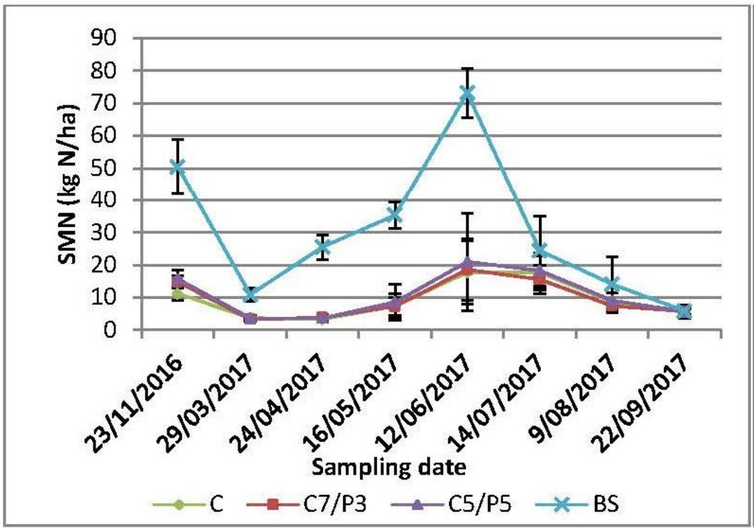

Figure 1: Soil mineral nitrogen content evolution (kg N/ha) in 30 cm depth under the different modalities. C = pure barley, C7/P3 = mix of 70% barley and 30% pea, C5/P5 = mix of 50% barley and 50% pea, BS = bare soil. Bars indicate standard deviation. SMN content in the soil before ASC implantation was in average of 49 kg N ha^{-1}

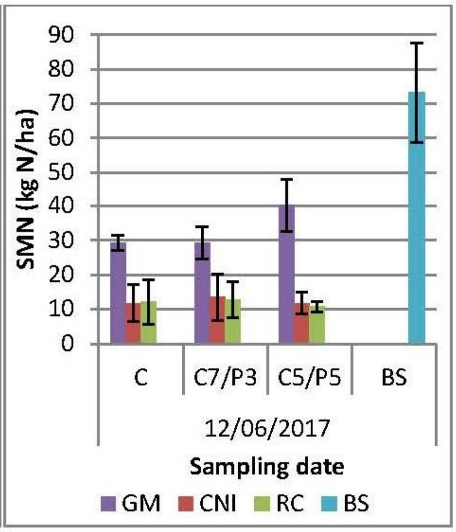

Figure 2: Soil mineral nitrogen evolution (kg N/ha) in 30 cm depth two weeks after cabbage plantation. GM = green manure, CNI = chopped and no-incorporated, RC = roller-crimping, C = pure barley, C7/P3 = mix of 70% barley and 30% pea, C5/P5 = mix of 50% barley and 50% pea, BS = bare soil. Bars indicate standard deviation

4 Discussion and Conclusions

ASCs reduce nitrogen leaching risk (Tonitto et al., 2006) but have a negative impact on nitrogen and soil water availability at cabbage plantation particularly when their destruction is close to the plantation date without incorporation into the soil (Mulvaney et al., 2010). The SMN in BS plots has been leached below 0-30 cm depth during the winter but, in April, mineralisation started again. This mineralisation may have been stimulated in the BS treatment due to tillage before plantation and to a better soil water stock in absence of ASC. The difference generated at the plantation remained till the cabbage's harvest. Legume in ASC can add nitrogen that can be valorised by the succeeding crop (Ranells and Wagger, 1996). This is observed under GM modality.

The ASC termination management and mode impact the SMN content at cabbage plantation. This can be explained by a more precocious termination and an incorporation of the ASC residues into the soil. In GM plots the termination was done approximatively 1 month before cabbage plantation and during this period the ASC did not take up SMN while ASC residues had started to mineralise. As in BS, the soil water stock could be rebuilt. In GM treatments, the nitrogen and water were therefore more available for cabbage than in CNI and RC plots.

In conclusion, the fertility management by the use of winter cover crops is influenced by several parameters such as the legume proportion in the ASC mix, the ASC termination date and mode. These parameters will impact the SMN and water availability at spring crop plantation. The results suggest that to improve the performances obtained under GM, CNI and RC management modes, nitrogen fertilisation should be adapted independently, for each modality, at plantation. ASC termination dates under CNI and RC modalities should also occur at an earlier stage.

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Can we expect reduced nitrous oxide emissions from soil in diversified cropping systems?

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1 Introduction

Reduction of greenhouse gas emissions from soil is one of the expected benefits for ecosystem services that could be provided by diversified cropping systems. There is a manifold of impacts by crop diversification on processes in soil that influence nitrous oxide production and reduction (Decock et al. 2015). Field data and the understanding of the processes is however limited and we expect the effects will be highly dependent on the kind of diversification applied.

2 Materials and Methods

DiverFarming measures the effect of diversification on greenhouse gas emissions in the field in several case studies. The measurements were performed manually on the field using static dark chambers and analysed on a GC system (Verhoeven and Six, 2014). The fluxes were calculated respecting non-linear chamber behaviour and visualised on a shiny web application (Hüppi et al. 2018). We will present observations from at least three DiverFarming case studies to elucidate the effects of diversified cropping systems on nitrous oxide emissions. Treatment effects of the different diversification schemes will be tested on the cumulative emissions of the covered dataset.

3 Results

Data from two field seasons will show nitrous oxide emissions from 3 different case studies. During emission peaks there are different trends among the treatments, with a tendency for reduced emissions in the diversified plots. However the upcoming field seasons and case studies will allow to confirm or infirm these observations.

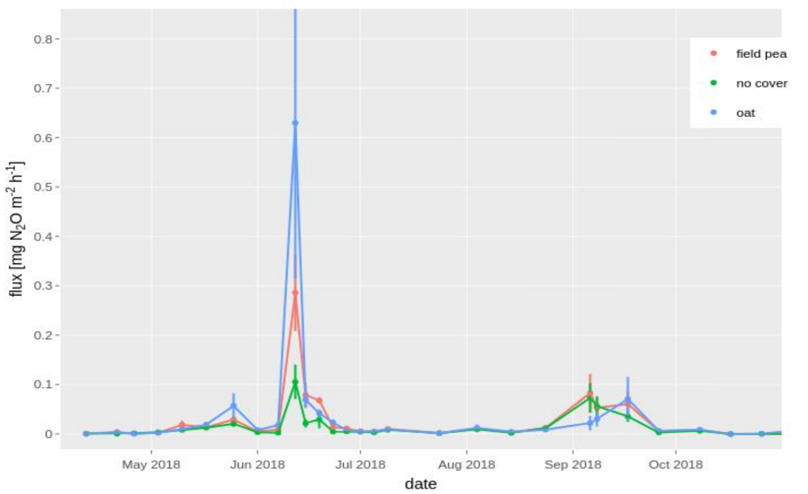

Figure 1. Exemplary nitrous oxide emission data from a case study in Hungary, where asparagus is growing with different kinds of intercropping (field pea, oat or no cover = control)

4 Discussion and Conclusions

Possible mechanisms to reduce those emissions are discussed from short term observations and with respect to how it could be reflected in models. The nitrous oxide dataset of the chosen DiverFarming case studies be limited to provide insights into mechanisms. We will study the literature and use our mechanistic understanding of nitrous oxide formation come with hypothesis of what can be expected.

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SESSION 10. NEW INTER AND STRIP-CROPPING: CROP AND ECOLOGICAL PERFORMANCES

Chairs: Guénaelle Hellou (ESA, France),
Eric Justes (CIRAD, France)

ORAL PRESENTATIONS

- Intercropped melon-cowpea organic system can improve melon yield and land equivalent ratio
  Speaker: Raúl Zornoza, Universidad Politécnica de Cartagena, Spain
- Trait combinations for efficient nitrogen utilization in pea-barley and wheat-faba bean plant teams field-grown in Sweden
  Speaker: James Ajal, Swedish University of Agricultural Sciences, Sweden
- Mobilizing within-field diversity for ecosystem service delivery in temperate arable systems
  Speaker: Lenora Ditzler, Wageningen University & Research, The Netherlands
- Grain legume-cereal intercropping increases the reliance on dinitrogen fixation in grain legumes and enhances soil N acquisition in cereal plants: A meta-analysis
  Speaker: Carolina Rodriguez Gonzalez, Swedish University of Agricultural Sciences, Sweden
- Impact of fertilization and legume sowing density on intercropped triticale-pea performances under organic farming - Synthesis of three years of trials
  Speaker: Didier Stilmant, CRA-W, Belgium
- Intercropping promotes both agronomic and ecological aims: the case of organic strip cropped cabbage (*Brassica oleracea* L.)
  Speaker: Juventia Stella, Wageningen University & Research, The Netherlands
- Weed species' competition for different N sources along gradients in a pea-barley intercrop
  Speaker: Ortrud Jäck, Swedish University of Agricultural Sciences, Sweden
- Exploring below-ground interspecific root-root interactions to understand advantage of intercropping in terms of productivity, nutrient use and soil fertility
  Speaker: Long Li, China Agricultural University, Beijing, China

POSTERS

- ReMIX: an opportunity to improve yield and stability of organic grain legumes for human consumption, providing ecosystem services.
  Presenter: Cristina Virto, INTIA, Spain
- Spatial and temporal variability of interactions in pea-oats mixed cropping on field-scale: Yield stability and nutrient use
  Presenter: Julian Zachmann, University of Hohenheim, Germany
- To mix or not to mix? Working on crop diversification in the silage maize dominated landscape in the Netherlands
  Presenter: Wijnand Sukkel, Wageningen University & Research (WUR), The Netherlands
- Intercropping of sunflower with legumes in relation to biological and productive properties of sunflower
  Presenter: Brankica Babec, IFVCNS, Serbia
- Objective depended successes for pea-wheat strip intercropping
  Presenter: Wijnand Sukkel, Wageningen University & Research (WUR), The Netherlands

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Intercropped melon-cowpea organic system can improve melon yield and land equivalent ratio

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1 Introduction

Including legumes in intercropping systems may be a good alternative to the maintenance of soil fertility, increase the biodiversity and soil organic matter, and reduce the use of N fertilizers, which is linked to lower greenhouse gas emissions. Cowpea (*Vigna unguiculata* L. Walp) is a grain legume native of southern Africa, although it is widely consumed all around the word (Singh, 2014). It is a species well adapted to stressful environments associated with high temperatures, drought or low fertility, and so is considered a suitable alternative crop in arid and semiarid regions (Chikoye et al., 2014). Hence, the aim of this study was to assess the effect of different combinations of intercropped melon (*Cucumis melo*) with cowpea (*Vigna unguiculata*), with decrease of external inputs on crop yields, land equivalent ratio (LER) and crop quality parameters under Mediterranean semiarid conditions.

2 Materials and Methods

This study was carried out in Cartagena, SE Spain, with semiarid Mediterranean climate. We compared a melon monocrop with different melon-cowpea intercropping systems in summer 2018: Row intercropping 1:1 (melon:cowpea), row intercropping 2:1 (melon:cowpea) and mixed intercropping. The field experiment was designed as a randomized block with three replications, and each plot had 150 m^2. Monocrop system was included in a separated block, distant 200 m from intercropped systems to avoid the influence of the attraction of insects by the growth of cowpea. Melon seedlings were planted in a density of 0.4 plants m^{-2}, with a spacing of 200 cm between rows and 120 cm between plants in all plots (monocropped and intercropped systems). Cowpea seeds were sown between two rows of melon in the row intercropped systems, spacing 100 cm between melon and cowpea rows. Under row intercropped systems, cowpea was separated 20 cm plants in the same row. Density of plants was 2.5 plants m^{-2} and 1.5 plants m^{-2} in the row 1:1 and row 2:1 systems, respectively. In the mixed system, cowpea was sown in all melon rows between two melon plants, and so in a density of 0.4 plants m^{-2}, with a spacing of 200 cm between rows and 120 cm between plants. So, density of melon was the same in the different treatments, but the density of cowpea changed. All crops were drip irrigated and grown under organic management. In intercropped systems we reduced the fertilizers rate by 30% compared to melon monocrop. Melon and cowpea were simultaneous harvested from 31 July to 10 August. Harvest was carried out manually as traditionally performed in the area to avoid damages in the melon fruits, since they lie on the soil. To calculate the land equivalent ratio, a cowpea monocrop was established at the density of 5 plants m^{-2}, with a spacing of 100 cm between rows and 20 cm between plants, the traditional pattern of this crop.

3 Results

Intercropping combinations significantly increased melon yield, the number of melons per hectare and the average weight of melons (Figure 1). Melon yield increased by 34 to 70%, compared to melon monocrop, and marketable yield by 40-80%. The best intercropped system for this parameter were the row 2:1 and mixed intercropping, with values of 24759 kg ha^{-1} and 26272 kg ha^{-1}, respectively (Figure 1A). Increases in crop yield were associated to increases in the number of melons per plant and in their size. The number of melons per hectare increased up to 6556, 7722 and 8278 in the row 1:1, mixed intercropping and row 2:1 systems, respectively, compared to the 5605 melons per ha in the monocrop (Figure 1B). The weight of melons significantly increased compared to monocrop (3.21 kg) in all diversified systems without significant differences among them, with values ranging from 3.70 to 3.90 kg (Figure 1C). No significant differences in melon quality parameters were observed, except for sugar content, that was slightly higher in the monocrop

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melons (13.1%), compared to intercropped systems (12.4-12.6). LER was 1.82, 1.91 and 1.89 for 1:1, 2:1 and mixed intercropping, respectively, highlighting the significant increase in land productivity when intercropping melon with cowpea.

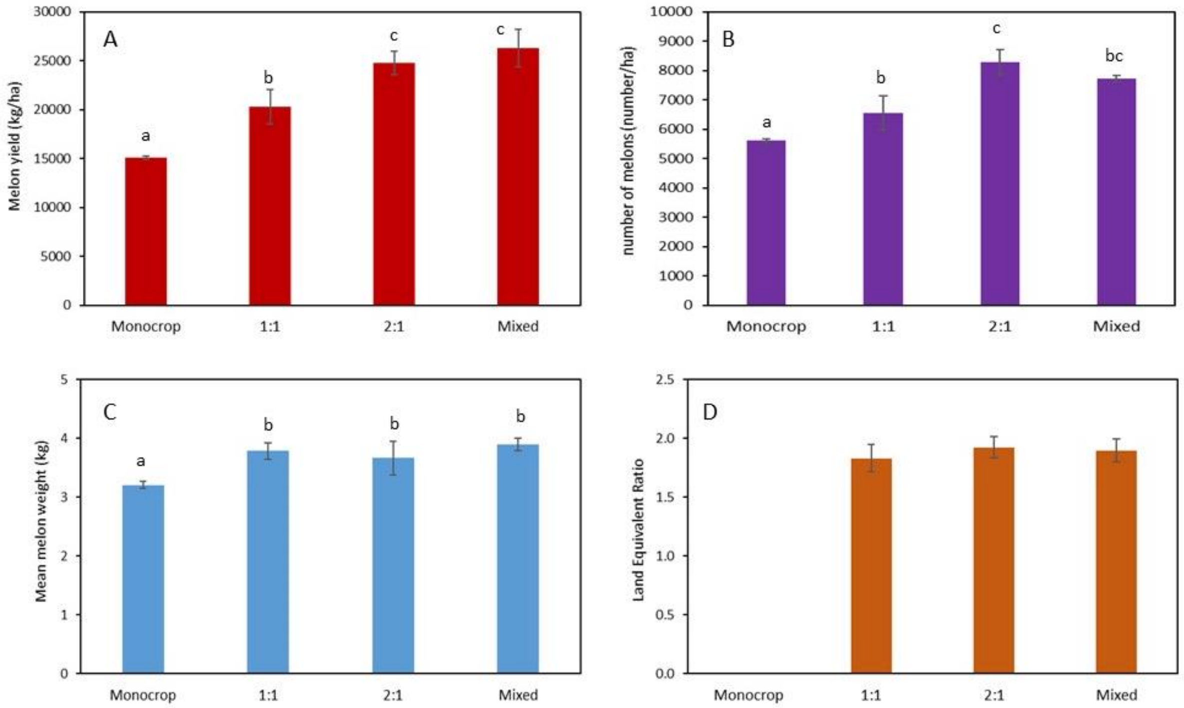

Figure 1. Melon yield (A), number of melons (B), mean melon weight (C) and land equivalent ratio (D) of the melon monocropped and intercropped systems under organic management. Vertical bars denote standard error. Different letters above bars indicate significant differences among systems after Tukey post hoc test at $p < 0.05$.

4 Discussion and Conclusions

Melon crop needs pollinators to sustain high production throughout an increase of the number of melons per plant. The flowering of cowpea attracts numerous insects, which many of them are pollinators and beneficiary organisms. As cowpea flowering coincided with melon flowering we can hypothesize that the presence of cowpea flowers will facilitate melon flowers pollination, contributing to increase the number of melons per plant. In addition, cowpea crop has a very active rhizosphere, with intense rhizodeposition that activates microbial populations, with the capacity of mobilizing soil nutrients (Sánchez-Navarro et al., 2019). Cowpea is also able to fix atmospheric nitrogen, contributing to increase soil fertility. These characteristics of cowpea could be responsible for the increase of the average size of melons in the intercropped systems, since nutrients were likely to be more available. These two factors favoured the increase of melon yield in the diversified cropping systems. As melon yield was increased compared to monocrop, and there was an additional production of cowpea, LER was almost 2 in intercropped systems. Thus, the introduction of cowpea in intercropping with melon resulted in a sustainable system, with decreases in the use of external inputs while increasing melon yield and LER, with no negative effect on melon quality.

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Trait combinations for efficient nitrogen utilization in pea-barley and wheat-faba bean plant teams field-grown in Sweden

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1 Introduction

Under current climate scenarios, achieving reasonable crop yield has increasingly become difficult without using large amounts of nutrient fertilizer inputs. These high-input systems are characterized by large amounts of nutrient loss, especially nitrogen to lower soil layers and groundwater, which have detrimental environmental effects. Promoting farming methods that encourage efficient resource use will ensure more sustainable ways of producing food without compromising yield or quality of product. Production methods that maintain or increase diversity in the field have shown great potential in stabilizing yields and increasing resilience under changing environments, without much reliance on external nutrient inputs. Mixed cropping is most widely used, partly because mixed species or cultivars utilize the synergy that may result from the morphological, architectural or physiological differences that the species or cultivars grown in the mixture possess. Specifically, the use of legumes in cereal-legume based species mixtures (or plant teams) have been associated to increased yield and improved grain quality through a better utilization of nitrogen (N). These positive attributes on yield and quality may be explained by beneficial interactions of the mixture components through their different functional traits. For example, enhanced N uptake is found to occur in non-legume (cereals) components when grown together with legumes.

The objective of this study is to investigate mechanistic explanations linking trait interactions and N utilization to the productivity of selected cereal-legume plant teams grown under Swedish conditions. We hypothesize that plant teams with a greater functional trait space enhance N uptake and utilization, resulting in higher growth and yield *(H1)*; and yield advantages in plant teams as compared to the corresponding pure cultures are correlated with the specific abilities of the team components to compete for, and utilize, the available N *(H2)*.

2 Materials and Methods

Field experiments were established in the 2017 and 2018 growing seasons in Uppsala, Central Sweden. The region is characterized by cold temperate climate with spring-sown crops favourably growing between May and September. Average temperatures during the growing season range between 5°C to 25°C. However, 2018 was an exceptionally dry year receiving only two rainfall events (7 mm in total) before the onset of flowering. The two consecutive year trials with the same plant teams were intended to explore inter annual variability in the plant team performance. The study was carried out in the context of the EU Horizon 2020 project "Designing InnoVative plant teams for Ecosystem Resilience and agricultural Sustainability (DIVERSify)". The cereal-legume mixtures comprised of pea-barley and wheat-faba bean teams sown in a replacement design at 50:50 proportion of the cereal-legume components. For each cereal component, three cultivars were used; and two cultivars were selected for the legume component. The plants were subjected to two fertilizer treatments; unfertilized control and additional N, phosphorus (P) and potassium (K) of 90, 15 and 29 kg ha^{-1}, respectively, in the pea-barley teams; and unfertilized control and additional N, P and K of 140, 24 and 46 kg ha^{-1}, respectively, in the wheat-faba bean teams. Periodic harvests at flowering and maturity were done to monitor plant team performance. Additionally, N accumulation efficiency was calculated to link resource utilization to productivity.

3 Preliminary results

During the growing period, additional nutrients in the high input system did not give a consistent yield increase to the components in the mixture (Table 1). The yield difference between pure barley culture grown under the low and high input systems ranged between 0.2 to 0.5 t ha^{-1} in 2017, with even lower yields differences recorded in the 2018 growing season. Wheat grown as pure culture followed a similar trend.

Within each nutrient treatment however, irrespective of the growing season, the cereal partners performed better in mixtures than the corresponding pure cultures except for wheat (cv. Diskett) that yielded 0.1 t ha^{-1} less when grown with faba bean (cv. Fuego) in 2018. The legume partners however did not profit from species mixing as lower yields were obtained in mixtures compared to pure cultures in all cases.

Table 1. Mean ± SD of grain yield (t ha^{-1}) for selected cereal-legume plant teams grown under low and high nutrient input in the 2017 and 2018 growing seasons in Uppsala, Sweden.

	2017				2018			
	Low input		High input		Low input		High input	
Plant teams	*cereal*	*legume*	*cereal*	*legume*	*cereal*	*legume*	*cereal*	*legume*
pea+ barley								
Barley RGT Planet	2.4±0.7		2.9±0.9		0.6±0.4		0.8±0.1	
Barley Tamtam	2.7±0.6		2.9±0.3		0.8±0.1		0.9±0.1	
Pea Ingrid		0.9±0.2		1.0±0.4		1.6±0.2		1.6±0.1
RGT Planet+Ingrid	4.4±0.9	0.7±0.3	3.1±1.0	0.7±0.3	0.9±0.3	1.5±0.4	1.1±0.1	1.4±0.3
Tamtam+Ingrid	3.7±1.9	0.8±0.5	4.1±1.1	0.8±0.2	0.9±0.1	1.4±0.3	1.4±0.2	1.3±0.2
Faba bean+ wheat								
Wheat Diskett	1.8±0.6		1.9±0.9		1.4±0.2		1.8±0.3	
Wheat KWS Alderon	2.8±0.8		2.9±0.8		1.9±0.2		2.2±0.2	
Faba bean Fuego		1.7±0.4		1.8±0.3		1.5±0.2		1.4±0.3
Diskett + Fuego	2.5±1.0	0.8±0.3	3.2±0.9	1.0±0.2	1.3±0.7	1.2±0.2	2.4±0.9	1.1±0.6
KWS Alderon+ Fuego	4.3±0.8	1.0±0.2	4.5±1.7	1.0±0.2	2.9±0.3	0.9±0.1	3.0±1.2	0.9±0.0

Compared to the lowest-yielding teams, the most productive teams included cereal components producing many tillers and thus supporting a greater functional trait space (e.g. *H1*). Additionally, wheat and barley tiller number was positively correlated with the amount of N accumulated over the growing season (e.g. *H1 & 2*).

4 Discussion and conclusions

The lack of yield increase in response to additional nutrient supply is likely attributed to adequate levels of soil available N even in the low nutrient treatment of this experiment. The generally low yield in the 2018 growing season is attributed to the long dry period experienced during that year. In general, the diversity in e.g. tiller number among the cereal cultivars investigated here contributed most to the performance of the plant teams; supporting the hypothesis that greater functional trait space (here accomplished by the cereal partner) is associated with greater yield *(H1)*. Higher tiller number in the cereal partners was associated with increased resource exploitation capacity, here reflected by increased N pools, linking this trait to both N economy and the observed yield advantage in the best performing teams (*H1 & 2*). Nitrogen is known to boost tiller number in cereals (Wang et al., 2017), and consequently the productive tillers give rise to more leaves that further increase light interception and photosynthetic surface area.

In the systems evaluated, cereals were greater beneficiaries of positive interactions and contributed most to the observed yield advantage through enhanced functional trait space, but the magnitude of the benefit depended on the specific combination of mixture components. Cereals with larger number or plasticity of productive tillers have a greater capacity to accumulate more N in plant biomass, and the relationships identified might provide an example for a mechanism linking trait interactions and N utilization to the productivity of cereal-legume plant teams.

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Mobilizing within-field diversity for ecosystem service delivery in temperate arable systems

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1 Introduction

In Europe as elsewhere, mechanization and economies of scale have driven a shift towards very large mono-cropped arable fields. While external inputs enable a controlled, automated, and uniform approach to managing these fields, abundant use of such inputs has led to a cascade of failing ecosystem controls and the overstepping of planetary boundaries (Rockström *et al.*, 2009). We posit that the industrial arable field can be redesigned to utilize ecological processes in place of external inputs using a combination of diversity measures operating in three dimensions: spatial, temporal, and genetic. The rationale for activating these dimensions is grounded in theory and evidence of how biodiversity supports and enhances ecological control processes (Robertson *et al.*, 2014; Tittonell, 2014). Here we showcase an application of a three-dimensionally diversified field design (strip cropping) and analyze this system's delivery of targeted ecosystem services. With empirical data from two long-term experiments in the Netherlands (2012-2017), we examine the effectiveness of stacking multiple crop diversification dimensions to mitigate disease spread (*Phytophthora infestans*) in potato and enhance biocontrol potential in wheat.

2 Materials and Methods

The experiments were located at the Broekemahoeve Proeftuin near Lelystad and the Droevendaal Experimental Farm in Wageningen and both managed according to organic regulations. At both locations and for both potato and wheat, three experimental treatments were tested: 1) large-scale sole-cropped reference fields, 2) sole-cropped, single cultivar strips, and 3) mixed strips. For potato, mixed strips consisted of a cultivar mixture which included one non-*PI* resistant cultivar and two *PI*-resistant cultivars. For wheat, mixed strips were sown as a polyculture including wheat and faba bean in an additive design. All strip treatments were 3 meters wide. In potato, *PI* infection was visually monitored and scored from first observed infection date until crop termination. In wheat, the activity density of epigeic natural enemies of aphids was assessed using pitfall trapping at regular intervals throughout the growing season. Treatment differences were analyzed using generalized linear mixed models and cross-year comparisons were conducted using effect size metrics applied in meta-analyses of ecological data (Fox *et al.*, 2015).

3 Results

We found that *PI* infection in potato was significantly lower in strips ($p < 0.001$) than in the reference across all years at the Broekemahoeve experiment. Additionally, within a single growing season at Droevendaal, the rate of disease spread was slowest in mixed-cultivar strips compared to the reference ($p < 0.01$). These results show that for potato, the stacking of spatial (strip arrangement) and genetic (cultivar mixing) strategies did multiply the benefits of diversification.

In strip-cropped wheat we found larger catches of all epigeic natural enemy groups except Pterostichus ground beetles compared to the reference, pointing to strong biocontrol potential linked to spatial diversification. However, including faba beans in the wheat strips did not significantly increase natural enemy abundance compared to sole wheat strips. Catches in strip treatments scored significantly better ($p < 0.001$) than the reference on two diversity indices (species richness and Shannon diversity), but again there was no difference between sole- and mixed-species strips. In the case of wheat, stacking genetic diversity with spatial diversity did not further enhance biocontrol potential.

4 Discussion and Conclusions

The example of strip cropping provided here illustrates that different dimensions of diversity are needed to activate the delivery of different ecosystem services, as ecological processes operate at different scales. The movement of *PI* spores occurs at a finer resolution (plant—plant) than the movement of epigeic arthropods, so implementing two diversity measures at once returned increased benefits to disease mitigation. Arthropods operate at a wider range (> 1 m), so while the strip arrangement led to greater abundance of most natural enemies, adding a finer resolution of diversity by introducing a polyculture did not further increase the abundance of these organisms.

These results point to the importance of designing cropping systems such that the activated diversity dimensions affect the ecological process scales of the desired ecosystem service(s). Here we show that in some cases, strip cropping single species and cultivars may be enough to deliver the desired service, but in others the addition of the genetic dimension may be beneficial. Overall, we conclude that strip cropping is a promising strategy for mobilizing the benefits of within-field crop diversity to enhance ecological control potential in temperate cropping systems, particularly because it can be implemented within the mechanical constraints of current farm technology.

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Grain legume-cereal intercropping increases the reliance on dinitrogen fixation in grain legumes and enhances soil N acquisition in cereal plants: A meta-analysis

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1 Introduction

Grain legumes such as peas, beans and lentils provide valuable ecosystem services via the provision of high-quality food and feed, symbiotic nitrogen fixation and promote other ecosystem services through enhancing crop diversification.Yet, grain legumes cover low areas in European agriculture. One reason is that grain legumes have lower yield stability than dominant crops, such as cereals. Intercropping is an agroecological practice, in which several crop species are grown simultaneously in the same field, which pursues to maximize the use of growth resources to enhance yields and the resilience of cropping systems. This practice helps to increase productivity and yield stability, and to reduce environmental impacts of current cropping systems. The aim of this study was to systematically review the effects of intercropping on the N use by grain legume and cereal plants in temperate agroecosystems.

2 Materials and Methods

We conducted a meta-analysis using 207 paired observations from 29 studies to (i) quantify the overall effect of grain legumes-cereals intercropping on the use of N_2 fixation in legumes, and soil nitrogen acquisition in the cereals and legumes compared to the sole crops, and (ii) assess how different intercrop designs, crops species, and management practices influence these responses. The meta-analysis was comparing the log ratio of responses in the intercrop and in the sole crop. The log ratios were weighted by the standard deviations and sample sizes provided by the studies. In cases where the original study did not report measures of standard deviation, we applied a simple imputation using the mean of the existing variance values to account for these missing vales. Mixed effect models were used to estimate mean log ratios and explain the between-study variability of the response using various moderators such as intercrop composition, fertilization rates, legumes species, soil properties, management practices and previous crops. Levels of statistical significance and 95% confidence intervals were reported for each response and each moderator [1].

3 Results

The proportion of N derived from N_2 fixation was, on average, 15.7% (95% confidence interval (CI) = [11.1, 20.4]) higher for the intercropped grain legumes compared to legume sole crops. Intercropping reduced the amount of N_2 fixed by (-13.2%), but the effect was not significant (95% CI = [-25.6, 1.4]). The magnitude of the effects on N_2 fixation varied across legumes species, intercrop compositions and the method used to calculate N_2 fixation. Soil nitrogen acquisition in intercropped grain legumes was significantly reduced by (-58.1%) compared to sole crop legumes (95% CI = [-66.5, -47.5]), while the soil N acquired by the intercropped cereal was 53.4% higher than the sole crop cereal (95% CI = [20.2, 95.6]). However, the total soil N acquisition was not higher in intercrops than in cereal sole crops. In addition, we found significant effects of intercrop composition, nitrogen fertilization rates and soil type on the differences in soil N acquisition between sole crops and intercrops.

4 Discussion and Conclusions

These results highlight that intercropping consistently stimulate complementary N use between grain legumes and cereals. Thanks to the efficient acquisition of soil nitrogen in cereals, intercropped grain legumes rely more on biological dinitrogen fixation than grain legume sole crops. Furthermore, since grain legumes are generally weak competitors for soil nitrogen, intercropped cereals increase their per-plant nitrogen acquisition, especially in intercrops where the cereal sowing density is lower than in the corresponding cereal sole crops. Several ecological mechanisms may act in synergy in grain legume-cereal intercrops: reduced within-species competition and increased competition and complementarity between species, leading to a more efficient overall use of biologically fixed and soil-derived nitrogen resources. As a consequence, grain legume-cereal intercropping makes it possible to save external nitrogen inputs with maintained total crop nitrogen acquisition. Along with previous studies showing that yield stability is improved in grain legume intercrops compared to sole crops [2], this meta-analysis demonstrates that intercropping has clear advantages in an agroecological perspective. Resources are used more efficiently, with potential benefits for farm-level profitability, lower risk of environmentally harmful nitrogen losses, and lower greenhouse gas emission associated with reduced nitrogen fertilizer rates. These findings highlight the contributions of cropping systems diversification via intercropping to enhanced sustainability in grain legume and cereal production.

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Impact of fertilization and legume sowing density on intercropped triticale-pea performances under organic farming – synthesis of three years of trials

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1 Introduction

Due to lower and less regular yields and in spite of numerous advantages (N fixation, protein content in the plant, cereal diseases and pest limitation…), grain legumes are rarely cropped in Walloon area. Nevertheless, in low inputs farming systems they play, based on their symbiotic N_2 fixation proprieties, a key role to sustain soil fertility (Bedoussac *et al.* 2015). In this context, in order to counter poor competitiveness of legumes against weeds, to limit pest and diseases development and/or to limit lodging risks, peas are often associated to cereals in intercropping schemes. Now, it is difficult to reach an interesting pea density in the harvested mixture, not to high, in order to limit lodging risks, especially with fodder pea, and not to low, in order to have a real added value and contribution of the legume to N delivery to the system.

In order to modulate final pea content in the mixture and global yield, we propose to test the impact of three different pea sowing densities, both for protein pea and fodder pea, and of three different levels of fertilization at the end of winter.

2 Materials and Methods

To explore these strategies, a trial was set up during three cultural years (2014, 2015 and 2017) in Ardenne (loamy-rocky soil; 450 m above sea level; 1100 mm average annual rainfall and 7.5°C as average annual temperature). Fodder and classical peas were tested in association to triticale (×*Triticosecale* Wittm.). Previous crop was spelt (*Triticum spelta* L.). The experimental scheme was a split-plot design in four blocks. Pea type (fodder vs protein pea) was the main plot parameter.

Triticale (cv. 'Sequenz' and 'Borodine' in 2014 and 2015, respectively) was sowed at 350 seeds m^{-2} in association to fodder pea (cv arkta). The three doses (Low – Inter – High) tested for the fodder pea were 15, 20 and 25 seeds m^{-2} on first year and 10, 15 and 20 seeds m^{-2} on the second and third years. In association to protein pea (cv James on the first year and Enduro on second and third years), triticale was sowed at 210 seeds m^{-2} (60% of the full dose) in association to 60, 80 or 100 seeds m^{-2} for pea.

The three levels of N fertilisation tested; 0, 40 and 80 kg ha^{-1}, were applied during the first month of spring, through the application of Orgamine (7-5-10+2), simultaneously to weeding intervention with a light harrow. As organic fertilisers also deliver P and K, contrasted N fertilisation schemes also led to contrasted P and K fertilisation schemes with gradients of 0 – 29 – 57 units for K_2O and 0-57-114 units for P_2O_5.

Fresh and dry yields were quantified. In parallel, two kilograms of triticale/pea grains mixture were sampled, per parcel, to quantify, by NIRS, on the mixture and on each of its components (pea grains and triticale grains), DM, ash, protein, starch, and cellulose contents. Parameters analysed were the grain yield, the protein content of the mixture, the cereal protein content and the legume/cereal proportions in the harvested mixture.

The results reported hereafter relate to the two first years of testing.

3 Results

On average, grain yields recorded in 2014 (1929 and 3272 kg ha^{-1}) were lower than 2015 yields (6652 and 6796 kg ha^{-1}) for associations with fodder and protein pea, respectively. These yields were not impacted ($p>0.19$) neither by pea sowing density nor by N treatment. Nevertheless, associations with fodder pea led to significantly lower yield ($p<0.04$) in 2014 (-41.0%) where we observed a trend ($p=0.08$) of yield decrease in parallel to legume sowing density increase, probably due to lodging sensitivity of fodder pea associations and to the late harvesting under bad weather conditions. Huge yellow rust pressure observed on triticale, in 2014, would also contribute to the globally low yields recorded that year.

At the opposite to yields, harvested association compositions, in terms of pea/cereal proportions, mixture protein content and cereal protein content, were significantly impacted by sowing densities and/or NPK fertilisation (Table 1). In average, an increase of legume sowing density by 66% (ratio between maximum and minimum pea sowing densities) or more (fodder pea associations in 2015) led to a parallel increase of 129 [70 to 169] g $kgDM^{-1}$ of the pea content and of 16.5 [11 – 23] g $kgDM^{-1}$ of the protein content in the harvested mixture. Nevertheless, main part of the increase (75% for pea content in the harvested mixture and 66% for protein content) occurred when shifting from low to intermediate densities. This positive effect of legume sowing density on protein content in the harvested mixture is of interest to improve the level of autonomy in livestock farming systems. An increase of pea sowing densities also led to an average and, at highest densities, significant increase of triticale protein content by 5 to 12 g $kgDM^{-1}$ (7.5 g $kgDM^{-1}$ in average) (Bedoussac and Juste, 2010). In parallel, NPK supplies decreased pea proportion and protein content in the harvested mixture, in a significant way in 2014, without significant impact on triticale protein content. Based on these results and in line with literature (e.g. Bedoussac *et al.*, 2015), the occurrence of N fertilization reduce the competitiveness of the legume species in the association without increasing the yield.

Table 1. Effects of pea sowing density and NPK fertilisation on the characteristics of triticale-pea grains mixtures harvested. Pea sowing density * N supply interaction was significant (*p<0.02*), with fodder pea, for protein content and pea content in 2014 and 2015, respectively.

	Pea content (g $kgDM^{-1}$)				Protein content (g $kgDM^{-1}$)				Triticale protein content (g $kgDM^{-1}$ for the cereal)			
	Fodder pea		Protein pea		Fodder		Protein		Fodder		Protein	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Pea sowing density												
Low	711	236^{b}	606^{b}	423^{b}	230^{b}	149^{c}	204	176^{b}	107^{b}	121^{b}	94^{b}	125^{b}
Inter	756	310^{a}	667^{a}	523^{a}	240^{a}	159^{b}	212	190^{a}	109^{b}	121^{b}	97^{ab}	128^{ab}
High	761	364^{a}	676^{a}	592^{a}	242^{a}	169^{a}	215	199^{a}	119^{a}	127^{a}	101^{a}	130^{a}
N supplies (kg ha^{-1})												
0	819^{a}	328	714^{a}	537	256^{a}	163	228^{c}	191	108	122	97	126
40	719^{b}	292	666^{b}	524	232^{b}	157	212^{b}	190	111	123	97	127
80	690^{b}	290	569^{c}	478	224^{c}	158	192^{a}	185	116	124	98	129

Per factor and within each column, means quoted with different superscript letters are significantly different at the level $\alpha = 0.05$.

4 Discussion and Conclusions

In conclusions, these results don't support the use of organic fertilization to secure triticale/pea intercrop yield. A modulation of legume sowing density, even if not improving yield, allows improving pea and protein proportion in the harvested crop, of interest to improve protein autonomy of livestock farming systems.

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Intercropping Promotes both Agronomic and Ecological Aims: The Case of Organic Strip Cropped Cabbage (*Brassica oleracea* L.)

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1 Introduction

Input-dependent intensification and ecosystem simplification in industrialized agriculture focuses on the maximization of only one ecosystem service: production. This single focus of yield maximization comes at the expense of other ecosystem services, for instance, sustainable pest control. Optimizing synergies between provisioning and non-provisioning ecosystem services is difficult because often trade-offs are incurred. In highly productive agricultural systems, increases in biodiversity may incur proportionate yield losses and vice versa (Gabriel *et al.*, 2013). In this study, we investigated the potential to simultaneously improve both agronomic and ecological outcomes of cropping systems through the implementation of various intercropping designs. Research has shown that intercropping delivers a higher yield through facilitation and complementarity, while suppressing pest via pest habitat dilution and/or habitat provision for natural enemies (Letourneau *et al.*, 2011; Yu *et al.*, 2015). Utilizing a network of crop diversification experiments across the Netherlands, we analyzed the effect of ten intercropping designs on cabbage yield and quality with the aim to answer two primary questions: 1) What is the effect of different intercropping designs with increasing complexity on cabbage leaf damage by herbivorous pests?; and 2) How does these designs affect cabbage yield? Focusing on the spatial and genetic dimensions of crop diversification, we hypothesized that increased system complexity via intercropping would reduce the magnitude of pest damage and would, therefore, allow organic cabbage growers to increase attainable productivity per plant.

2 Materials and Methods

This study was conducted in four organic farms in the Netherlands from May to November 2018. The agronomic specification of the intercropping designs is summarized in table 1. Cabbage (white cabbage (*Brassica oleracea* L. var. *capitata*) or cauliflower (*Brassica oleracea* L. var. *botrytis*)) was strip cropped in alternating strips with wheat (*Triticum aestivum* L.) or a grass—clover mixture (*Lolium multiforum* L., *Trifolium pratense* L. and *Trifolium repens* L.). In one of the designs, a wildflower strip was sown next to the cabbage strip. The presence of flowering plants supports biological control by parasitoids, though its effectiveness appears to depend on attractiveness and nectar accessibility (Wäckers, 2004).

Table 1. Overview of the experimental setup at the four locations with their associated intercropping designs, crops, sowing dates, fertilization and pesticide application.

Location	Intercropping design	Crop association[1]	Cabbage planting and harvest dates	Fertilizer application for cabbage	Pesticide application for cabbage
1. Droevendaal 0.75m (between-) and 0.38m (within-) row distances	a. Strips/Mono (3m) b. Strips/Substitutive c. Strips/Additive d-f. Strips/Rotation g. Pixel cropping h. Reference (sole crop)	a. W—C(r) b. W—C(r) and C(c) c. B + W—C(r) d-f. W—C(r)—G—L—G—P g. C(r) + C(c) and/or W, R, B, P, L h. C(r)	June 14, 2018 – October 31, 2018	20-25 t FYM + 2 t OPF 11-0-5	No
2. Broekemahoeve 0.75m (between-) and 0.38m (within-) row distances	a. Strips/Mono (3m) b. Strips/Substitutive c. Strips/Additive	a. W—C(r) b. W—C(r) and C(c) c. B + W—C(r)	June 14, 2018 – November 18, 2018	20-25 t FYM + 2 t OPF 11-0-5	No
3. Rozendaal 0.50m (between-) and 0.40m (within-) row distances	a. Strips/Mono (3m) h. Reference (sole crop)	a. R—C(s) h. C(s)	May 8, 2018 – October 12, 2018	30 t/ha liquid manure (5.93 kg/ton N and P)	0.2 L : 500 L /ha Spinosad July 9, 2018
4. ERF 0.75m (between-) and 0.50 (within-) row distances	a. Strips/Mono (6m, 12m, 24m) a. Strips/Mono (24m) h. Reference (48m)	a. G—C(b)—F + G a. G—C(b) —G (sowing error) h. C(b)	July 5, 2018 – October 18, 2018	35 m^3/ha liquid manure	1 kg/ha Xentari (Bt) Sep 17, 2018

[1] Abbreviations:
B: broad bean (*Vicia faba* L.) cultivar Pyramid; C(b): cauliflower (*Brassica oleracea* L. var. *botrytis*) cultivar Balboa; C(c): cabbage (*Brassica oleracea* L. var. *capitata*) cultivar Christmas Drumhead; C(r): cabbage (*Brassica oleracea* L. var. *capitata*) cultivar Rivera; C(s): cabbage (*Brassica oleracea* L. var. *capitata*) cultivar Storema; F: wildflower strip; G: grass (*Lolium multiforum* L.); L: leek (*Allium porrum* L.); P: potato (*Solanum tuberosum* L.); R: grass—clover mixture (*Lolium multiforum* L., *Trifolium pratense* L. and *Trifolium repens* L.); W: wheat (*Triticum aestivum* L.)
Bt: *Bacillus thuringiensis,* FYM: farm yard manure; OPF: organic plant fertilizer

3 Results

We quantified fresh weight and leaf damage by herbivorous pests for 476 individual cabbage plants. Across experiment sites, lower herbivore damage and maintained fresh marketable weight were observed in strips designs compared to sole crops. The presence of wildflower strips next to cabbage reduced feeding damage by more than 50% ($F_{4,101} = 13.89$, $P < 0.001$). No correlation was observed between herbivore damage and marketable weight. We found a negative correlation between crop diversity and damage level per cabbage: designs with a higher number of species and/or cultivars exhibited lower feeding damage (Figure 1). For every addition of one species or cultivar, crop damage was reduced by 10% ($F_{1,28} = 18.49$, $P < 0.001$). We observed no clear relationship between crop diversity and fresh marketable weight per cabbage, however, five out of seven intercropping designs produced total yields per area equivalent to the sole-crop reference.

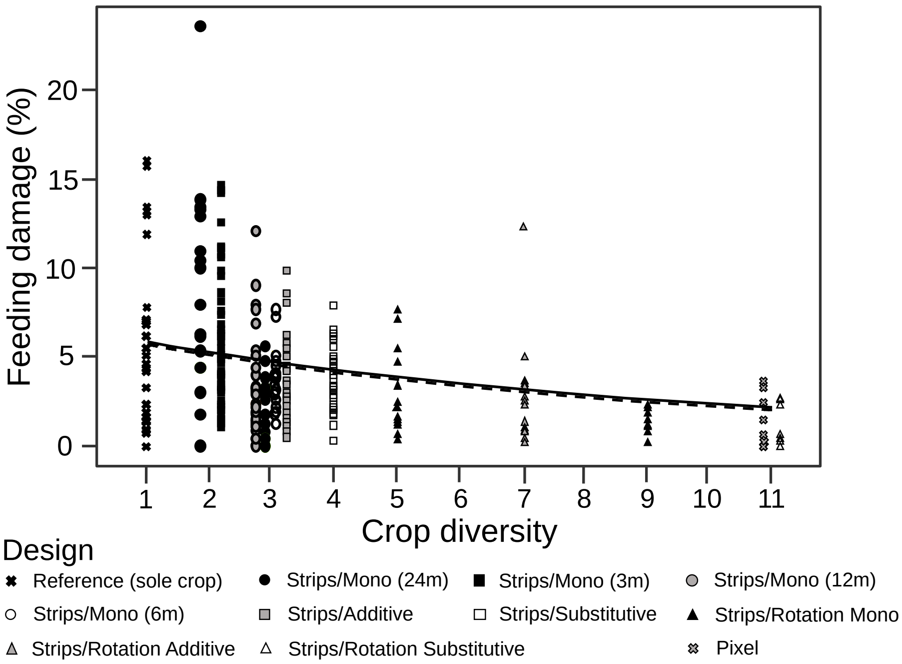

Figure 1. Relationship between crop diversity and feeding damage. The feeding damage was log back-transformed. Crop diversity was measured by summing the number of species in the design including different cultivars (E.g. it is 1 in Reference (sole crop), 2 in Strips/Mono and 4 in Strips/Substitutive). On each graph, two regression lines representing inclusion (dotted line) or exclusion (solid line) of the Pixel cropping design data were plotted; the respective equations are included in the graphs. Asterisks in regression equations indicate a significant fixed effect of crop diversity. Symbol represents design.

4 Discussion and Conclusions

Our results show that crop diversification via strip cropping can promote synergies between agronomic and ecological aims. While we rejected the hypothesis that there would be a direct correlation between damage level and attainable yield, five out of seven intercropping designs were able to maintain yield per unit area. These results provide a starting point for redesigning arable fields to enhance ecological resilience in the transition towards more sustainable farming systems. A better understanding of crop functionality and management needs in diverse arrangements will be relevant for such redesign.

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Weed species’ competition for different N sources along gradients in a pea-barley intercrop

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1 Introduction

The intensification of crop production during the recent decades came along with negative side effects such as eutrophication of water bodies, pesticide resistances and loss of diversity. Therefore the development of resource efficient and sustainable cropping systems is required and became a focus in agricultural research. One example is cereal-legume intercropping systems that have been proposed especially due to their complementarity in nitrogen (N) acquisition, increased crop yields and grain protein contents. This complementarity in N acquisition, which is based on different N source use, rooting depths and temporal N demands changes N availability throughout the growing season in intercropping systems compared to the sole crops, which affects weed species competitiveness. A major challenge in crop production is weed competition which can lead to high yield losses. Most cropping systems studies regard weeds as homogenous group but do not take into account their very divers nature. However, in which way N availability affects different weed species’ accumulation of soil and fertilizer N and thus their competitiveness with crops remains unclear. We conducted a field experiment with pea-barley intercrops and the respective sole crops with and without additional N supply using the abundant weed flora to assess weed species competitiveness for different N sources along N gradients. The two dominant weed species, *Chenopodium album* and *Galeopsis spp.* are both nitrophilic but differing in their root and shoot growth response to N. We hypothesised that the species (i) differ in their response to N availability along N gradients in the chosen cropping systems, (ii) differ in their competition for fertilizer N in the cropping systems and (iii) show different N source preferences.

2 Materials and Methods

The study was carried out in the context of the EU Horizon 2020 project “Designing InnoVative plant teams for Ecosystem Resilience and agricultural Sustainability (DIVERSify)”. The field experiment was conducted in 2017 in Uppsala, Sweden. Pea (cv. Ingrid) and barley (cv. Tamtam) were grown as sole crops and 50:50 intercrops without or with 90 kg ha^{-1} additional N supply in 3 replicates. ^{15}N enriched ammonium-nitrate was applied in micro-plots within the large plots to measure fertilizer N uptake of crop and weed plants. Aboveground biomass was sampled at crop flowering and maturity and samples were analysed on biomass, N content and N isotope ratios.

3 Results

Biomass and N accumulation of *C. album* was higher than of *Galeopsis spp*. at both N levels and in contrast to *Galeopsis spp*., *C.album* responded to additional N supply with increased biomass and N accumulation. Further *C. album* accumulated more biomass and N than *Galeopsis spp.* in both sole crops. Consequently, *C. album* accumulated larger amounts of fertilizer N than *Galeopsis spp*, although *Galeopsis spp.* covered a higher demand of its N demand from fertilizer N. Both weed species covered larger proportions of their N demand from fertilizer N in sole-crop barley, followed by the intercrop and sole-crop pea.

4 Discussion and Conclusions

The results show that altered N availability in intercrops and sole crops affect weed species competitiveness, with the effects being species dependent. *C. album* benefitted from increased N availability, outcompeting the less competitive *Galeopsis spp.* and being a major competitor for fertilizer N in all crops.

Exploring below-ground interspecific root-root interactions to understand advantage of intercropping in terms of productivity, nutrient use and soil fertility

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1 Introduction

Intercropping advantages are mainly derived from interspecific interactions, including above- and below-ground complementarity, competition and facilitation. There has been extensive research on interspecific interactions on above-ground parts, but relatively limited on below-ground interactions between intercropped species. The aim of the study was to examine the role of interspecific root-root interactions in overyielding and efficient nutrient utilization of intercropping.

2 Materials and Methods

We used root barriers in field experiments to determine relative contribution of above-ground and below-ground interactions to faba bean/maize and wheat/maize intercropping advantage in terms of land equivalent ratio (LER). Symbiotic N_2 fixation of faba bean grown alone and intercropped with maize was measured by ^{15}N natural abundance method in field experiments. Phosphorus acquisition of faba bean and maize was investigated under pot experiments under greenhouse condition by adding sparingly soluble P (such as $AlPO_4$, $FePO_4$, $CaHPO_4$) and organic P into soils, with different intensities of interspecific root-root interactions created with solid root barrier, nylon mesh root barrier and without root barrier between faba bean and maize. To determine soil fertility after years of intercropping of faba bean/maize, chickpea/maize, soybean/maize and oil rape seed/maize, soil fertility parameters were determined in three long-term field experiments conducted initially in 2003 and 2009 in Gansu Province, Northwest China.

3 Results and Discussions

There are significant productivity advantages of faba bean/maize, chickpea/maize, soybean/maize and cereals/cereals (wheat/maize) intercropping. One-thirds for wheat/maize and all for faba bean/maize intercropping advantages are contributed to root-root interactions by using root barrier experiment under field condition.

With regard to N complementarity utilization of faba bean/maize intercropping, maize usually has more root competitiveness to soil mineral nitrogen than faba bean does and leads to reduction in soil mineral nitrogen, thus facilitating nodulation and symbiotic N_2 fixation of faba bean (Figure 1). Intercropped maize caused a two-fold increase in exudation of flavonoids (signaling compounds for rhizobia) in the systems. Roots of faba bean treated with maize root exudates exhibited an immediate 11-fold increase in the expression of chalcone-flavanone isomerase (involved in flavonoid synthesis) gene, together with a significantly increased expression of genes mediating nodulation and auxin response as well as up-regulation of key nodulation genes such as ENOD93, which promoted nitrogen fixation after 35 days (1).

Through greenhouse experiments, we found that the interspecific rhizosphere effect significantly increased P uptake by maize on average for all P sources, compared to uptake without a rhizosphere effect. Phosphorus uptake by maize with a rhizosphere connection (mesh barrier) was 30% greater than that without an interspecific rhizosphere connection (solid barrier) for pots without any P addition, 116% greater for pots with Fe-P addition, 56.1% greater for pots with Al-P and 12% greater for pots with Ca-P. As shown in Figure 3, the mechanisms underlying enhanced P acquisition by intercropping include (1) rhizosphere acidification by P-efficient species resulted in a pH decrease in the rhizosphere, which increased the availability of insoluble inorganic P in soil, such as $FePO_4$ and $AlPO_4$; (2) carboxylates from root exudation of P mobilizing species chelated Ca, Fe, and Al, consequently mobilized insoluble soil P, which will benefit the species and other species grown together with it; (3) greater phosphatase activity in the rhizosphere decomposed soil organic P into an inorganic form, which can be used by both species, such as wheat-chickpea and maize-chickpea (2, 3).

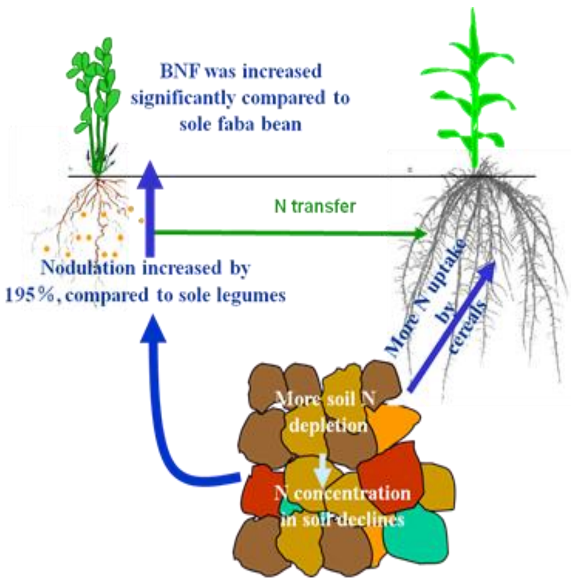

Figure 1. Mechanisms underlying enhanced biological N2 fixation of legume by N sparing effects in legumes/cereals intercropping

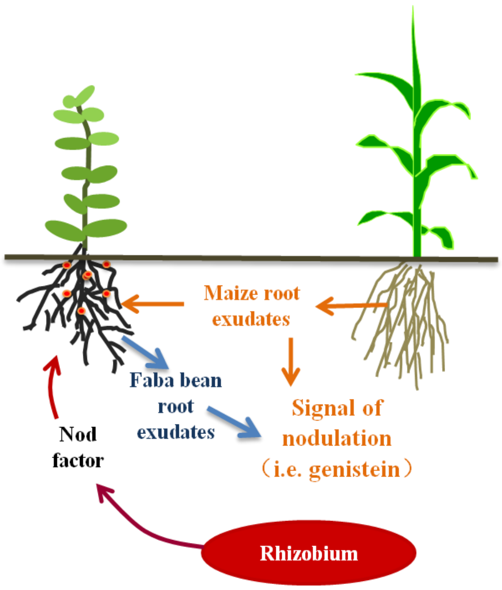

Figure 2. Mechanisms underlying enhanced biological N2 fixation of faba bean, which stimulated by maize root exudates in faba bean /maize intercropping

Further study with long-term field experiments in different soil fertility shows that the root-root interactions maintains soil fertility on a relative fertile soil and enhances soil fertility on a poor soil under continuous overyielding of intercropping. In highly fertile soil, intercropping overyielded at least 12 years, and maintained relatively stable productivity, and facilitated soil aggregation. In moderately fertile soil, overyielding was increased with increasing years. Intercropping improved soil physical and chemical properties significantly, and had less effects on enzyme activity. In newly-reclaimed desert soil, overyielding was increased with increasing years. Intercropping improved soil physical and chemical properties.

4 Conclusions

Our results highlight that interspecific below-ground root-root interactions play an important role not only in overyielding and efficient acquisition of nitrogen and phosphorus if suitable crops are combined, but also in maintaining or enhancing soil fertility, consequently promoting sustainability of agriculture.

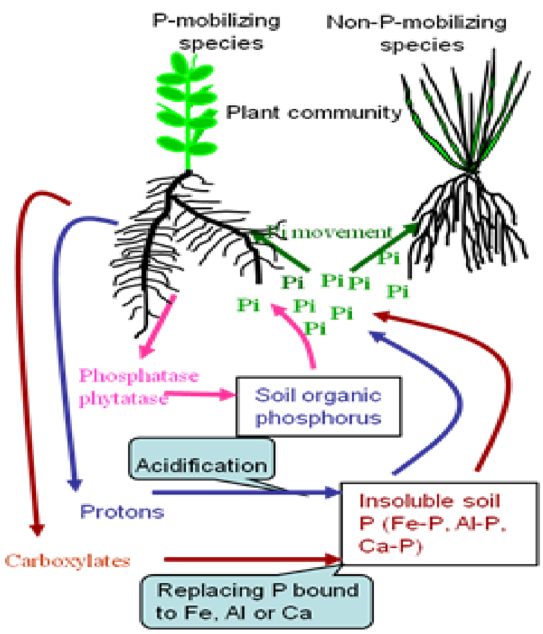

Figure 3. The mechanism underlying efficient P utilization for P mobilizing species and non-P-mobilizing species.

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ReMIX: An opportunity to improve yield and stability of organic grain legumes for human consumption, providing ecosystem services

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1 Introduction

Overexploitation of natural resources, increasing population and climate change all have an important impact on agriculture and soil conservation. Crop diversity, organic farming and in particular intercropping are presented as practical applications that maintain biodiversity and enhance ecosystem services while having the potential to reduce chemical inputs.

In Spain there is an increasing demand of organic grain legumes for human consumption and bread- making wheat; however, farmers have difficulties in producing these crops due, on the one hand to the difficulties in reaching sufficient protein in wheat and, on the other hand, to lodging, weeds and diseases pressure in legumes. ReMIX is a H2020 project that will exploit the benefits of species mixtures to design more diversified and resilient cropping systems, which are less dependent on external inputs and with a lower environmental impact. Grain legume-wheat mixtures are one of the species mixtures tested in ReMIX.

2 Materials and Methods

The effects of wheat density and sowing patterns in intercrops are being evaluated in an organic field trial established in Mendigorría (Navarra, Spain) during the 2019 season. Micro-plots of 12m^2 were sown on January 18th 2019 using the variables described below (Table 1) and using four replicates.

Table 1. Mono or intercrops sown, crop variety, percentage and seeds density of intercrops and sowing pattern (number of rows) in each treatment

Crop	Variety	Percentage of crop (seeds/m^2)			Number of rows
		Wheat	Chickpea	Lentil	
Wheat (sole)	Bonpain	100% (500)	-	-	8
Chickpea (sole)	Garabito	-	100% (50)	-	8
Wheat + Chickpea	Bonpain + Garabito	50% (250)	100% (50)	-	8
Wheat + Chickpea	Bonpain + Garabito	30% (150)	100% (50)	-	8
Lentil (sole)	Guareña	-	-	100% (200)	8
Wheat + Lentil	Bonpain + Guareña	30% (150)	-	100% (200)	8
Wheat + Lentil	Bonpain + Guareña	16% (80)	-	100% (200)	8
Wheat (sole)	Bonpain	100% (500)	-	-	3
Chickpea (sole)	Garabito	-	100% (50)	-	3
Wheat + Chickpea	Bonpain + Garabito	50% (250)	100% (50)	-	3
Wheat + Chickpea	Bonpain + Garabito	30% (150)	100% (50)	-	3
Lentil (sole)	Guareña	-	-	100% (200)	3
Wheat + Lentil	Bonpain + Guareña	30% (150)	-	100% (200)	3
Wheat + Lentil	Bonpain + Guareña	16% (80)	-	100% (200)	3

For assessing the incidence of foliar and root diseases 5 plants per crop were randomly chosen in every micro-plot and repetition in two different dates. Foliar diseases of cereals were assessed in the three latest leaves fully developed, whereas in legumes, four leaves, two below and two above the first flower, were evaluated. Foliar diseases evaluation was performed determining the number of leaveswith a sign of disease (frequency), and in the same leaves, by determining the percentage of the visible area affected by the disease (severity). Foot diseases were evaluated, determining the percentage of affected feet (frequency) and, visually, the percentage of the affected stem assessing the damage in four categories: 0-25%, 25-50%, 50-75% and 75-100% (severity) in wheat, and using a scale from zero (no symptoms of disease) to eight (dead plant) in legumes.

In order to evaluate weeds three random samplings were performed to count the number and species of weeds located in a $0.1m^2$ area. As weeding was performed using two different tools, depending on the sowing pattern, data collection was carried out maximum five days before and between ten and fourteen days after weeding. Weeding was performed using a flexible spike-tooth harrow in order to reduce weeds in micro-plots that were sown in eight rows. An inter-row cultivator was used in micro- plots sown in three rows when the crop reached the appropriate phenological development stage.

The height of the plants will be evaluated at the end of the crop cycle, whereas yield and nitrogen content in wheat grain will be assessed after harvesting.

3 Results

In order to compare the different treatments and the efficacy of the weeding tools, the number of weeds was evaluated before and after weeding. Preliminary results indicate that no differences were found between sole crops and intercrops in the number of weeds when crops were sown at eight rows. However, when crops were sown at three rows, weeds were reduced by 30% as an average in intercrops as compared to sole crops. After weeding the number of weeds was reduced by 27% and 63% in treatments sown at eight and three rows respectively, The plants the most affected by weeding were *Anagallis arvensis* with a reduction of 85%, *Lactuca virosa* (69%), *Sinapis arvensis* (68%), *Chenopodium album* (60%) and *Polygonum aviculare* (58%).

Diseases data are being collected at this time, whereas data of height, yield and nitrogen content in wheat grain will be collected and analyzed upon harvest.

4 Discussion and Conclusions

Intercropping, species mixtures, associated crops or "plant teams" are defined as simultaneous crops cultivated in the same area for a long period of time. Species mixtures, specifically grain legumes for human consumption and bread-making wheat, could be a useful tool in organic farming compared to the use of these species in monocultures, as they can contribute to enhance crop productivity (Bedoussac *et al.*, 2015), bread-making quality of wheat, and reduction of weeds and diseases pressure (Zang *et al.*, 2019). In organic farming intercrops have special interest due to the limitations in the use of chemical inputs. Yield advantages in intercrops occur when components compete partially for the same growth resource. In this respect, legume-cereal mixtures have advantages due to nitrogen fixation of legumes from the air resulting in higher soil nitrogen available to cereals. In summary, the greater resilience of the species mixtures to biotic and abiotic stress can potentially reduce fossil energy use and improve ecosystem services, increasing, in turn, yield and stability of these arable crops.

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Spatial and temporal variability of interactions in pea-oats mixed cropping on field-scale: Yield stability and nutrient use

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1 Introduction

Cereal-grain legume mixtures have the potential to increase yield and cereal grain protein concentration and stabilise yields compared to sole cropping, particularly in low-nitrogen (N) input systems and organic farming where N is often a limiting resource (Bedoussac *et al.*, 2015). Farmers' fields may have a high heterogeneity in soil characteristics (e.g. nutrients, texture, moisture content) which influences spatial crop growth and yield potential. According to the principle of "Ecological Precision Farming", individual plants in mixed cropping can naturally adapt on a very small scale to a given heterogeneity resulting in higher yield stability, given the complementary use of resources, e.g. for N in cereal-legume mixtures (Jensen *et al.*, 2015).

Within the EU-H2020 project "ReMIX", this adaptation of cereal-legume mixtures to soil heterogeneity is investigated on a pea-oats mixture grown in Germany and Sweden. The main hypotheses are:

- Mixtures are able to adapt to heterogeneity more efficiently than their respective sole crops by supressing weeds and producing higher and more stable yields.
- Mixtures use nitrogen more efficiently and oats achieve a higher grain protein content.
- In mixtures, species can be differentiated by remote-sensing and their relative canopy cover can be determined.

2 Materials and Methods

Field design: SLU (Sweden) and UHOH (Germany) have been co-developing and aligning a two-year (2018-2019) and two-site experiment, in relation to field selection and soil characterisation. To mimic farmers' conditions, fields with a considerable gradient in slope were chosen as a first indicator for heterogeneity in soil characteristics across the field. Field size was 1.4 ha in Germany. In 2018, sole and mixed crops of pea and oats were sown in replicated, parallel strips along the slope of the field. Sowing ratio in mixture was 50 % of oats sole crop (160 seeds m^{-2}) and 75 % of pea sole crop (60 seeds m^{-2}).

Soil heterogeneity: Preliminary experiments showed a significant correlation between electromagnetic conductivity (EC, measured with EM38, Geonics, Canada) and soil clay-content as indicator for possible heterogeneity, e.g. in soil water availability. In 2018, EC was measured across the field showing a large heterogeneity. Further soil analyses include e.g. mineral nitrogen, phosphate, pH, water content, and soil compaction.

Species differentiation: For determination of the canopy cover of each species within the mixture, a remote sensing method is developed to separate species based on images taken with a drone covering the entire field.

Yield determination: At maturity, 120 above ground samples (1 m^2) were taken across the field for the three cropping systems and separated into respective crops and weeds, and the dry weight of grain and straw was determined. Parameters of crops (e.g. thousand kernel weight and grain protein concentration) and soil (e.g. mineral nitrogen, phosphorus) will be measured in stored samples after yield analysis.

3 Results

In intercropping (IC), mean oat grain yield was 3999 kg ha^{-1} compared to 5328 kg ha^{-1} in oats sole crop (SC) stripes, although oats crop density was only 50 % in IC (Figure 1). Pea grains yielded 3400 kg ha^{-1} in SC and only 891 kg ha^{-1} in IC. In IC, oats developed 36 % more shoots with panicles and peas had 43 % less pods per plant meanwhile thousand kernel weight did not change significantly. Yield variation was high for pea in IC, medium for pea in SC and most stable for oats and total IC yield. Although there was no weed control, only little amount of weed biomass was found in oats SC and IC, meanwhile SC pea had a considerable higher weed biomass (Figure 2). Differences in EC did not explain the variability in yield, tested for each cropping system.

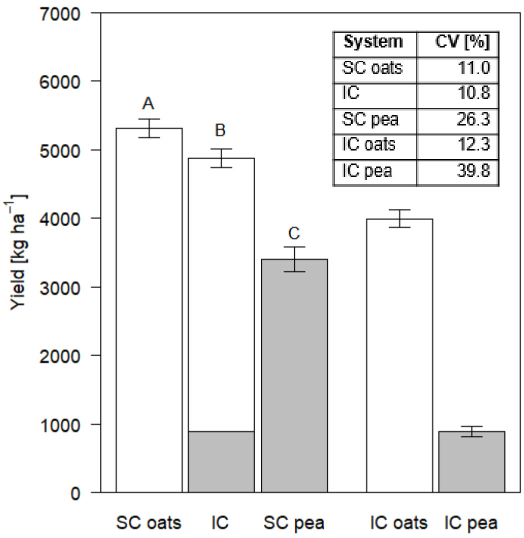

Figure 1. Grain yield of different cropping systems, hand harvested at UHOH in 2018. Bars headed with same capital letters are not significantly different ($p<0.05$). Error bars indicate standard error (n=120). CV is Coefficient of Variation.

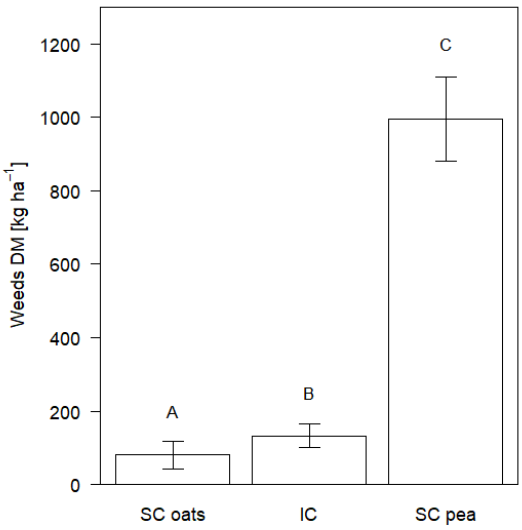

Figure 2. Dry matter of weeds biomass at crop maturity at UHOH in 2018. Bars headed with same capital letters are not significantly different ($p<0.001$). Data was log-transformed for significance analysis. Error bars indicate standard error (n=120).

4 Discussion and Outlook

Oats are very plastic in tillering and thus have a high competitive potential (Saunaite *et al.*, 2013). Already 15 % oats in an intercropping with legumes can be sufficient to half the weed soil cover (Kimpel-Freund, 1999). Thus, oats were also supressing the pea in this experiment, resulting in lower pod production and yield. The higher yield stability in intercrops can be affiliated to the compensation potential of mixture partners, in this experiment especially of oats.

The relation of EC to yield showed a significant correlation in heterogeneous fields, but in many cases additional specific field information is necessary to explain the relationship in detail (Fraisse *et al.*, 2001). For further analysis of the variability, stored soil samples will be analysed (e.g. nutrients, clay content and pH) and specific information like elevation and soil compaction will be considered.

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To mix or not to mix? Working on crop diversification in the silage maize dominated landscape in the Netherlands

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1 Introduction

Roughage for Dutch dairy farms is dominantly produced by maize and (semi) permanent grassland. Silage maize production plays a central role in the Dutch arable agricultural landscape. On about 205,000 hectares silage maize (2018) is grown, making it the largest arable crop in the Netherlands (40% of the Dutch arable land, 11% of the Dutch agricultural land). The silage maize cropping system is dominated by maize continuous monocultures. The dominant cropping system of maize monocultures, and its subsequent management practices results in unwanted negative effects on the environment and thereby on production levels. Soil quality is gradually decreasing (negative impact on soil structure, increased risk on compaction, negative OM balance), runoff and leaching of nutrients and pesticides is threatening groundwater quality, (above and belowground) biodiversity is under pressure and the production of emissions like nitrous oxide cause serious threats to the environment. Moreover, experts estimate that the production level of silage maize is about 15% lower than the potential production [a].This is potentially caused by the suboptimal soil quality (e.g. soil organic matter (OM) breakdown, compaction), presence of diseases, pests and weeds; the inadequate application of cultivation techniques and legal limitations in fertilization rates [b].

The five-year EU project DiverIMPACTS will link its goals (*to achieve the full potential of diversification of cropping systems for improved productivity, delivery of ecosystem services and resource-efficient and sustainable value chains*) to the existing Dutch multi-stakeholder programs on roughage production and soil quality. Via a system approach, Wageningen University & Research (WUR) poses alternative cropping strategies in DiverIMPACTS, with a central role for crop diversification of maize monocultures in time and space, through an integrated effort of case study work and field experiments combined with demonstration plots, breeding & smart innovation in machinery use by their partners, Nordic Maize breeding (NMB) and Laurens van Run Zaden (LVR). In this paper we present the integrated work of WUR, NMB and LVR in our field experiment and demonstration plots.

2 Materials and Methods

The field experiment takes place on a conventional experimental farm of Wageningen University & Research near Lelystad, Flevoland. The long term field trial was established in 2009 with the aim of researching sustainable silage maize crop production management practices, with the focus on soil tillage, weed control and cover crop strategies. Since spring 2018 the objectives of DiverIMPACTS are weaved into this existing long term field trial. One existing treatment and two specially added treatments for DiverIMPACTS are of specific interest to the DiverIMPACTS project. The treatments consist of (a) maize monoculture with a winter fodder crop, (b) sorghum monoculture with a winter fodder crop and (c) maize-sorghum intercrop with a winter fodder crop. From spring 2019, treatments with maize-runner beans mixed crop (d) and maize and flower strips (e) have been added. The treatments are compared to the reference system in the region, consisting of continuous maize monocultures without a winter crop. Together, the five treatments explore the potentials of crop diversification in time and space. The three treatments explored in 2018, where chosen based on the combination of factors like: interest shown by farmers for certain crop diversity strategies, interest of farmers for a second fodder cash crop in their rotation (sorghum) and the potential benefits of adding sorghum to the system, in terms of ecological benefits. Sorghum could contribute to the current challenges of the silage maize cropping system, by improving the OM content of the soil, its deep rooting properties - valuable in the battle against soil compaction - and its expected reduced vulnerability against drought, fungi and maize stem borer (*Ostrinia nubilalis*). Dutch farmers and research organisations see both drought and damage by the maize stem borer as biggest threat for the silage maize system in the next 10 years.

Besides the field experiment, two on-farm demos are performed in 2018 and will be performed the upcoming years. The demos have been designed by NMB, a breeding company focussing on short season maize cultivars and LVR, a seed producer specialized in roughage crops such as early maize varieties and winter peas. The demonstration plots serve as invaluable '*experimental ground'*, in which many crop combinations can be screened. They serve as a '*fishing ground*', in which potential treatments can be picked up to be further tested in field experiments.

3 Discussion and Conclusions

Trade-offs between ecological benefits and economic and agronomical challenges of diversified silage maize systems will occur. Doublecropping-systems can be a sustainable form of crop-rotation and may be very profitable. When really early (ultra early) varieties of silage maize are used, maize can be planted later or harvested earlier. Ultra early maize varieties enable farmers to harvest one or even two cuts of grass silage or other winter fodder crops, with a harvest in spring before planting maize. After an ultra-early maize harvest, planting crops like grass-clover, winter rapeseed or a mixture of winter cereal – winter peas is possible. The growth of a winter crop which is harvested in spring, opens opportunities for a herbicide free maize cultivation. However, combining a winter crop and a herbicide free maize cultivation meets challenges in the management. Success and failure of the maize crop, lie close together and depend on the chosen combination of a winter crop, the sowing system and management of the maize crop [c]. Opportunities are there too, e.g. the potentials of strip cultivation in the stubble of the winter crop, where the regrowth facilitates a micro climate for the emerging maize plants. The use of interrow mulchers have the potential to (help) control both the regrowth of the winterstubble and weeds. Mulched particles will also suppress intra-row weed growth. This approach is expected to stimulate biodiversity and reduce soil erosion. The potentially improved soil quality might deliver positive feedback loops towards the system and deliver increased and stable production levels. However, farmers will potentially '*loose'* valuable tonnages per hectares the first years, when soil quality has not yet been restored.

Additional added value and functionality of intercropping systems may be explored by specific combinations of intra-row partner crops and inter-row cover crops. Examples of these are e.g. antagonistic effects by allelopathy for wireworm and nematodes management. Symbiotic effects may exist on N-fixation and P-mining and release for uptake of plants. Biodiversity will be improved by using long-flowering period cover crops. Local protein production will be promoted by intra-row cropping of maize with beans. Above mentioned opportunities and challenges will require innovative mechanisation systems (e.g. robotica), specific adaptive plant breeding efforts, matching main crop on side crops for e.g. water, light and nutrient requirements and a mindset release of the dependency of herbicides and pesticides.

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Intercropping of sunflower with legumes in relation to biological and productive properties of sunflower

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1 Introduction

Intensive sunflower production is mainly focused on increasing seed yield, but less importance is given to soil properties, potential ecosystem services and resources conservation. This practice can cause the reduction in organic matter content in the soil, loss of soil fertility, increased erosion, as well as pollution of ground waters. Hence, it is necessary to introduce alternative practices such as intercropping that has raised much attention because it could improve agriculture production for many crops. Previous research has shown that it is best to combine two crops, including one from *Fabaceae* family. Plants from this family have the ability to create a large amount of above-ground mass, strong root systems with high absorption power, ability to adapt to shady conditions, suppressive effect on weeds and the ability to fix atmospheric nitrogen and provide nitrogen for other plant species that are intercropped with (de la Fuente et al., 2014). Commonly intercropped with legumes are crops from a *Poaceae* family, whereas the combination of sunflower with legumes is relatively rare. The reason for this may be that in earlier period there were no hybrids tolerant to different diseases and pests. However, today there are justifiable reasons for studying combinations of sunflower and the most important legumes. The goal of this research is to analyze and recommend sustainable technology of sunflower cultivation in intercropping systems and select the legumes most suitable for intercropping with sunflower, aiming to increase productivity per unit area. The assumption is that intercropping of red clover and alfalfa with sunflower will give similar results.

2 Materials and Methods

For the purpose of our study, field experiment was set up with three hybrids of sunflower (Dukat, Rimi PR and NS Gricko) intercropped with three types of legumes (*Vicia sativa* L., *Medicago sativa* L., and *Trifolium pratense* L.), whereas sole cropping of sunflower hybrids was used as the control. The two-year trial was set up on the experimental field of the Institute of Field and Vegetable Crops, Novi Sad (45°20'32.2"N 19°51'42.8"E) as a random block system in 4 repetitions. Hybrids of sunflower were sown as main crop at first half of April at 24 x 70 cm, while the legumes were sown a day before. The research was carried out in production years 2017 and 2018, and the preceding crop was sorghum. The trial compared the effect of intercropping on productive properties of main crop (number of full seeds of per head and seed yield per hectare). Data were processed in the statistical software SPSS using two-way analysis of variance, with the hybrids and legumes as factors.

3 Results

The results indicated a significant contribution of hybrids ($F= 437.90^{**}$; $F= 659.89^{**}$), legumes ($F= 50.62^{**}$; $F=20.95^{**}$), and their interaction ($F=11.01^{**}$; $F=12.42^{**}$) on the dependent variables, both for 2017 and 2018, respectively. Analysis of variance was carried out for each hybrid individually in order to determine which hybrid had the best performance with the legumes. In 2017 and 2018, F-test established significant differences for both variables in hybrid NS Gricko (Table 1. and 2.). Hybrid NS Gricko had the highest seed yield per hectare in sole cropping in 2017 and 2018, while seed yield per hectare was the highest when intercropped with red clover compared to other legumes (Table 1. and 2.). F-test for hybrid Rimi PR, carried out in 2017, showed significant differences for both variables (Table 1.). This hybrid had the highest seed yield per hectare in sole cropping, and when intercropped with red clover (Table 1.). In 2018, significant differences were established by the F-test for the number of full seeds per head, and seed yield per hectare (Table 2). Rimi PR had the highest seed yield per hectare in sole cropping, and when it was intercropped with alfalfa (Table 2.). F-test for hybrid Dukat, conducted in 2017 and 2018 established significant differences in number of full seeds per head, and seed yield per hectare (Table 1. and 2.). This hybrid had the highest seed yield per hectare in sole cropping in both years, and when intercropped with alfalfa (Table 1. and 2.).

Table 1. The influence of legumes on hybrids in 2017

	NS Gricko		Dukat		Rimi PR	
	NFSH	***SY***	***NFSH***	***SY***	***NFSH***	***SY***
Common vetch	744.54	2.61	1333.64	2.14	1395.43	2.38
Red clover	977.70	3.43	1536.24	2.54	1915.26	2.97
Alfalfa	948.06	3.27	1541.54	2.68	1785.31	2.94
Sole cropping	1059.63	4.00	1900.64	3.15	2063.30	3.31
F-test	43.33^{**}	4.16^{**}	69.27^{**}	13.37^{**}	126.50^{**}	11.53^{**}

NFSH - number of full seeds per head; SY - seed yield per hectare;
Values represent means of each variable, ** $p < 0.01$

Table 2. The influence of legumes on hybrids in 2018

	NS Gricko		Dukat		Rimi PR	
	NFSH	***SY***	***NFSH***	***SY***	***NFSH***	***SY***
Common vetch	925.66	3.58	1220.39	1.93	1424.39	2.49
Red clover	975.92	3.75	1530.15	1.90	1648.14	2.65
Alfalfa	956.54	3.68	997.91	2.06	1639.09	2.70
Sole cropping	1046.03	3.95	1638.75	2.58	1794.76	2.92
F-test	6.04^{**}	4.05^{**}	53.30^{**}	5.1931^{**}	28.52^{**}	6.6931^{**}

NFSH - number of full seeds per head; SY - seed yield per hectare;
Values represent means of each variable, ** $p < 0.01$

4 Discussion and Conclusions

The results of interactions in 2017 and 2018 showed that the influence of legumes on all three tested hybrids is evident. Hybrid Dukat had the lowest seed yield per hectare overall, which was to be expected given that this is a short vegetation hybrid. The investigated years differed considerably in terms of precipitation and temperature during the vegetation period but for the most sunflower hybrid clear pattern of suitable combination emerge. The lack in precipitation in the period of legume emergence mostly affected red clover. The two-year research showed that intercropping sunflower hybrids with common vetch results in the lowest seed yield per hectare compared to other legumes, most probably because of the strong competition for abiotic resources. Hybrids intercropped with red clover and alfalfa behaved differently in relation to the given weather conditions. According to Martin-Guay et al., (2018) individual yield of intercropped crops can be smaller compared to sole crops, which is in agreement with our results, but their cumulative yield is higher. Also the safety of production is higher because unfavorable conditions can affect one crop more than other. Hence, it can be concluded that intercropping is economically more cost-effective than sole cropping. Furthermore, after harvesting the sunflower, red clover and alfalfa can remain as already established crops for next years animal feed production. All the above mentioned points to the need for a more detailed study of sunflower cultivation technology through the intercropping system. The problems of intensive agriculture must be gradually resolved and intercropping is the system that meets the demands of sustainable agriculture.

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Objective depended successes for pea-wheat strip intercropping

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1 Introduction

Monocropping, a common agricultural practice in Europe, has its main focus on the delivery of provisional services by land: the production of food, fodder and fiber. Other ecosystem services such as cultural, supportive and regulative services are often poorly sustained. As monocultures lack diversity, pests and diseases spread explosively as there is an abundance of host plants. Factors which hamper crop productivity may result in the application of fertilizer, herbicide and pesticide to increase crop yields. The application of agrochemicals has however severe consequences for the environment and human health. There is an urgent need to develop sustainable agricultural systems that support valuable ecosystem services such as biodiversity and soil quality whilst sustaining a fair agricultural income for farmers. Intercropping may pose a solution to these challenges as it benefits from the delivery of a wide range of supportive and regulative services.

The four-year EU project ReMIX aims to exploit the benefits of species mixtures to design diversified and resilient agro-ecological arable cropping systems less dependent on external inputs. Therewith contributing to the redesign of European cropping systems. Within ReMIX, Wageningen University and Research conducts several field trials on the relationship between species mixtures and aboveground biodiversity and the combining ability of plant varieties in species mixtures. Here we present our findings of the 2017 stripcropping field trial on pest- and disease suppression and agronomical performance.

2 Materials and methods

In an organic field trial we studied dry pea variety 'Rebel' (*Pisum sativum)* and spring wheat variety 'Lennox' (*Triticum aestivum*) as sole crop (monoculture) and in mixture: alternating pea and wheat strips with different widths; 0.25m, 0.5m, 1.5m, 3m and 6m. Wheat was sown in densities of 350 seeds/m2, while pea was sown in densities of 50 seeds/m2. In the 1.5m, 3m and 6m strip widths, pea and wheat were fertilized separately, 30 kg N and 100 kg N respectively. Strip widths 0.25m and 0.5m were fertilized with 50% of the N requirements of spring wheat + 30 kg N/ha to support the initial grow of the pea; in total 80 kg N/ha. The fields were fertilized with feather meal, which has a fast releasing nitrogen effect and an NPK composition of 11-0-0. The experiment was conducted in 2017 on an experimental plot of 1.1 ha on a loamy soil in Lelystad, the Netherlands.

The following pests and diseases were monitored: mildew, septoria (*septoria tritici blotch*), rust, russian wheat aphids (*Diuraphis noxia*), bird cherry aphids (*Rhopalosiphum padi)*, rose grain aphids (*Metopolophium dirhodum*) and pea aphids (*Acyrthosiphon pisum*). Natural enemies for aphids were also monitored and scored. Agronomical performance indicators included leaf chlorophyll content during the final four weeks of the growing season and plant biomass distribution after harvest, as well as nitrogen content of wheat grains and pea seeds. The advantage of intercropping compared to monoculture was determined by the Land Equivalent Ratio (LER); the ratio of the area under large scale references to the area under intercropping needed to give equal amounts of yield at the same management level.

3 Results

Results show that intercropping significantly decreased aphid abundance in pea compared to monoculture pea. No significant difference was observed in the number of natural enemies between different strip widths and monoculture pea. Epigeal natural enemies were however not monitored in this study. Epigeal populations might have been higher in strips explaining the decreased presence of pea aphid. In wheat, no significant differences in number of aphids and natural enemies were found, neither in presence of mildew, septoria and rust.

Yield of wheat grain was significantly higher in intercropping than in monocropping. The highest yield was found in the smallest strips, 0.25m and 0.5m, where a higher number of seeds per plant and an increased number of tillers were counted. Pea seed yield was significantly lower in the smallest, 0.25m and 0.5m, strips than in wider strips. The highest yield was found in the widest strip, 6m, which was significantly higher than in monocrop. Due to the difference in fertilization between the smallest, 0.25m and 0.5m, and the wider strips, yield differences between strips cannot be directly related to configuration. Nonetheless, total nitrogen use efficiency (%) was significantly higher for all the strip widths compared to the monoculture and all strip widths had a LER>1, indicating a per-area advantage to intercropping compared to monoculture. Although often related to weed suppression, these advantages could not be linked to weeds in this study. Between strips there was no significant difference in LER, indicating that the strip width is not of importance to increasing LER. Considering the differences in yields between strips widths for pea and wheat, the choice of strip width seems to depend on the objective of the grower.

4 Discussion and Conclusions

Although results seem promising and provide a starting point for the redesign of European cropping systems, more research is needed in order to further unravel and confirm the relations found. Besides strengthening our knowledge on mechanisms and performance of intercropping systems, the need for technological innovation to allow for successful implementation by farmers should not be underestimated. Namely, the use of small strips poses technological challenges for implementation and plays therefore a pivotal role in the transition of European agriculture to more resilient agro-ecological arable cropping systems.

SESSION 11. PERFORMANCES OF DIVERSIFIED AGROFORESTRY SYSTEMS

Due to the withdrawal of some authors, the presentations that were initially allocated to Session 11 were reallocated to other sessions. Session 11 was thus cancelled.

- How to reconcile short-term and long-term objectives in agroforestry systems? An application of viability theory to mixed horticultural systems

  Speaker: Raphaël Paut, INRA, France

  ▸ *reallocated to* SESSION 6. DIVERSIFICATION BENEFITS: THEIR ECONOMIC VALUE AND CARRY-OVER EFFECTS

- Does crop diversification ensure mixed cropping systems health?

  Speaker: Marc Tchamitchian, INRA, France

  ▸ *reallocated to* SESSION 8. CROPPING SYSTEM DIVERSIFICATION TO SUPPORT BIOCONTROL

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SESSION 12. BREEDING FOR INTRASPECIFIC DIVERSITY

Chairs: Jörg Peter Baresel (Technical University of Munich, Germany),
Maria Finckh (University of Kassel, Germany)

ORAL PRESENTATIONS

- Innovative approaches to optimize genetic diversity in wheat for sustainable farming systems of the future (INSUSFAR)
  Speaker: Odette Weedon, University of Kassel, Germany
- Information system ROBUSTUM for diversity breeding
  Speaker: Lorenz Bülow, JKI, Germany
- Production risk in organic winter wheat cultivation - heterogeneous populations vs. pure line varieties
  Speaker: Torsten Siegmeier, University of Kassel, Germany
- Economic performance of organic winter wheat production with composite cross populations
  Speaker: Torsten Siegmeier, University of Kassel, Germany
- Performance, diversity and stability of population-varieties developed within a wheat participatory breeding program in France
  Speaker: Gaëlle van Frank, INRA, France
- Yield stability and yield variability of diverse wheat populations to inter- and intra-site heterogeneity
  Speaker: Robert Oliver Simon, Technical University of Munich, Germany

POSTERS

- Agronomic performance of 200 winter wheat lines selected from a Composite Cross Population (CCP) in a low-input system
  Presenter: Jelena Baćanović-Šišić, University of Kassel, Germany
- Evaluating and selecting root traits in wheat in a hydroponic system for adaptation to organic farming
  Presenter: Johannes Timaeus, University of Kassel, Germany
- Evaluation of the impact of wheat/rye translocation on the stability of wheat doubled haploids in different environments
  Presenter: Zygmunt Kaczmarek, IPG PAS, Poland
- Yield potential of heterogeneous wheat populations under differing fertilizer regimes in an organic system
  Presenter: Odette Weedon, University of Kassel, Germany
- Heterogeneous wheat populations as a viable alternative to commercial varieties under organic management
  Presenter: Odette Weedon, University of Kassel, Germany
- White lupin (*Lupinus albus* L.) with increased fat and reduced alkaloids content
  Presenter: Wojciech Rybiński, IPG PAS, Poland

- Nitrogen and phosphorus use efficiency in the recombinant [*accacia*×normal leaf] lines of a mapping population of field pea (*Pisum sativum* L.)
  Presenter: Magdalena Gawłowska, IPG PAS, Poland
- Opportunities of diversification of the cereal centric organic farm system with soybean production in Hungary
  Presenter: Éva Hunyadi Borbélyné, ÖMKi, Hungary
- Biotechnological approach to creation of new pea cultivars with target features
  Presenter: Tadeusz Adamski, IPG PAS, Poland
- Association analysis of phenotypic traits in selected and propagated lines derived from different winter wheat composite cross populations
  Presenter: Dominic Dennenmoser, University of Kassel, Germany
- Forage potential of small grain cereals and mixtures in organic agriculture
  Presenter: Mária Megyeri, Hungarian Academy of Sciences, Hungary
- Performance of bulk populations of wheat compared with commercial cultivars
  Presenter: Jörg Peter Baresel, Technical University of Munich, Germany
- Stability of bulk populations of wheat compared with commercial cultivars
  Presenter: Jörg Peter Baresel, Technical University of Munich, Germany
- Intrinsic diversity enhances productivity and disease tolerance in bulk populations of wheat
  Presenter: Jörg Peter Baresel, Technical University of Munich, Germany
- Yield and quality of recently generated wheat populations compared with their parents and mixtures
  Presenter: Jörg Peter Baresel, Technical University of Munich, Germany
- A simple and effective method for estimating competitive ability of wheat varieties
  Presenter: Jörg Peter Baresel, Technical University of Munich, Germany
- Differences in breeding progress in winter wheat between conventional and organic farming in Germany
  Presenter: Samuel Knapp, Technical University of Munich, Germany
- Network for the dynamic management of winter barley genetic resources
  Presenter: Lorenz Bülow, JKI, Germany
- ECOBREED - Increasing the efficiency and competitiveness of organic crop breeding
  Presenter: Vladimir Meglič, KIS, Slovenia
- Nutritional characteristics of common buckwheat (*Fagopyrum esculentum* Möench) genetic resources
  Presenter: Lovro Sinkovič, KIS, Slovenia
- Harnessing crop diversity of common bean to preserve its nutritional quality under a changing climate
  Presenter: Marta Vasconcelos, Universidade Católica Portuguesa, Portugal
- Greenhouse gas emissions of diverse wheat populations vs. varieties
  Presenter: Robert Oliver Simon, Technical University of Munich, Germany
- On-farm winter wheat variety trials in organic farming
  Presenter: Mihály Földi, ÖMKi, Hungary

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European Conference on Crop Diversification
September 18-21, 2019
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Innovative Approaches to Optimize Genetic Diversity in Wheat for Sustainable Farming Systems of the Future (INSUSFAR)

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1 Introduction

More frequent occurrences of extreme weather conditions jeopardize agricultural sustainability. Additional challenges arise through the need to limit future use of fertilizers, pesticides and herbicides in order to reduce environmental impacts and energy use. Therefore, breeding goals need to include tolerance towards numerous abiotic and biotic stresses. Most breeding approaches aim to identify relevant stress factors and select single, preferably monogenetic traits conferring resistances or tolerances, while continuing to improve overall yield. However, due to the higher variability of environmental conditions, an alternative strategy such as the increasing of intraspecific diversity is of interest. The INSUSFAR project assesses the potential of highly diversified plant material based on multiparental wheat bulk populations for its potential to enhance the sustainability and resilience of future cropping systems.

2 Materials and Methods

INSUSFAR comprises of (a) a meta-analysis of the official wheat variety trials in Germany in order to assess the role of plant breeding in the development of yield and yield stability, (b) testing wheat populations with different genetic backgrounds and evolutionary histories in multiple environments, and (c) assessing stability in time and evolutionary changes of populations under different conditions.

3 Results

The variety trial data revealed that since the year 2000, wheat yield levels have stagnated and yield stability declined dramatically. Also, there was a notable difference between organic and conventional testing environments with the genetic gain being higher in more favourable environments. Many of the recently released varieties, though having a higher yield potential, reacted with stronger yield decrease in less favourable conditions indicating that high yield potential and tolerance towards a broad range of stress factors are difficult to combine in single genotypes.

Wheat composite cross populations with modern genetic backgrounds yielded as well as commercial varieties with comparable grain protein content. Regardless of the stability index used, yield stability and stability of protein content were always higher in populations than in pure line cultivars, confirming our hypothesis that breeding for diversity is a valuable strategy to enhance the resilience of cropping systems. Root analyses under hydroponic conditions revealed a continuous evolution towards higher seminal root length in seedlings from organically maintained populations compared to populations maintained under conventional conditions, pointing to the effects of the different forms and spatial distribution of nutrients available in the two farming systems. This demonstrates the potential of populations to adapt to certain environments.

4 Discussion and Conclusions

We conclude that populations with a complex genetic structure can compete with line varieties concerning yield and quality, but have a better buffering capacity towards environmental stresses, making populations a valuable addition to commercial varieties in order to cope with changing climate conditions.

Acknowledgements

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Information system ROBUSTUM for diversity breeding

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1 Introduction

Success of diversity breeding also depends on a consistent documentation of the breeding material used and generated. In contrast to classical breeding based on clearly defined uniform varieties and lines, reliable recording of the plant material used in diversity breeding is much more challenging as it deals with highly heterogeneous mixtures, landraces and populations. For example, the INSUSFAR project aims at analyzing the effects of biodiversity within winter wheat and winter barley populations on their ability to adapt to low input farming conditions. These populations were derived from complex crossings, were subdivided, have undergone years of adaptations by cultivation under diverse conditions and at different locations, and in order to clearly define the different populations, a comprehensive information system is needed that enables consistent documentation of population descendance and cultivation history. INSUSFAR furthermore analyzes historical data on the breeding progress during the past two decades and conducts socio-economic and ecological studies of farming systems. In addition, during the course of INSUSFAR, the individual project partners deliver a very diverse array of data that have to be stored and have to be provided to all project partners for further analyses. This is achieved by the implementation of a diversity breeding information system that meets the specific needs of the INSUSFAR project.

2 Materials and Methods

A comprehensive demand analysis was conducted to identify the individual needs of the project partners regarding the information system. Based on the contributions of the partners, 11 use cases are described that define the functional requirements for the information system. Varieties, lines and populations are defined as breeding material that can be linked by breeding actions. These can be crossing of parent varieties or lines, merging of multiple lines to form a population, multiplication, subdivision or cultivation of a population under certain conditions. Thus, the use cases cover all INSUSFAR aspects where data are generated, extracted, stored and retrieved including data on the origin of populations and pedigrees of varieties, data on cultivation conditions, genetic data, characterization and evaluation data from field trials, climate and soil data, historical trial data, as well as economic data. In addition, non-functional and technical requirements are defined within the demand analysis regarding user friendliness, maintainability, extendibility, flexibility and adaptability of the information system.

3 Results

A benchmarking with other information systems already existing or under development and based on the requirements for the INSUSFAR project revealed that no other information system is actually able to meet all requirements of the INSUSFAR project. The information system thus needs to be newly designed for INSUSFAR. However, some individual components from other information systems may be incorporated. This information system was named ROBUSTUM. To meet the short-term need to store and retrieve historical trial data, a basic database was designed and implemented in a first step and 11,888 records from German variety trials between the years 2001 and 2015 representing 307 varieties tested at 60 locations were imported into the database. The data can be retrieved by the project partners using a web-based user interface and query tool.

4 Discussion and Conclusions

The structure of ROBUSTUM was designed based on the use cases defined previously. Despite of a classical relational database running in the background, the user-system interactions of ROBUSTUM are based on activity diagrams to realize user-friendly modules with respect to breeding material import, editing, query, or export. The functionality for breeding material documentation and to record crosses as breeding actions was exemplarily tested using an entire MAGIC crossing scheme that starts with 32 winter barley varieties and that comprises 716 crossing steps and lines and that was imported into ROBUSTUM. For optimal illustration of such complex structures, and module for graphical display of pedigrees was also implemented. Furthermore, a functionality was designed that enables adding of further attributes to specific tables. ROBUSTUM will provide access to the data generated within the project also beyond the duration of INSUSFAR, and will furthermore comprise a flexible structure to serve as an information system template for related future diversity breeding projects.

Production risk in organic winter wheat cultivation - heterogeneous populations vs. pure line varieties

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1 Introduction

Functional (genetic) diversity is said to be especially important for resilient cropping systems (Howden et al. 2007). Genetically heterogeneous composite cross populations (CCP) of winter wheat show high adaptability (Döring et al. 2015) and yield stability (Brumlop et al. 2017). Therefore, composite cross populations may enable winter wheat producers to cope with increasing biotic and abiotic pressure due to climate change. However the question will be whether higher yield stability can economically offset the reduced yield potential.

2 Materials and Methods

An economic farm model based on a cost benefit analysis was established to compare net return and production risk of organic winter wheat production with CCP and pure line varieties. Two CCPs with both yield- and quality-oriented parent varieties (YQI and YQII) are compared with ten reference varieties (4 conventional cultivars, 4 from organic breeders, 1 hybrid, 1 feed wheat). The organic production system was modelled with a stochastic approach (Monte Carlo simulation) based on trial data, market prices and standard data. Using iterative simulations (20,000 model calculations), possible results of the target variables were calculated according to the probability distributions of the individual input parameters. Yield distributions were estimated from trial data from the INSUSFAR project (2016 and 2017) using maximum likelihood statistics. Discrete distributions were defined for machinery and labor costs.

Table 1. Model input parameters that are subject to Monte-Carlo-Simulation

Model input	Unit	Probability distribution	Comments
Yield	t/ha	continuous	estimated from field trial data (Maximum-Likelihood)
Quality	% Protein	continuous	estimated from field trial data (Maximum-Likelihood)
Market prices	€/ha	continuous	estimated from historical data (Maximum-Likelihood)
Machinery costs	€/ha	discrete	estimated based on field trial effects
Labor costs	€/ha	discrete	estimated based on field trial effects

The individual results of this stochastic simulation can be presented cumulatively as a curve with the corresponding probabilities of occurrence, the risk profile. Risk profiles were used to compare the agronomic options. The evaluation of risk profiles was based on the concept of stochastic dominance.

3 Results

The populations showed a high stability with a moderate economic performance (net return; €/ha). The conventional cultivar 'Achat' dominates the CCP YQI (1st order stochastic dominance) and so do 'Hybery', 'Elixer' and 'Kerubino'. The varieties 'Genius' and 'Poesie' as well as 'Capo' showed a higher net return but also a higher variance and therefore lower stability. Without knowledge of the individual risk-benefit function of decision makers, no recommendation can be given here. The organic varieties 'Butaro' and 'Wiwa' are dominated by the CCP with 2nd order stochastic dominance. If risk neutrality or aversion is assumed, CCPs are preferable here. Both CCPs showed a relatively low variance of results. CCP YQII dominated half of the reference varieties in the N-fertilization treatment. Especially in the scenario with N-fertilization a trade-off between stability and yield was observed. The hybrid variety 'Hybery' and the feed variety 'Elixer' had a high net return and therefore, despite higher variance, dominated the other varieties and the two CCPs.

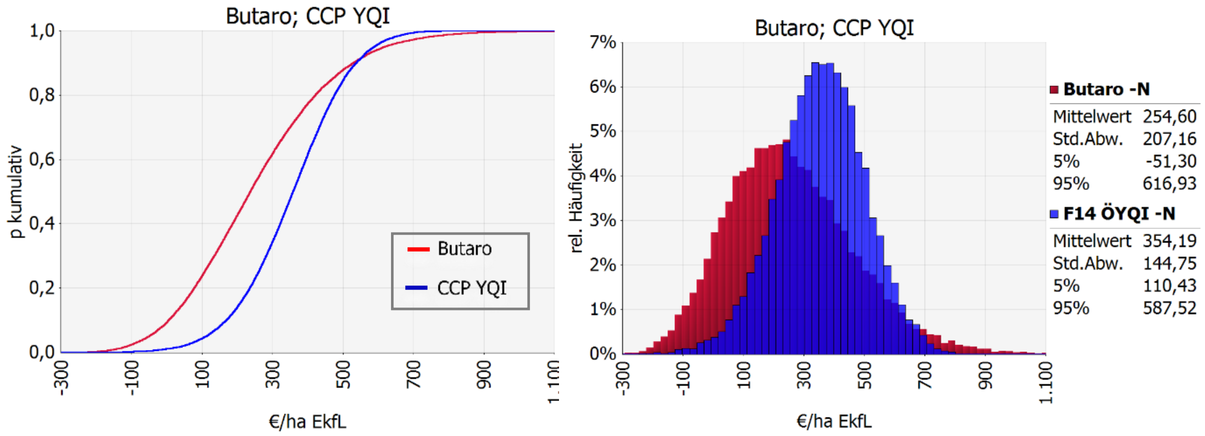

Figure 1. One example for a probability distribution (right) and the cumulative probabilities (left) of the net return [€/ha] of the composite-cross population YQI (blue) and the organic variety 'Butaro' (red)

4 Discussion and Conclusions

CCP economically outperform organically bred high quality varieties. CCP show equal performance compared with varieties popular in organic farming ('Capo'). However, even though they show lower variance CCP are economically inferior to modern high-yielding varieties.

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Economic performance of organic winter wheat production with composite cross populations

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1 Introduction

Diversity is often seen as a key to stable yields and resilient cropping system (Brenda 2011; Finckh 2008). Evolutionary plant breeding and the cultivation of genetically heterogeneous composite cross-populations (CCP) are an approach to increase diversity with the aim of achieving more stable yields (Döring et al. 2015). However, there is a trade-off between a high short-term yield potential for line varieties and the possible long-term yield stability of CCP.

2 Materials and Methods

The economic performance and production risk of CCP were calculated and compared with pure line varieties using cost benefit accounting. An organic production system was modelled based on field trial data (yield, quality), market information (prices) and standard data (machinery and labor costs) to calculate the net return of the winter wheat production. This paper compares two CCPs with both yield- and quality-oriented parent varieties (YQI and YQII) with ten reference varieties.

Table 1. Model entries

E-wheat (conv. bred)	hybrid-/ feed-wheat	E-wheat (org. bred)	CCP
Achat	Elixer	Butaro	YQI
Capo	Hybery	Poesie	YQII
Kerubino		Tobias	
Genius		Wiwa	

Systematic differences between CCP and pure line variety cultivation were identified in project field trials. For example, higher weed suppression was observed with CCP (Weedon et al., 2016), which affects machinery and labor costs. For risk analysis, stochastic simulation (Monte Carlo simulation) was performed using [at]Risk software. Probability distributions were used for various input parameters. Yield distributions were estimated directly from experimental data from the INSUSFAR project (harvest years 2016 and 2017). Simulations for two fertilization scenarios (0 kg N and 100 kg N) were calculated.

3 Results

In the scenario without N-fertilization, reference varieties from conventional breeders achieved the highest expected values with respect to the benefit-cost difference. All conventional varieties except 'Capo' were above 400 €/ha net return. The hybrid wheat 'Hybery' and the feed wheat 'Elixer' were clearly superior, but also the conventional quality varieties showed good results. The performances of the organic varieties and the CCP were below 400 €/ha. The CCP YQI and YQII had expected values of 354 €/ha and 357 €/ha respectively, they were ranked 9 and 10. The standard deviation (SD) was between 145 €/ha (CCP YQI) and 263 €/ha ('Elixer'). The variance of the CCP results was relatively low. YQI had the lowest standard deviation with 145 €/ha and YQII with 177 €/ha the third lowest. In summary: The CCP are inferior to the conventional varieties - except 'Capo'. They are comparable with the varieties from organic breeders and 'Capo'.

Table 2. Expected mean net return with and without nitrogen fertilization

+ 100 kg N			0 kg N		
Entry	**Mean in €/ha**	**SD in €/ha**	**Entry**	**Mean in €/ha**	**SD in €/ha**
Hybery	**869,5**	257,4	Hybery	**702,6**	208,0
Elixer	751,6	251,3	Elixer	564,9	262,7
Genius	629,8	214,5	Achat	512,9	183,0
Achat	563,7	220,7	Genius	476,6	236,7
Kerubino	429,3	267,5	Kerubino	435,0	189,4
CCP YQII	419,2	**142,4**	*Poesie*	*371,6*	*257,4*
Poesie	*415,3*	*215,1*	*Tobias*	*366,5*	*159,6*
Tobias	*410,7*	*185,5*	Capo	366,1	187,6
Capo	400,2	249,7	CCP YQII	357,0	176,6
Wiwa	*366,7*	*213,3*	CCP YQI	354,2	**145,1**
CCP YQI	361,0	184,4	*Wiwa*	*308,1*	*214,4*
Butaro	*297,5*	*176,1*	*Butaro*	*254,6*	*207,2*

SD: green <200 €/ha; yellow 200 - 240 €/ha; >240 €/ha
Italic letters: organically bred varieties

In the treatments with N fertilization, the five conventional varieties achieved the highest expected values. 'Hybery' was 1st with 869 €/ha and 'Butaro' was 12th with 297 €/ha. The CCP YQII with 419 €/ha ranked 6th just behind the conventional varieties, the CCP YQI had the second lowest performance with 361€/ha. The standard deviation was between 142 €/ha (CCP YQII) and 267,5 €/ha ('Kerubino'). The variance of the CCP results was in the lower range. YQII with 142 €/ha had the lowest and YQI with 184 €/ha the third lowest standard deviation.

4 Discussion and Conclusions

The cultivation methods of CCP and varieties in organic agriculture hardly differ. A considerable cost saving by a conversion to CCP is not to be expected. Therefore, revenues mainly influence the economic performance. Revenue is influenced, apart from yield, also by quality. Whether a variety/population gains excellence through differences in protein content depends on the yield difference and the price margin of the quality levels.

At the field trial sites, the CCPs were productively and economically at the same level as the varieties from organic breeding, with the CCP YQII having the highest net output with N fertilization behind the conventional varieties. As expected, these results fit in with previous studies on yield stability by Weedon et al. (2016). Simulations of on-farm conditions and soil conservation cultivation suggest that the CCP can also compete with varieties from conventional breeding. However, these calculations are based on a very small data base, so that further investigations are necessary in order to make reliable statements. An economic performance at the same level as popular varieties from organic breeding indicates CCPs competitiveness under low-input conditions.

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Performance, diversity and stability of population-varieties developed within a wheat participatory breeding program in France

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1 Introduction

Modern agricultural systems rely on very little crop genetic diversity, especially with the use of homogeneous elite varieties grown on large areas. However crop genetic diversity within fields is a lever for a more sustainable production (Østergård et al. 2009), allowing for a greater stability through combined resistances to biotic and abiotic stresses (Kiaer et al. 2012, Finckh et al. 2000, Mundt 2002). In France a Participatory Plant Breeding (PPB) project has been applied on bread wheat since 2006, involving farmers, facilitators of the farmers' seed network Réseau Semences Paysannes (RSP) and INRA researchers (Diversity, Evolution and Adaptation of Populations team). The project aims at developing farmers' varieties that are adapted to farmer's objectives and needs based on decentralized selection in farmers' fields (Rivière et al. 2013). Methods and tools for on-farm breeding were developed to help farmers' reappropriation of on-farm breeding knowledge and seed autonomy. This project leads to the development of heterogeneous populations-varieties whose within-variety genetic diversity is expected to enhance the capacity to adapt to farmers' practices and environments.

2 Materials and Methods

In a two-years experiment on six farms presenting contrasted pedo-climatic environments, we evaluated the agronomic behavior of ten of the first populations developed by farmers within the PPB program (hereafter PPB populations) compared to two commercial pure line varieties. In each farm, the trial consisted in a complete randomized two blocks design. Morphological and agronomic traits have been measured such as plant height, spike length and weight, spike color, curve and presence of awns on individual plants, and thousand kernel weight, protein content and yield at the plot level. We searched for local adaptation of the PPB populations, considering the farm where they have been selected as their home and testing local vs non local status. Stability over time was quantified by the coefficient of variation of each variety associated to the *Year* effect and *Year x Farm* interaction. Within-variety genetic diversity, quantified by the Nei index, was assessed using SNP markers on 90 individuals per population and 30 individuals per commercial line. These markers were located in neutral zones of the genome (52 markers) and on candidate genes for heading precocity (34 markers).

3 Results

For most measured traits, although the *Population* effect was limited except for spike color and presence of awns, the *Population x Farm* interaction was larger than the *Population x Year* interaction, highlighting the potential to select populations adapted to environments and practices. Some PPB populations had very interesting responses when considering grain yield, protein content as well as biomass production and weed competitiveness as they were taller than the commercial pure lines. Six of them were not significantly less productive than the two commercial pure lines when comparing overall grain yield per population. These varieties were interesting especially in less productive environments were they yielded more than commercial lines. While significant *Population x Farm* interactions were found for yield and yield components, no clear

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pattern of local adaptation was detected. However, we found that populations' protein content was more stable over years than that of commercial pure lines, as the mean coefficient of variation associated to *Year* effect and *Year x Farm* interaction were 23.8% and 35.3% respectively (p=0.03). Moreover, protein content stability over time was positively correlated to within-variety genetic diversity (R=0.58, p=0.047), with no significant drawback on protein production (R=0.38, p=0.22).

Figure 1. A commercial pure line surrounded by PPB populations

4 Discussion and Conclusions

These results seemed promising to the farmers involved in the PPB process, as they exhibit interesting yield and protein content compared to commercial varieties – one of which, Renan, is widely used in organic farming. They also show the wide adaptive potential of PPB populations, stressing the importance of seed exchange networks for agrobiodiversity conservation and use. They emphasized the benefits of genetic diversity for stability over years which is of great interest to farmers.

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Yield stability and yield variability of diverse wheat populations to inter- and intra-site heterogeneity

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1 Introduction

Future farming systems will have to compensate for lower fossil fuel inputs in order to diminish the impact of agricultural systems on climate change while mitigating the rising yield instability induced by climate change. One way to compensate is the introduction of cropping systems on a higher self-regulation level of crop diversity, including morphological and disease resistance variability of genotypes (Howden et al. 2007). These properties could lead to a higher yield stability when exposed to unfavorable growing conditions, such as water or nitrogen scarcity (Becker and Léon 1988, Evans 1993). In order to assess the potential for higher yield stability of diverse crop populations, the inter-site heterogeneity as well as the intra-site heterogeneity can be addressed, where inter-site means differences with a relatively large scope such as climate or soil type and intra-site referring to a smaller scope of site conditions such as a variation in field moisture capacities.

2 Materials and Methods

We evaluated the crop yield, yield variability, and yield stability of composite cross populations (CCPs, Döring et al. 2015) of winter wheat (*Triticum aestivum* L.) compared to wheat line varieties in four-year field experiments in several heterogeneous environments. The field experiments were located on eight German farms with varying site conditions among and within them (2 farms in Hesse, 2 farms in Baden-Wuerttemberg, 4 farms in Bavaria). Each of the sites was classified into categories low, medium, and high using the sites' mean yield levels. On each of the farms a highly heterogeneous plot was chosen in order to assess the varieties' reaction to inter-site heterogeneity. At each site, a high-yield, high-quality composite cross population, CCP YQ, a high-quality composite cross population consisting of newer line varieties, CCP Q, as well as the reference variety Florian was compared to each farms' wheat variety (Akratos, Ataro, Reform, Wiwa). Varieties were sown in strips with a length of at least 100 m. Yield was recorded for plots set equally along the strips. Based on kernel yields, environmental variance (S^2) and Wricke's ecovalence (W^2, Wricke 1962) were calculated. Water capacity was used an indicator of sites heterogeneity. Field capacity was assessed by manual sampling and by measuring the electric conductivity (Heil and Schmidhalter 2017). Based on the field capacity and yield values, maps indicating three zones within the site (high, medium, and low) were interpolated using ordinary kriging (Cressie 1988).

3 Results

With respect to the inter-site heterogeneity, there was significant difference between the observed yield levels among all farms (low: 3.4 t ha^{-1} at 86% DM, medium: 5.7 t ha^{-1}, high: 7.9 t ha^{-1}). Mean yield levels showed no difference within low and medium yield sites (low: 3.3-3.6 t ha^{-1} at 86% DM, medium: 4.8-6.0 t ha^{-1}), but significant difference within the high yield farms (7.4-9.0 t ha^{-1} at 86% DM). Yield variances of the genotypes differed for low and high yield areas but not for medium yield area. At the low yield area, Florian showed the highest variance, while both populations showed the lowest variance. At the high yield area, CCP Q showed the lowest variance, while CCP YQ and Reform showed the highest. For W^2 across yield categories, both composite cross populations had the highest stability while line varieties performed worse. S^2 showed highest stability for Reform and CCP Q, followed by Florian. CCP YQ showed the lowest stability using this parameter.

4 Discussion and Conclusions

In our assessment of intra-site heterogeneity, field capacity showed a high explanatory power regarding yield levels (R^2=0.64). The yield levels among the three yield zones, regarding both line variety and composite cross populations, showed significant differences. Within the high yield zone, Florian showed higher mean yields compared to the composite cross populations, while both populations showed lower yield variance.

Yields within the medium yield zone showed no difference in yield or yield variance, regardless of variety. Although yields within the low yield zone were not different, yield variance for both populations were significantly larger than for Florian. The results could point to a difference in water use efficiency between line variety and populations.

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Agronomic performance of 200 winter wheat lines selected from a Composite Cross Population (CCP) in a low-input system

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1 Introduction

The use of wheat composite cross populations (CCPs) as an alternative to pure line varieties can contribute to yield stability due to a higher degree of buffering capacity towards biotic and abiotic stresses (Dawson and Goldringer, 2012). Furthermore, such genetically diverse populations allow for adaptation to specific environments and agricultural systems, thereby ensuring greater resilience (Costanzo and Bàrberi, 2013). Hence, CCPs can cope with expected limitations to pesticides much better than genetically uniform varieties and are therefore a valuable approach for sustainable crop protection (Storkey et al., 2019).

CCPs can also serve as important source for selection of phenotypes with desired traits, such as disease resistance towards pathogens (and new races), drought stress, nutrient use efficiency, etc. However, it is still unclear whether novel molecular methods, such as association mapping or marker assisted selection, can be adequately applied to CCPs. Accurate knowledge of underlying phenotypic traits of a given population is required if association analyses should be performed. This study focusses on the agronomic performance of 200 lines selected randomly at the Techincal University of Munich in 2015 from single plants of a CCP maintained there since 2008. The CCP has been created in 2001 in England via the half diallel crossing of 20 genetically diverse parents with high yield and/or baking quality potential (Döring et al., 2015). There were no specific selection criteria within the population to demonstrate a high genotypic and morphological variation.

2 Materials and Methods

The lines were sown in October 2017 and 2018 in organic (low-input) fields at the University of Kassel together with a CCP from which the lines had been selected previously. The pre-crop was grass-clover. Each line was sown at 350 seeds m^{-2} in 5 x 1.5 m and 7 x 1.5 m plots in 2017 and 2018, respectively, in three replicates. Throughout the season, field emergence, soil cover at BBCH 30 (early vigour), foliar disease severity, plant height, biomass (straw, total), fertile ears m^{-2}, harvest index, and grain yields (machine and hand harvest) were assessed. These data will be additionally used for genome wide association studies (GWAS). Data of the season 2018/19 will be available at the conference, but are not included here. Data were analysed with R version 3.6.0 using the package '*psych*' for matrix correlations.

3 Results

Results of the first experimental season were affected by yellow rust (*Puccinia striiformis*) in spring. In addition, a severe spring and summer drought that, in combination with a late brown rust (*Puccinia recondita*) epidemic caused early ripening of all selected lines. Thus, susceptible varieties lost about 50-60 % of the green leaf area through yellow rust already by the end of May while on average 90% non-green leaf area was assessed among all lines on 25th of June. For these reasons, grain yields were low, ranging from 2.4 to 4.6 t ha^{-1} with an overall average of 3.8 t ha^{-1}. Both yellow and brown rust affected lines yielded up to 35% less than the mean (-0.54, $P > 0.01$; Pearson's product moment correlation; Table 1) while very resistant lines were on average only 7.5% better than the overall average. There was no correlation between plant height and grain yield (-0.14, $P = 0.71$) (Table 1).

Table 1. Pearson correlation coefficient matrix of wheat agronomic traits in the GWAS field experiment 2018. * and ** indicate significant linear correlations (Holm adjustment) at P< 0.05 and P<0.01, respectively.

	Soil cover	Emergence	AUDPC	Plant height	HI	Straw yield	Fertile ears	Biomass
Yield	0.25*	-0.03	-0.54**	-0.14	0.4**	0.32**	0.24*	0.53**
Soil cover[1]	-	0.03	-0.19	0.27**	-0.22*	0.47**	0.2	0.42**
Emergence		-	-0.03	-0.1	-0.07	0	0.33**	-0.03
AUDPC[1]			-	0.12	-0.17	-0.24	-0.15	-0.33**
Plant heigth				-	-0.63**	0.43**	-0.01	0.2
HI[1]					-	-0.43**	-0.09	-0.04
Straw yield						-	0.58	0.92**
Fertile ears							-	0.6**

[1] Soil cover at BBCH 30; AUDPC = Area under the disease progress curve; HI = Harvest index.

4 Discussion and Conclusions

In the season 2017/18, wheat traits were predominantly affected by drought and rust diseases. Slafer and Araus (2007) pointed out that breeding for semi-dwarfism in the past had improved overall stress tolerance in small grain cereals. This suggests that short plants were more tolerant to reduced water availability than tall plants resulting in the greater yield performance under the extreme conditions of the year 2018. This would further explain why positive correlations between plant height and grain yields that generally occur under humid conditions (Law et al., 1978), were not observed in our study. As some lines yielded about 25% more than the overall average, we hypothesize that other plant characteristics related to drought resistance, such as root-to-shoot ratio, flowering time, leaf rolling, etc. may have improved their performance (Bodner et al., 2015). For these reasons, the CCP lines may serve as a valuable source for detection of chromosomal regions that are responsible for drought tolerance and probably other traits that help to overcome drought stress.

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Evaluating and selecting root traits in wheat in a hydroponic system for adaptation to organic farming

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1 Introduction

Traits conferring competitiveness of wheat plants are crucial for weed tolerance and weed suppression (Andrew et al., 2015) and therefore hold the potential for reduced chemical or mechanical weed management. Moreover, competitive ability is also a key trait of crop plants for their suitability within species mixtures as an approach for diversification (Annicchiarico et al., 2017). While above ground traits conferring competitive ability in wheat such as height and ground cover can be assessed with sufficient efficiency in the field this is much more challenging for root traits. Therefore, Bertholdsson et al. developed a hydroponic system for root phenotyping (Bertholdsson et al., 2016). We used this hydroponic system to study evolutionary changes in root traits of composite cross populations (CCPs) under organic and conventional farming.

2 Materials and Methods

Early vigour was assessed in spring 2018 using a hydroponic system based on Bertholdsson et al., (2016). Seeds were grown in containers (20 L) filled with a balanced complete nutrient solution with a phosphate buffer (pH 6.5) (Larsson, 1982) at 2mM N concentration. The seeds were placed in strips of corrugated cardboard with 10 mm within row spacing with the embryo facing down towards the solution and suspended over special frames into the hydroponic containers and connected with filter paper strips as wicks with the solution. The lower part of the cardboard was ironed beforehand to prevent seeds from falling down. The plants were grown in a greenhouse with 18/12 oC (day/night) temperature regime for two weeks at a photoperiod of 16 h supplemented with artificial light to maintain a minimum light intensity of 250 µ mol quanta m-2 s-1. The 13 entries were randomized as rows of ten plants per entry in a single container and replicated eight times. The nutrient solution was renewed after seven and ten days and aerated by continuous bubbling of air through the solution. Every two days, two replicates were sown to allow sufficient time for handling and processing of the plant samples after each harvest.

3 Results

CCPs evolving under organic conditions exhibited significantly increased seminal root length, root weight and decreased total and specific root length compared to CCPs evolving under conventional conditions. In addition, we found that wheat root traits of conventionally and organically bred varieties only differed systematically in average root diameter that was higher in organic varieties. Also, seminal root length and shoot length measured in hydroponics correlated with ground cover and shoot length measured in the field. This supports the hypothesis that fine and shallow root systems represent an adaptation of wheat varieties to high inputs of soluble inorganic fertilizer and it opens the possibility to non-destructively select in hydroponic systems for root traits conferring competitive ability.

4 Discussion and Conclusions

Building on these results, we selected wheat plants in the hydroponic system for contrasting seminal root length from a CCP evolved in an organic farming system (OYQ2). 20 Plants with the longest and 20 plants with the shortest seminal roots were selected from each of two batches of hydroponic culture (201 and 222 individuals). Subsequently we transferred 80 plants to 10 l pots with a mixture of sand, peat and field soil. The next generation of selected plants will again be phenotyped in the hydroponic system to evaluate the effect of selection based on root traits.

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Evaluation of the impact of wheat/rye translocation on the stability of wheat doubled haploids in different environments

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1 Introduction

Winter wheat is the main cereal crop species in Poland. For cultivation, better-yielding varieties are developed, but these are not always more resistant to biotic and abiotic stresses. To improve the characteristics of winter wheat, alien resources are used in breeding; for instance, the short arm of rye chromosome 1 (1RS) has been incorporated into chromosome 1B of the wheat genome (1BL). Wheat cultivars carrying the 1B/1R wheat-rye translocation frequently exhibit better agronomical features than cultivars without the translocation.

In wheat breeding, in addition to traditional methods, doubled haploid (DH) and single seed descent (SSD) techniques have been used for the creation of new genotypes with desirable properties (Adamski et al. 2014).

2 Materials and Methods

The main purpose of this work was to investigate whether the 1B/1R translocation present in some winter wheat varieties has an influence on the yielding capacity of DH and SSD lines with and without wheat-rye translocation, and their response to different environmental conditions (Adamski et al. 2014). To achieve this goal, a series of field experiments was conducted in four different environments, each in a complete block design with two replications. In each experiment the same 20 DH lines and 20 SSD lines were grown. Grain yield, plant height and thousand-grain weight were measured.

There are many methods of analyzing the results of series of experiments. An important part of this analysis concerns the structuring of genotypic-environmental interactions. In this work, the analysis is based on the randomization- derived mixed model of observations from series of experiments (cf. Caliński et al. 2005). In particular, statistical methods—one-dimensional as well as multidimensional—and appropriate methods of structuring genotype-by-environment (GE) interaction were applied. They enabled:

- evaluation of the studied DH and SSD lines, taking into account various aspects of their interaction with environments, and assessment of their main effects and interactive effects;
- analysis of interesting comparisons between lines with and without 1B/1R translocation in terms of their main effects and interactions with environments;
- investigation of the structure of GE interaction by determining the participation of particular environments in their interaction with lines.

Analysis of a series of experiments also provides the possibility of selecting lines that are stable and unstable in various environments. Lines exhibiting high adaptive ability will be used in breeding new wheat varieties. The results of statistical calculations will indicate whether the translocation affects the occurrence and level of genotype-by-environment interaction.

3 Results

The results of evaluation of the studied DH and SSD lines are given, taking into account various aspects of their interaction with environments. Analysis of variance performed for a series of experiments with 40 DH and SSD lines, translocated and untranslocated, for three traits showed significant differences between environments and genotypes. Genotype-by-environment interaction was not significant only for plant height. The structure of GE interaction was also investigated, by determining the participation of particular environments in their interaction with lines, as well as the participation of particular DH and SSD lines in their interaction with environments. Analysis of a series of experiments also provided the possibility of selecting lines that are stable and unstable in various environments. The testing of the significance of DH and SSD lines main effects and their interaction with environments made it possible to distinguish SSD translocated lines with positive and significant main effects for all studied traits and SSD lines.

4 Discussion and Conclusions

Analysis of a series of experiments provided the possibility of choosing lines that are stable and highly yielding in various environments. Comparison of average yields for types of genotypes made it possible to distinguish SSD translocated (SSDT) as the highest yielding lines. The results of statistical calculations showed that translocation may have a significant influence on the yield of lines and the level of their interaction with the environment. Further research should be conducted into this issue.

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Yield potential of heterogeneous wheat populations under differing fertilizer regimes in an organic system

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1 Introduction

The unpredictability of future climatic conditions, as well as the growing pressure to reduce agricultural inputs, present a huge challenge for breeders and farmers to create more resilient crop varieties and develop future agricultural systems able to buffer changing and increasing abiotic and biotic pressures. European wheat varieties have a limited ability to react to present environmental conditions (Kahiluoto et al. 2019), leading to limited varietal resilience in the face of climate fluctuations. Evolutionary breeding aims to take advantage of increased genetic diversity in order to create crop populations with greater capacity to react to stress factors, to allow for adaptation to specific environments and agricultural systems over time, as well as to contribute to the dynamic management of genetic resources. The mechanisms of crop diversity such as co-operation, compensation, complementation and capacity (Döring et al. 2011), present within genetically diverse populations allows for greater response plasticity, which is of particular interest in organic systems characterized by higher abiotic and biotic stresses (Annicchiarico and Filippi 2007). One of the aims of the INSUSFAR (Innovative Approaches to Optimize Genetic Diversity in Wheat for Sustainable Farming Systems of the Future) project is to optimise intra-specific diversity for specific farming systems and to test the potential of such heterogeneous populations against pure line commercial varieties from different breeding origins.

2 Materials and Methods

In 2017/18, 21 heterogeneous winter wheat populations, 4 mixes (50:50 population:variety), as well as 10 commercial varieties from both organic and conventional breeding programmes were tested under both Low-Input (LI, 0kg N/ha) and High-Input (HI, 100kg N/ha) conditions in an organic field trial with four replicates. Assessments include groundcover (%), heading date, foliar and foot rot disease assessment, yield and yield parameters, protein and sedimentation value. The second trial is on-going.

3 Results

The year of 2017/18 was characterized by extreme drought resulting in low grain yields, ranging from 1.8-3.2 t/ha under 0kg N/ha and from 1.9-3.7t/ha under 100kg N/ha. Despite the dry conditions, the majority of the heterogeneous populations achieved significantly higher yields than the organically-bred E-class (baking quality) varieties and were comparable to conventionally-bred C (fodder quality) and E (baking quality) class varieties. The main foliar pathogen was brown rust (*Puccinia recondita*). The foliar disease severity was low to moderate from 17 to 41 % non-green leaf area (NGLA) at BBCH 70 (grain development stage). Under both fertility treatments, the heterogeneous populations had similar disease levels as the reference variety groups apart from the C class variety Elixer, which was highly susceptible to brown rust.

4 Discussion and Conclusions

The initial results show the potential of heterogeneous populations to buffer abiotic and biotic stress. This should be exploited in order to increase intra-specific diversity within the agricultural landscape and to encourage the use of adapted populations to specific environments. Results of the second experimental year (2018/19) will also be included.

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Heterogeneous wheat populations as a viable alternative to commercial varieties under organic management

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1 Introduction

Heterogeneous populations are of great interest not only for their agronomic performance and yield stability, but also for selecting for improved wheat quality in organic systems while maintaining intraspecific genetic diversity for optimal resilience to biotic and abiotic stresses. Under the Council Directive 2014/150/EU, the marketing of heterogeneous populations of wheat, oats, maize and barley is now permissible. A number of heterogeneous wheat populations have been registered and are available on the market. The potential of 11 wheat populations of differing origins in comparison to five commercial reference varieties was assessed in a replicated two-year field experiment under organic conditions.

2 Materials and Methods

In 2005, the F_4 of three winter wheat composite cross populations (CCPs) based on 9 high yielding parents (OY), 12 baking quality parents (OQ) or all 20 parents (OYQ) arrived at University of Kassel, Germany, from the John Ines and Organic Research Centres, UK. Since their arrival, these three populations have been growing in about 150m^2 plots each under organic management with two parallel non-mixing populations. In 2016/17 and 2017/18, these six populations (F_{16} and F_{17}) were compared to four additional commercial populations, two from Dottenfelder Hof (Germany) and two MAGIC populations from the National Institute of Agricultural Botany (NIAB, UK). Five commercial pure line varieties were included as reference in the two-year experiment using a randomized complete block design with 3 replicates. Agronomic parameters such as grain yield, thousand grain weight and protein content, foliar and foot rot diseases and lodging were recorded.

3 Results

Grain yields in 2016/17 ranged from 5.3 to 6.2t/ha, with only the varieties ‘Achat’, ‘Capo’ and the populations ‘OYQII’ and ‘NIAB Elite’ reaching yields above 6t/ha. Three populations were particularly prone to lodging (>50% of the plot). Foliar disease incidence was low for all entries, foot rot diseases were moderate with little difference between entries. The season 2017/18 was marked by extreme drought and a strong epidemic of brown rust (*Puccinia recondita*). Grain yields of the populations ranged from 3.4 to 4.2 t/ha, for the pure varieties from 3.3 to 3.8 t/ha. The populations ‘NIAB Elite’, ‘Brandex’ and ‘OYI’ achieved the highest yields and the commercial variety ‘Wiwa’, the lowest. Area Under the Disease Progress Curve (AUDPC) ranged from 492 for the variety ‘Tobias’ to 823 for the variety ‘Poesie’. With the exception of ‘Tobias’ the populations had lower AUDPC values in comparison to all commercial varieties.

4 Discussion and Conclusions

Overall, heterogeneous wheat populations performed as well as currently grown pure line varieties, with some populations such as ‘NIAB Elite’, ‘OYQII’, ‘Brandex’ and ‘Liocharls’ showing great potential as viable alternatives to a number of commercial varieties.

Acknowledgement

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White lupin (*Lupinus albus* L.) with increased fat and reduced alkaloids content.

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1 Introduction

Crops diversification provides the farmers with a wider choice in the production of a variety of crops in a given area so as to expand production related activities on various crops. Apart from cereals a very large group of various crops constitute legumes. During recent years legume reintegration in cropping systems and crop rotation have increased. Main advantages of this group of crops – N-fixation and high protein content – result from a symbiosis with root bacteria and nitrogen contributed by legumes can be supplied for to subsequent crops. Apart from yellow lupin and narrow-leafed lupin the third lupin crop cultivated in Poland is white lupin. As a leguminous plant both fertilizing soil and giving high protein, green matter and dry seeds white lupin can play more important role in the Polish agriculture. With regard to crop diversification as a strategy for food and nutritional security, undoubtedly white lupin is a good diversification option in Poland; the area under white lupin in Poland may increase when its nutritional properties are improved, i.e., when its alkaloid content is decreased and its fat content is increased; as such, the authors aim to identify hybrids with low alkaloid content and high fat content.

2 Materials and Methods

The research material comprised 60 hybrids of F_4 progeny originated from various combination of selected white lupin accessions and cultivars used as parental components for crosses. The collected seeds were analysed in term of theirs chemical components. Total alkaloid content and individual alkaloid composition were evaluated by gas chromatography. Soxhlet analysis was performed in order to quantify seed oil in 120 F_5 hybrids. Composition of fatty acids was determined using the Hewlett Packard gas chromatograph.

3 Results and Discussion

Obtained results indicate on broad variation of alkaloids content from 0,0014 to 0,1417 % in the cross combination cv. Lotos x Butan; 0,0055 – 0,0307 % in the combination Amiga x Boros and 0,0004 – 0,0395% in the combination Amiga x Pikador. Average alkaloid content in analysed combinations was: 0,0447%; 0,0167% and 0,0091% respectively as compared to 0,0242% in seeds of high yielding Polish standard cultivar Butan. The highest number of low alkaloid accessions (on the level 0,0004%) was found in hybrid seeds of Amiga x Pikador combination. Alkaloid composition expressed in percentage of total alkaloid content was highly differentiated. Three major alkaloids (abundance > 10 %) were revealed: lupanine, 13-hydroxylupanine and 13-benzoyloxylupanine. In examined hybrid seeds, lupanine was the highest alkaloid in all the combinations, ranging from 32 to 100 % for few hybrid with the lowest alkaloid content on the level 0,0004%. In terms of second analysed traits – fat and fatty acids content initial material constituted three crossing combination. On considered selections, one of them produced the most valuable recombinants (cv. Kalina x wild accession – AL22), used for obtaining F_5 plants. Among them 120 were selected and estimated for fat content and fatty acids composition. The average fat content for analyzed recombinants is 13,6% as compared to average content of parental forms on the level 12 %. Obtained results ranging from 12,1% to 15,6% indicate on very broad variability of fat content in hybrid seeds. Among them in seeds of twenty two plants the fat content exceeded 14%. From a dietetic point of view more important as quantity in lupin seeds is the quality of oil (Boschin at al. 2008). On average the fatty acid in examined materials ranked in following order of abundance: oleic acid ($C_{18:1}$) > linoleic acid ($C_{18:2}$) > linolenic acid ($C_{18:3}$) > palmitic acid ($C_{16:0}$) > eicosenoic acid ($C_{20:1}$) > stearic acid ($C_{18:0}$) > erucic acid ($C_{22:1}$). As a consequence, in relation to linolenic and linoleic content the examined white lupin seeds showed a very favorable ω-3/ω-6 fatty acids

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ratio (0,51) ranging from 0,38 to 0,65. Similar, very favourable ω-3/ω-6 ratio ranged from 0,49 to 0,79 obtained Boschin et al. (2008). The high number of accessions with particularly valuable essential linolenic acid content (ω-3) detected Rybiński et al.(2018) in the wild lines of Polish white lupin collection. The high value of ω-3/ω-6 fatty acids ratio is typical of white lupin whereas other lupin crops i.e. yellow lupin and narrow-leafed lupin, have lower ω-3/ω-6 ratio due to a much higher linoleic acid content (Rybiński et al. 2014).

4 Conclusion

Analysis of the seeds of obtained white lupin allowed to recognize hybrids with decreased alkaloid content and increased fat content in term of theirs potentially use as a good diversification option in Polish agriculture.

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Nitrogen and phosphorus use efficiency in the recombinant [*accacia*×normal leaf] lines of a mapping population of field pea (*Pisum sativum* L.)

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1 Introduction

In European countries productivity of field pea is considerably affected by instabilities in water and nutrient accessibility. In these conditions, yield potential depends on plant physiological capacities to an efficient utilization of environmental resources (water, nutrients).

2 Materials and Methods

In field experiments 2018, variance and co-variance between components of nitrogen and phosphorus efficiency was evaluated among lines of the Polish mapping population [Wt10245□Wt11238] during the whole growth season under varied nitrogen nutrition. To assess the correlation between seed yield and the efficiency of nitrogen utilization, field experiments were carried out in the different climatic and soil conditions (Wiatrowo, 2 locations, Przebędowo, one location, 2 replicates in each location). The soil analysis was carried out. They concerned forms of nutrients available for plants.

3 Results

The yield from a plant was the largest in Wiatrowo, in the optimal location (6.6 g/ plant), the smallest in Przebędowo (5.0 g/ plant). The yield in "optimal" and "weak" Wiatrowo location was lower than in the previous year in this population [Wt10245×Wt11238]. In Przebędowo, the yield was higher than in the previous year. The pea yield and nitrogen utilization efficiency (NER_{gen}) were positively correlated in optimal and stress locations (Wiatrowo, optimal conditions r=0.72, stress conditions: Wiatrowo r=0.67, Przebędowo r=0.62). The seed yield and phosphorus utilization efficiency (PER_{gen}) were positively correlated in optimal condition (Wiatrowo, r=0.91).

4 Discussion and Conclusions

Soil treatment effects (E) were significant for yield, amount of seed weight/amount of nitrogen accumulated in seeds (Gw/Ng), $\%N_{gen}$, $NER_{gen,}$ nitrogenase activity N although genotype-treatment (G-E) interactions were significant for all characters, except nitrogen content in vegetative mass ($\%N_{veg}$). Noteworthy, relationships between GY and nitrogen efficiency were weaker in nitrogen-limited conditions (optimal conditions r=0.72, stress conditions: Wi, r=0.67, P, r=0.62).

The results indicate that the importance of components of physiological efficiency for pea yielding decreases in the sub-optimal conditions. Broad variability of all physiological traits gives a high probability QTL mapping with success.

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Opportunities of diversification of the cereal centric organic farm system with soybean production in Hungary

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1 Introduction

Today soybean is one of the most important plantbased protein and vegetable fat sources for the most countries in the world. Production exceeded 340 million tonnes in 2018, of which only about 20% is GM-free, with only one fifth of this is certified. In the past decade the cropping area of soy has increased in Hungary to approximately 70.000 hectares. Organic soy bean production area is currently ca. 1.000 ha. This area is less than the possible areas in our agro-ecological conditions. The soybean for forage is needed in Hungary as well as in the rest of the EU to supply organic livestock's. Moreover, soya as a leguminous crop can diversifying the cereal centred crop rotations, what is currently dominant in the country.

2 Materials and Methods

This paper summarizes research results of organic soya production, which conducted at three cereal centric organic farms in 2018 in Hungary, in frame of the DiverIMPACTS project.

Growing conditions also varied among the different research sites (Table 1). The aim of our on-farm research is to sample results from regular farm operations, so farmers were allowed to growing with their standard production methods, and only the varieties being changed for each test plot. Each test was conducted on 0.25-0.5 ha per variety in stripe design.

Trial sites were located in West-Transdanubia (Tornyiszentmiklós - 1, Miháld - 3, and the East-Hungarian Plain in Tiszaigar - 2). Objective of the research was examining the possibility of successful soy cultivation and to determine the specific varieties of soybean which favour these areas. Early maturity varieties (ES Mentor, Aires, Borbála, S0880) were tested as main crops at sites 1 and 2, super early varieties (Merlin, Bettina, Regina, Amandine were assessed as second crops at site 3. During the trial period we recorded weather conditions and at the harvest the phenological parameters of plants, calculated the weight of yields, measured the oil and protein content (%) with NIR-analiser (Mininfra).

Table 1. Growing system parameters at the research sites (2018)

Research site	Tornyiszentmiklós	Miháld	Tiszaigar
Aspect of soybean cultivation	optimal location (soybean yields are 2.5-3 t/ha in this area	optimal location	droughty (soybean yields are 1.5-2 t/ha in this area)
Humus content of soil (%)	1.5	2	1.4
Fore crop	maize	spelt	winter barley
Date of sowing	23. 05.	28. 05.	01. 07.
Row spacing (cm)	50	75	48
Number of plants	600	400	600
Time of maturity	01. 10.	20. 09.	25. 10.

3 Results

At location 1 the fore crop was maize. The yields were 2.6-3 t/ha, depending on the variety. The protein content was mostly around 40%. This yield is considered to be favourable, especially without irrigation and t fertilization. The precipitation was during the main growing period (from May to August) 535 mm, which was more than the average, and despite the maize precrop, weed control was successful because the necessary machinery was available (the weed density was under 5 % at the harvest). The best performing variety was Borbála. At location 2 spelt was the fore crop. The soybean yields were 1.5-1.7 t/ha, the protein content was mostly 35-37%. The precipitation was only slightly above 100 mm in the main growing period (from May to

August). An extreme drought characterized this cropping year in the region. Despite the favourable fore crop and the efficient weed control the weed density was under 10 % at the harvest), the low precipitation was decisive for the yields of all varieties. The Borbála has the highest yield, but also the lowest protein content. At location 3, near to the location 1, soy was sown as second crop after winter barley. Sowing was done only at the beginning of July due to the rainfall at the harvest of barley. By the end of October, the super early varieties was ready for harvest. The weed pressure was lower than in soy as main crop in the previous year. Pathogens and pests did not make damage the site significantly. The yields were 1.4-1.7 t/ha, the protein content was around 40%. The best performing variety was Amandine. Parameters of plants can be seen in Table 2.

Table 2. Phenological parameters of soybean varieties in 2018
Mean of 3 X 10 plants

Variety	Plant high (cm)	Divergence Nr.	Nodes/plant Nr.	Pods/plant Nr.	Seed/pods Nr.	Thousand seed weight	Protein %	Oil %	Yield g/plant	Yield kg/ha
Site 1*										
Es Mentor	70	0.4	13.0	31.9	2,4	181	40.5	22.0	13.68	2873
Aires	72	0.2	11.5	26.4	2,6	179	39.3	21.8	12.46	2617
Borbála	85	1.3	12.7	22.8	2,7	239	40.7	20.0	14.50	3056
S0880 0	78	0.0	11.6	27.6	2,4	185	41.0	21.5	12.41	2606
Mean	**76**	**0.4**	**12**	**27**	**3**	**196**	**40.0**	**21**	**13.28**	**2788**
Site 2*										
Es Mentor	56	0.5	9.9	14.1	2.33	158	37.3	24.1	5.21	1094
Aires	72	1.5	11.6	20.5	2.30	167	35.9	23.2	7.86	1651
Borbála	62	1.9	11.1	19.6	2.23	189	31.8	25.2	8.26	1734
S0880	50	2.8	10.1	20.3	2.17	155	34.5	24.6	6.81	1429
Mean	**60**	**1.7**	**10.7**	**18.6**	**2.3**	**167**	**34.9**	**24.3**	**7.0**	**1477**
Site 3*										
Merlin	77	2.2	10.2	24.5	2.20	192	41.8	19.4	10.33	1860
Bettina	71	1.6	10.3	16.9	2.43	193	40.8	18.3	7.92	1426
Regina	79	1.2	1.,0	22.8	2.27	193	43.2	18.7	9.96	1793
Amandine	86	2.1	10.4	22.0	2.43	194	41.6	19.7	10.40	1872
Mean	**78**	**1.8**	**10.5**	**21.5**	**2.3**	**193**	**42.6**	**19.0**	**9.65**	**1738**

*: Site 1: Tornyiszentmiklós, Site 2 Tiszaigar, Site 3: Miháld

4 Discussion and Conclusions

These results show that soybean can be introduced as main and secondary crop into the cereal crop rotation in Hungary. The protein content of super-early varieties can reach 40 %. There are 300-600 kg differences in the yields, and 2-6 % in the protein content between the varieties in the research site. Without irrigation, the rainfall of the location is decisive for yield. The next crops are mostly cereals on these farms, which again supported by the soybean fore crop.

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Biotechnological approach to the creation of new pea cultivars with target features

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1 Introduction

Pea (*Pisum sativum* L.) is an important crop in European agriculture. Pea seeds, because of their relatively high protein content, are a valuable component of both the human diet and animal feed. In Poland the main source of protein for feed production is currently soya meal, imported from the Americas in a quantity of 2 million tons per year. To support the substitution of soya with domestic protein plants, a multi-year project entitled "Increasing the use of domestic feed protein for the production of high-quality animal products in conditions of sustainable development" was funded by the Polish government. The aim of the present study was to develop time-efficient biotechnological methods for the creation of new pea cultivars with desirable characteristics.

2 Materials and Methods

Materials for the study included four cross combinations of pea: Zekon x Tarchalska, Batuta x Tarchalska, Tarchalska x Gotik, Atlas x Tarchalska. Plants of generation F_2 were genotyped with SSR markers associated with resistance to powdery mildew, pea seed-borne mosaic virus and Fusarium wilt. The results of molecular analyses were statistically processed. The tested hybrids and their parents were compared with the theoretical best genotype, i.e. one that has all the positive alleles of all markers used. The distance of the objects from the theoretical ideal genotype was determined as the Jaccard Index (JI). The single seed descent (SSD) technique was applied to obtain a homozygous line (Surma et al. 2013).

3 Results

Among the parental genotypes, cv. Batuta appeared to be most similar to the ideal genotype (JI=0.333); the greatest distance from the ideal (JI=0.583) was found for cvs. Gotik and Tarchalska. Among 200 tested hybrids, only three lay in the smallest range of distances from the ideal (JI=0.167–0.333), while 13 hybrids were found at the largest distance (JI=0.833). Independently of the molecular results, all the tested F_2 generation plants were subjected to the SSD technique in combination with *in vitro* culture of embryos isolated from immature seeds. Growing *ex vitro* plants in a greenhouse, four generations per year were obtained. Using our approach, two years sufficed to obtain near-homozygous lines of generation F_7 (98.4% homozygosity in a locus) from the F_2 hybrids, which in the traditional method under field conditions would take five years.

4 Discussion and Conclusions

Traditionally, breeding new varieties of self-pollinated crops takes several years. To reduce the time needed to obtain genetically stable lines from heterozygous offspring, the doubled haploid (DH) system is widely used. Grain legume species are known to be recalcitrant to *in vitro* culture. As an alternative, the SSD technique coupled with the *in vitro* culture of embryos dissected from immature seeds has been developed for pea, field bean and lupins (Surma et al. 2013, Ogrodowicz et al. 2018). SSD lines can be developed either from randomly chosen F_2 plants or from hybrids selected in accordance with the defined breeding goal. In the present study, SSD lines were derived from hybrids of various cross combinations, which were genotyped using molecular markers associated with genes responsible for resistance to diseases. Statistical analysis and comparison of the hybrids and their parents with the theoretical ideal genotype led to identification of the most promising hybrids. The obtained SSD lines, after propagation, will be tested in terms of disease resistance, which will enable verification of the effectiveness of marker selection in F_2.

Genotyping of F_2 pea hybrids followed by use of the SSD technique in combination with *in vitro* culture of embryos can shorten by 2–3 years the time needed to obtain lines with a high degree of homozygosity, thus accelerating the process of breeding new varieties.

Acknowledgements

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Association analysis of phenotypic traits in selected and propagated lines derived from different winter wheat composite cross populations

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1 Introduction

Sustainable agricultural systems, as organic farming, need an excellent capacity for self-regulation allowing for overall reduction of external inputs while maintaining or increasing overall system output including delivery of ecological services. Biodiversity at all levels from microbial populations up to inter- and intra-specific diversity of plants is a major component in self-regulating systems (Loreau 2010). Aims and methods for breeding of crops adapted to self-regulating systems, such as heterogeneous populations, are different from most current breeding programs in several aspects. Thus, methods are needed that allow for (i) a heterogeneous crop structure; (ii) adaptation of populations to special environmental conditions; (iii) continuous improvement of heterogeneous populations by selection, without losing their plasticity and adaptability; and (iv) introduction of new genetic material into the population. Composite cross populations (CCP) are a concept that can meet those demands (Döring et al. 2011, 2015). Further, selections from CCPs might also be a useful resource for conventional line breeding and provide a basis for genome-wide association studies (GWAS) to find gene loci responsible for traits relevant for all farming systems. This study attempts to use wheat lines selected from CCP populations in order to test the applicability as diverse, but still restricted population for GWAS.

2 Materials and Methods

Out of 200 CCP lines, derived from different winter wheat CCPs (agronomic performance, cp. poster Schmidt et al.), DNA was isolated from 184, selected for contrasting phenotypes and homozygosity and genotyped by TraitGenetics (Germany) using a 20k wheat SNP (single-nucleotide polymorphism) array analysed on Infinium Ultra HD chip. The genotyping data, together with the phenotypic data were used for GWAS to link allelic changes to trait expressions. Several statistical methods for association were used, such as general linear model (GLM), mixed linear model (MLM), multi-locus mixed model (MLMM), fixed and random models circulating probability unification (FarmCPU), and network-based model approach, using GAPIT version 3 (Wang and Zhang, 2019) including K and Q matrix as well as netgwas (Behrouzi and Wit, 2019; Behrouzi et al., 2018) using Gaussian copula graphical model for reconstructing conditional independence networks. Covariate (Q matrix) was calculated using principal component analysis (PCA) based on 8961 selected SNPs, respectively.

3 Results

Preliminary GWAS results were obtained from ten phenotypic traits at the organically managed trial farm Frankenhausen (Northern Hesse, Germany) for the season 2017/18. GAPIT-related GWAS resulted in 4 candidate and 8–13 potential candidates for 4 of the 10 traits (area under the disease progress curve [AUDPC], plant height, straw yield, grain yield) included in the analyses. In contrast, the network-based GWAS resulted in 32–33 candidates for 7 of the 10 traits (AUDPC, fertile ears, harvest index, plant height, soil cover, straw yield and total biomass). There were several candidates with pleiotropic characteristics pointing simultaneously to harvest index and plant height, as well as AUDPC and field emergence.

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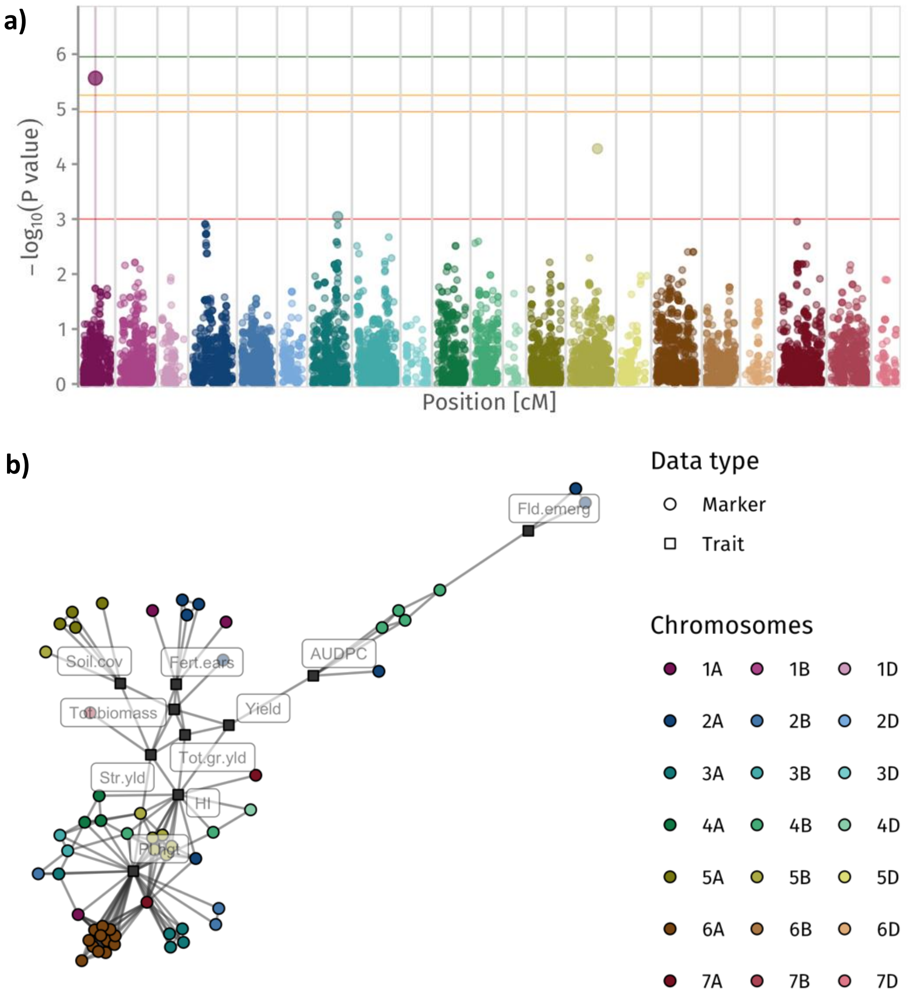

Figure 1. (a) Manhattan plot of negative log10 p-values of area under the disease progress curve (AUDPC) for each of the chromosomes (1–7) within the wheat subgenomes (A, B, D), horizontal lines: threshold for p-value of 0.001 as well as Bonferroni p-values of 0.1, 0.05 and 0.01; (b) Subnetwork of a network of 8961 marker, 10 traits (○, □) and direct interactions (—) between and within markers and traits.

4 Conclusions

Further investigations and comparison with different environments and methods are needed for a more complex understanding of the phenotypic traits in the development of diverse populations and mixtures in organic plant breeding.

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Forage potential of small grain cereals and mixtures in organic agriculture

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1 Introduction

Production of different cereals for green forage and silage has had a long tradition in crop production. In Hungary, cattle feeding is based mainly on maize silage. Small grain cereals (wheat, rye, triticale, oat and barley) are produced for silage either in monoculture or in cereal-legume mixtures have also an importance in feeding of ruminant animals. Nevertheless, the use of small grain cereal-based silage is not expansively used in cattle feeding and their production intensity is very different worldwide. Production of cereals and cereal-legume mixtures has several advantages: winter cereals utilize very efficiently the precipitation from autumn to spring. These crops can be effectively introduced in the crop rotation, and due to their early harvest they can increase the efficiency of land use. These advantages are more remarkable in organic agriculture.

2 Materials and Methods

Forage potential of winter cereals (triticale, winter oat, rye, emmer, spelt) and legumes (Hungarian vetch, hairy vetch and winter pea) were examined in an organic nursery in seasons 2012/13 and 2013/14 using small plots in three replications. Cereals and legumes were evaluated in monocultures and different mixtures were created: triticale-pea (Mixture1), triticale-oat-Hungarian vetch-pea (Mixture2), spelt-oat-hairy vetch-pea (Mixture3) and emmer-oat-hairy vetch-pea (Mixture4). Mixtures were sown in two cereal-legume seeding ratio: 50:50 and 40:60, based on seed numbers. Harvest was carried out in the end of the milk stage of the cereals. Randomly selected 1 m^2 area of each mixture plots were cut at the same time to determine the percentage of the components. Relative water content was determined and dry matter yield (DMY) was calculated. Crude protein content of the samples of monocrops and mixtures was determined by Kjehldal method.

3 Results

Considerable differences were found among DMYs of the different cereal species examined. One of the triticale varieties (Mv Sámán) had significantly the highest DMY (16.89 t/ha), while the spelt genotype had the lowest (9.19 t/ha). The Hungarian vetch had the significantly highest DMY (6.03 t/ha) among legumes. Comparing the two types of mixing ratio, the cereal-legume mixtures with 50:50 ratio had higher yields than the same mixtures with 40:60 ratio. The significantly highest DMY was observed in Mixture1 drilled with 50:50 ratio and the lowest was found in Mixture4 drilled with 40:60 ratio.

Protein yield of monocrops and mixtures was calculated from DMY and crude protein content. The results showed that the higher legume ratio did not increased the protein yield of mixtures.

Land equivalent ratio (LER) was calculated to evaluate the efficiency of intercropping compared to monocropping. LER was over 1 in all mixtures with 50:50 cereal-legumes ratio, which means there is an intercropping advantage and the resources were more efficiently used by mixtures than monocrops. Mixtures with 40:60 cereal-legumes ratio had lower LER than 1 indicating that there is a disadvantage in intercropping.

4 Discussion and Conclusions

The research was carried out to analyse the forage yield and protein-yield of different small grain cereals and mixtures under organic conditions. Highest DMYs and protein yields was observed at triticale varieties, among tested varieties under organic conditions. The dry matter yield of mixtures was increased with increasing cereal ratio. High legume ratio (60%) in mixtures are not recommended.

Acknowledgement

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Performance of bulk populations of wheat compared with commercial cultivars

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1 Introduction

Though improved crop management systems and efforts in wheat breeding have raised yield levels in Germany continuously until 2000, yield levels have stagnated more recently, combined with a dramatic impairment of yield stability due to less reliable weather conditions.

Therefore, breeding is becoming more and more challenging as breeders have to consider simultaneously more and in part also opposed breeding goals, such as tolerance towards heat, frost, drought or excess of water, water use efficiency as well as resistances to new strains and species of pathogens. A so far neglected strategy consists in raising intraspecific diversity by breeding highly diversified plant material based on multi-parental crosses (complex varieties or Multiple synthetic derivatives, Tsujimoto et al., 2015).

However, little is known, whether such populations can really compete with current commercial varieties, and under which environmental conditions or crop management.

2 Materials and Methods

Several wheat populations based on a diallelic cross performed by the John-Innes-Center, UK in 2001 were compared with 4 commercial high-quality varieties, 2 high-yielding varieties and 4 varieties bred for organic farming. The experiments were performed in 4 locations at two levels of N fertilization in 2016 and 2017. Two of the experiment sites were managed conventionally, two according to the principles of organic farming. In 2018, 5 additional populations with more recent genetic background were included. These had been generated by Technical University of Munich (Germany), NIAB (UK), and LBS Dottenfelder Hof ev., Germany).

3 Results

Compared with current commercial cultivars, the performance of populations was depending on their genetic background: the populations based on older or less adapted varieties yielded on average 3-5% less than the reference varieties (Figure 1) , while the populations with more recent genetic background were as productive as commercial varieties (Figure 2). Protein contents were highest in varieties bred for organic farming, while that of commercial cultivars and populations were lower and similar to each other (data not shown).

4 Discussion and Conclusions

We conclude, that bulk populations based on modern, adapted parents, may be considered as alternative to inbred lines, not only in conditions of organic farming, but also in many environments of conventional agriculture.

Further research is needed to assess the effective advantage, i.e. better yield stability and tolerance towards pathogens.

The full potential of populations is still not known, since up to now, the choice of the parents has been rather arbitrary. Optimized selection of parents, comprising also competition traits should rise further the productivity of populations.

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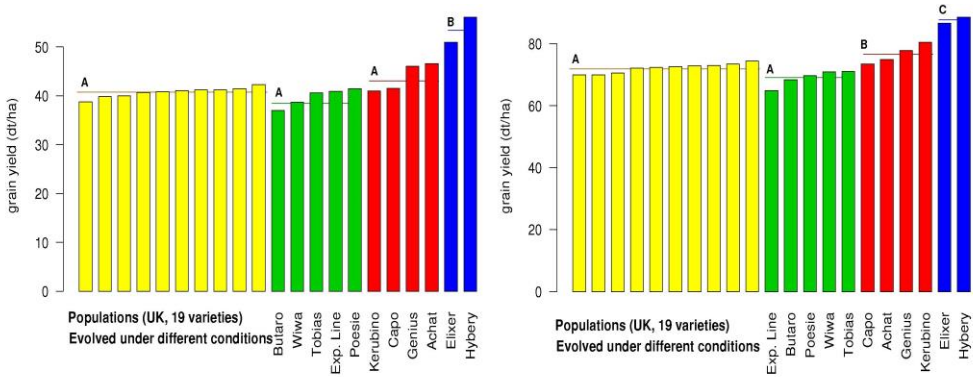

Figure 1. Populations based on older germplasm compared with varieties bred for organic and conventional farming. Data fro, 2016 and 2017, 2 sites managed organically. Letters refer to differences among groups (pairwise t-test, Bonferroni, p<0,05)

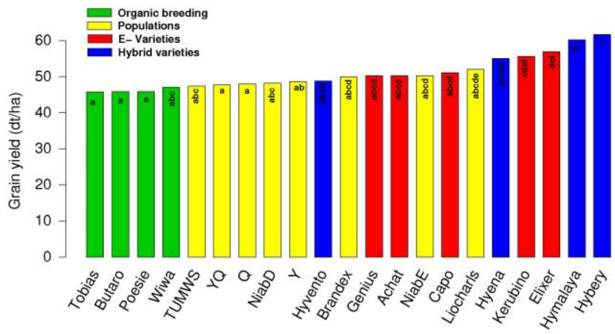

Figure 2. Grain yield of older (YQ, Y, Q) and recently released populations ("Licharls", "Niab Elite", "Niab Diverse", "Brandex") compared with line and hybrid varieties. Data from 2018, 2 environments (conventional and organic). Letters indicate significant differeces among populations (Tukey-test, p<0.05)

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Stability of bulk populations of wheat compared with commercial cultivars

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1 Introduction

Although improved crop management systems and efforts in wheat breeding have raised yield levels in Germany continuously until 2000, yield levels have stagnated more recently, combined with a dramatic impairment of yield stability. Therefore, breeding is becoming more and more challenging as breeders have to consider simultaneously more and in part also opposed breeding goals, such as tolerance towards heat, frost, drought or excess of water, water use efficiency as well as resistances to new strains and species of pathogens. A so far neglected strategy consists in raising intraspecific diversity by breeding highly diversified plant material based on multiparental crosses (complex varieties or Multiple synthetic derivatives, Tsujimoto et al., 2015).Though it has often been claimed, that yield stability of populations is higher than that of inbred lines, their full potential is yet not known. In this study, this is tested for German conditions in organic and conventional environments.

2 Materials and Methods

Ten Populations, based on diallelic crosses of 19 varieties released between 1930 and 2000 (Döring et al. 2015) were compared with 4 commercial high-quality varieties, 2 high-yielding varieties and 4 varieties bred for organic farming. In addition, 10 inbred lines extracted randomly from the populations were included. The experiments were performed in 4 locations and 2 levels of N fertilization in 2016 and 2017. Two of the experiment sites were managed conventionally, two according to the principles of organic farming. The total number of environments amounted to 16. Since 2018, 5 additional populations with more recent genetic background were included, which where so far only tested in 8 environments. Stability indices according to Eberhard and Russel, Finlay and Wricke were calculated for each variety based on yield data.

3 Results

Regardless of the stability index used, (dynamic) yield stability and stability of protein contents were always higher in populations than in cultivars, especially high-yielding cultivars with low grain protein content. Yield stability of the inbred lines was as low as that of the cultivars (Figures 1 and 2).

4 Discussion and Conclusions

This confirms our hypothesis that breeding diversified material may contribute to enhance the resilience of cropping systems. The improved stability is due to the diversity of the populations, not to their genetic background, as shown by the performance of the inbred lines. Further research is needed to assess the effective advantage, i.e. better yield stability and tolerance towards pathogens. The full potential of populations is still not known, since up to now, the choice of the parents has been rather arbitrary. Optimized selection of parents should rise further the productivity of populations.

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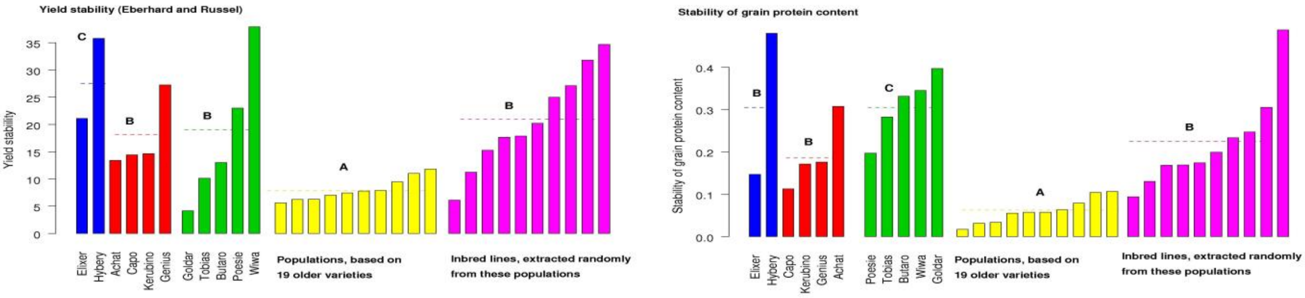

Figure 1. Yield stability and stability of grain protein content of commercial cultivars, populations and inbred lines extracted from these populations. Stability according to Eberhard and Russel. Letters indicate differences among groups (pairwise t-test, Bonferroni)

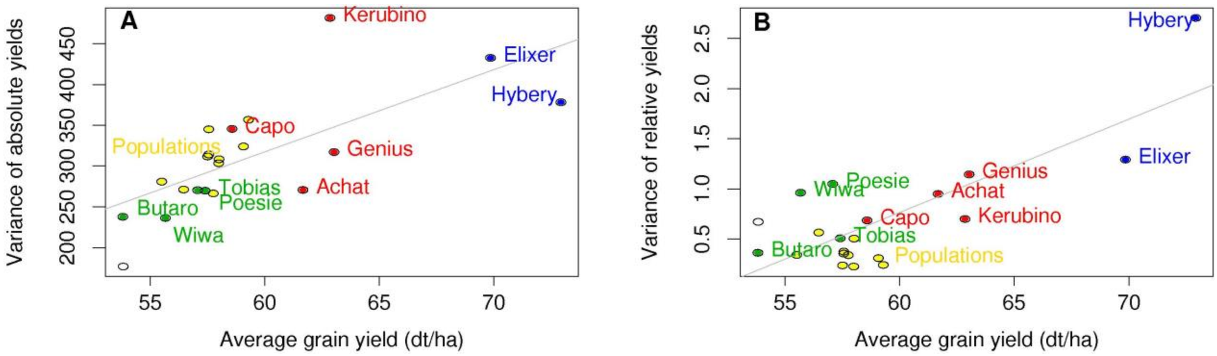

Figure 2. Static and dynamic stability plotted against yield. A: Variance of absolute yields, B: Variance of relative yields

Intrinsic diversity enhances productivity and disease tolerance in bulk populations of wheat

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1 Introduction

Considering the more frequent occurence of abiotic stress due to the climate change and the need for more resilient and sustainable cropping systems, strategies based in raising intraspecific diversity are of increasing interest, but have been widely neglected so far. One approach is the establishment of highly diversified plant material based on multiparental crosses (complex varieties or Multiple synthetic derivatives, Tsujimoto et al., 2015). Due to their buffering capacity, such populations have shown to be more stable than single lines, their productivity is similar or slightly superior compared to the mean of their parents. The yield of populations, compared with their parents is determined mainly by (a) additive genetic effects, which in populations should be equivalent to the average of their parents (b) epistatic effects, which may determine a part of the potential in selected inbred lines, but which will be partly lost and more limitedly be exploited in populations (c) complementary or combination effects among the single genotypes in the population (d) long-term evolutionary effects, which might be positive or negative for performance. The overall performance of a population depends on the entirety of these single effects.

2 Materials and Methods

In order to asses, if negative effects, e. g. due to an eventual loss of epistasy are relevant or compensated by combination effects, we compared 10 composite cross populations generated in 2002 based on 19 varieties (Döring et al., 2015) and evolved under different environmental conditions with lines randomly selected from the populations themselves in 2015/16 and 2016/17. The experiments took place at 4 experiment sites, two of them organically and two conventionally managed, with two levels of N fertilization in each site.

3 Results

Under organic management, yields of the inbred lines were in average considerably lower than those of the populations,whereas these differences were less marked under conventional management (Figure 1). In the presence of a strong infection pressure from yellow rust at the Experiment Station of Kassel University in 2016 and 2017, most of the single lines were heavily affected, while the populations were relatively healthy (Figure 2). Yield stability of the populations was considerably higher than that of the extracted lines. N fertilization had only little effect on yield in all environments and no genotype x fertilization interactions could be observed

4 Discussion and Conclusions

We conclude, that intrinsic diversity or populations contribute considerably to their performance, and that eventual losses of epistatic effects are largely compensated by combination effects among genotypes. Disease resistance play a major role in combination effects.

Further research is needed to assess the effective advantage, i.e. better yield stability and tolerance towards pathogens.

The full potential of populations is still not known, since up to now, the choice of the parents has been rather arbitrary. Optimized selection of parents should rise further the productivity of populations.

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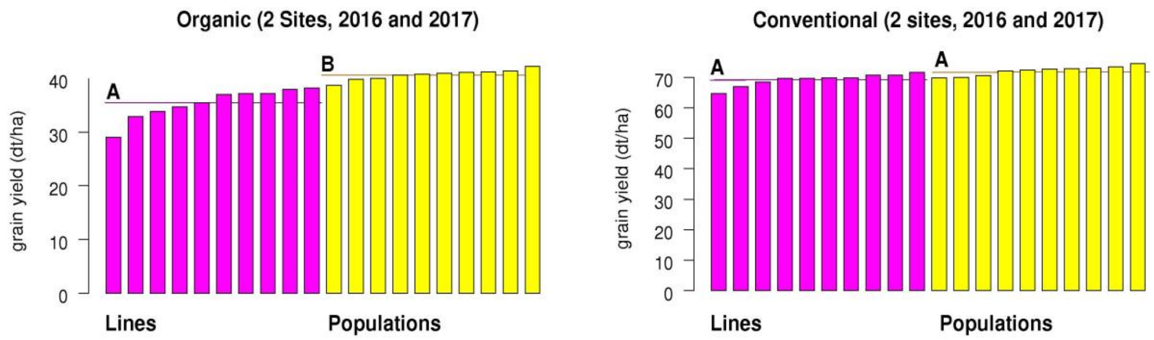

Figure 1. Yields of populations and extracted lines under organic and conventional farm management, 2016 and 2017, 8 environments in total. Letters indicate differences between groups (t-test, p<0,05)

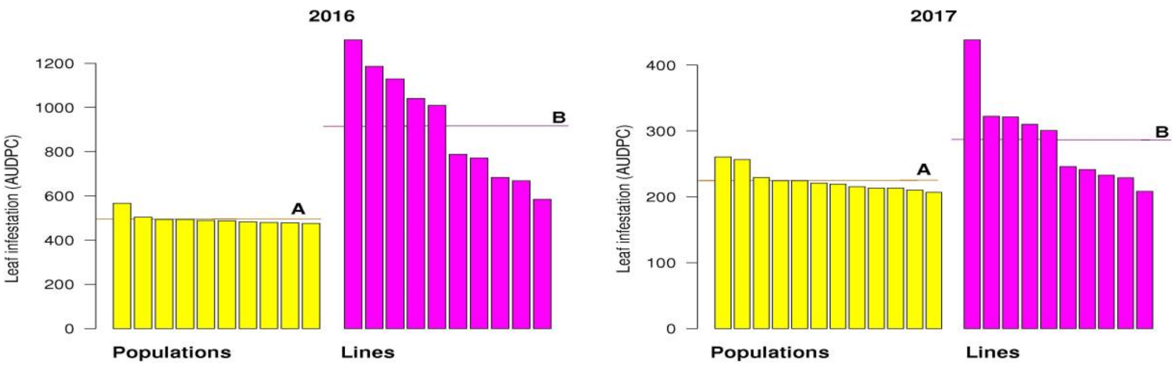

Figure 2. Cumulative degree of infestation with leaf diseases (AUDPC) of populations and extracted lines under organic farm management, 2016 and 2017, at Neu-Eichenberg experiment station, University of Kassel. Letters indicate differences between groups (t-test, p<0,05)

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Yield and quality of recently generated wheat populations compared with their parents and mixtures

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1 Introduction

Considering the more frequent occurence of abiotic stress due to the climate change and the need for more resilient and sustainable cropping systems, breeding strategies based on raising intraspecific diversity are of increasing interest. One approach, which has been widely neglected so far, is the establishment of highly diversified plant material based on multiparental crosses ("complex varieties" or "Multiple synthetic derivatives" (Tsujimoto et al., 2015). Aim is increasing yield stability, which is supposed to be higher in diversified plant material, as could be confirmed by own data (see poster on yield stability in this section). This this potential advantage can be exploited only, if this is not at the expense of yield level. Therefore, of particular interest for practical application is whether populations may compete with their parents and respective mixtures.

The yield of such populations, compared with their parents is (not considering long-term evolutionary effects) determined mainly by (a) additive genetic effects, which in populations should be equivalent to that of the average of their parents, (b) epistatic effects, which may determine a part of the potential in selected inbred line varieties , and consequently might cause lower yield in populations derived from the latter and (c) complementary or combination effects among the single genotypes in the population.

2 Materials and Methods

In 2013, three composite cross populations were generated by diallelic crosses among 7 spring wheat varieties, 8 winter wheat varieties and a combination of both. In 2015/16 - 2017/18, the populations (then in F5-7) were compared with their parents and respective mixtures in replicated field experiments. All Experiments took place at Viehhausen organic experiment Station of Technische Universität München, upper Bavaria.

3 Results

In all Populations, population yields were superior to the average of the parental varieties, in part also to mixtures of the parents (Figures 1 and 2). The best variety in each trial outyielded the populations in all populations and years, but, according to environmental conditions, was not the same every year. This is in accordance with previous results (Döring et al. 2015, Brumlop et al., 2017)

4 Discussion and Conclusions

We conclude, that the benefits of populations may be exploited without losing the achievements of plant breeding. The commercial varieties the populations are based on, have been selected for performance in pure stands, not for combination ability. A targeted selection of parental lines (which have not to be commercial varieties) for complementarity would therefore presumably improve the performance of wheat populations in the future and thus contribute considerably to an overall increase and enhancement of agricultural diversity. However, additional research is necessary in this area.

The full potential of populations is still not known, since up to now, the choice of the parents has been rather arbitrary. Optimized selection of parents should rise further the productivity of populations.

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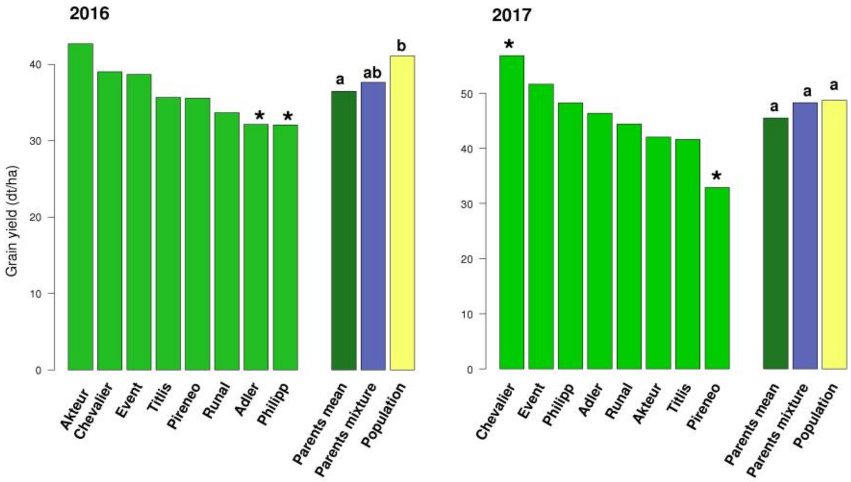

Figure 1. Yields of populations, Mixtures and parents, 2016 and 2017,at the organically managed Viehhausen Experiment Station of TUM. Letters indicate differences between groups. Asteriscs indicate differences from the respective population. (t-test, p<0,05)

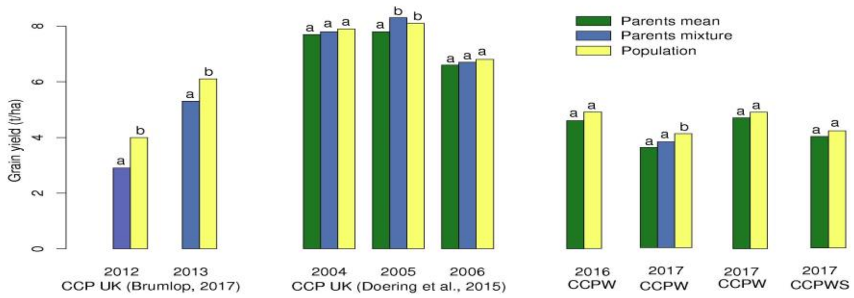

Figure 2. Yields of populations, Mixtures and means of parents,various experiments and populations: CCP UK: CCP generated in the UK in 2001, based on 19 varieties, CCPW, CCPS, CCPWS: Populations generated in 2013 by diallelic crosses among 8 Winter wheat varieties, 7 Spring wheat varieties and 15 spring and winter varieties, respectively. Letters

A simple and effective method for estimating competitive ability of wheat varieties

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1 Introduction

Studying weed suppression, or interaction within variety mixtures, demands separation of the harvested seed and this is costly and laborious. Therefore, we test the application of a high-throughput seed-sorting technique to discriminate between conventional wheat and the seed of the 'red wheat' cv. "Rosso". The data acquired also allowed an assessment of the ability of the different varieties to suppress yields. Plant height is often used an indirect trait for the weed suppression ability, but also represents a trade-off between yield potential and weed suppression, as plant height is often related to a reduced harvest index. The objective was to investigate the performance and suitability of the seed-sorting system and to test the relation of the estimated competitive ability with plant height

2 Materials and Methods

Over two growing seasons, eight winter wheat varieties were grown in 50:50 mixture with cv. Rosso (red kernels) and in control and mono-cropped stands under conventional or organic management. With 3 replicate plots for each control and mixture-treatments, cultivation was carried out in a split-plot design with mixture treatment as the main plot-factor.

For mixture treatment, a sample of around 180g of harvested seed was sorted by colour based on hue with the QSorter Explorer (qualysense.com), and the weight of the two resultant fractions recorded. Using the weight of the fractions and the plot yield, the yield of Rosso in each plot was derived. In order to determine the suppression of Rosso, the competitive effect was calculated as $CE = ((Yp- 2*Ym)/ Yp)$. Where: Ym is the yield of Rosso in the mixture plot; and Yp is the mean yield of Rosso in pure stand in the respective experiment. CE=0 indicates no interaction between the mixture components, and the higher the value of coefficient CE, the stronger the capacity of the conventional variety to suppress the yield of cv. Rosso. To assess how strongly CE is determined by the genotype, broad-sense heritability of a mean was calculated for each experiment as $h^2=Vg/(Vg+Ve/n)$, where Vg is the genetic variance, Ve the residual variance, and n the number of replicate blocks, from a random model with the effects variety and replicate blocks.

3 Results

Sorting took about 5 min *per* sample, including preparing and packing of samples. The unclassified fraction was negligible and sufficient purity was achieved after one run. In all four trials, conventional varieties differed significantly in their capacity to suppress the yield of cv. Rosso (Table 1). Heritability in single trials was higher where overall suppression was lower. The overall heritability over all trials was $h^2=0.80$.

Table 1. Mean competitive effect (CE), F-Test of variety effect from ANOVA, and heritability (h^2) for each experiment.

Year	Management	Mean CE (%)*	Variety (F)	h^2
2016	Conventional	10.6[d]	4.9**	0.80
2016	Organic	21.0c	7.5***	0.87
2017	Conventional	53.5[a]	2.9*	0.66
2017	Organic	41.4[b]	3*	0.67

* Comparison between trials, Tukey-Test (5%)

Assessing the yield-suppression capacity of the various varieties with respect to canopy height and CE revealed taller and short varieties are more or less competitive respectively (Figure 1). However, there were exceptions to this trend, as the dwarf hybrid variety Hybery is as competitive as the tall varieties, indicating the yield-suppressive capacity of other traits too.

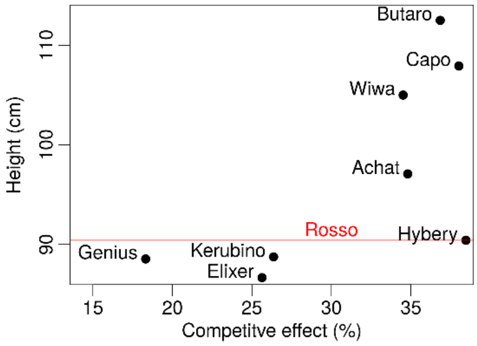

Figure 1. Relation of competitive effect (CE) to canopy height. Red line indicates the canopy height of Rosso

4 Discussion and Conclusions

Single-seed sorting proofed to be fast and reliable. The significant variety effect of CE and the high heritability indicated that the competitive effect on cv. Rosso is strongly determined by the variety. This suggests that the 50:50 mixture with a red variety in combination with high-throughput single-seed sorting could be used in variety testing to determine the weed suppression of wheat varieties. The relation between plant height and CE partly confirmed plant height as an indirect trait for weed suppression. However, the strong CE of the dwarf hybrid variety Hybery indicated that plant height is limited in its suitability as in indicator of weed suppression ability, which could furthermore help to overcome the trade-off between yield potential and weed suppression.

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Differences in breeding progress in winter wheat between conventional and organic farming in Germany

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1 Introduction

Plant breeding makes a significant contribution to increasing the yield and thus the efficiency of plant cultivation. An important question is whether breeding progress depends on management intensity and environmental conditions, i.e. whether more intensive or more extensive management systems benefit more from plant breeding. As a consequence, enhancement of intra- and intervarietal diversity might become necessary, i.e. varieties more adapted to specific environments and genetically less heterogeneous varieties, in order to increase plasticity concerning adaptation to stress and low-input management.

2 Materials and Methods

The yield data from the organic and conventional variety testing trials of winter wheat in Germany were used to investigate whether the observed breeding progress differs between conventional and organic farming. Winter wheat yield data were extracted from publicly available reports of the official variety trials ("Landessortenversuche", organic and conventional) from the years 2001 to 2017 and analysed using a mixed model to separate genetic progress (breeding progress) from non-genetic progress (agronomic and climate-related). Only varieties tested for at least 3 years were used for the analysis.

3 Results and Discussion

The dataset comprises about 2400 trials (conventional and organic) and the average yield level of the conventional trials was 95 dt/ha and 50 dt/ha under organic management. Breeding progress across all variety classes in the conventional trials under high intensity (with fungicides and growth regulators) was estimated to 0.41 dt/ha/year ($P<0.001$) and to 0.73 dt/ha/year for low intensity (without fungicides and growth regulators). For the organic trials this estimator was 0.09 dt/ha/year and was not significantly different from zero ($P>0.05$). The higher breeding progress under conditions without fungicides might indicate that the absence of breeding progress under organic conditions is not due the lack of increased resistances. However, the difference might be due to nitrogen limitation in the organic trials as trials with legumes as preceding crop show a higher breeding progress (0.11 dt/ha/year) than trials with non-legumes as preceding crop (0.02 dt/ha/year). We conclude, that breeding has to consider more the particular growth conditions, and that there is a need for a more diversified range of varieties; Moreover, a more diverse genetic structure of the varieties will additionally contribute to a better adaptation to sub-optimal conditions.

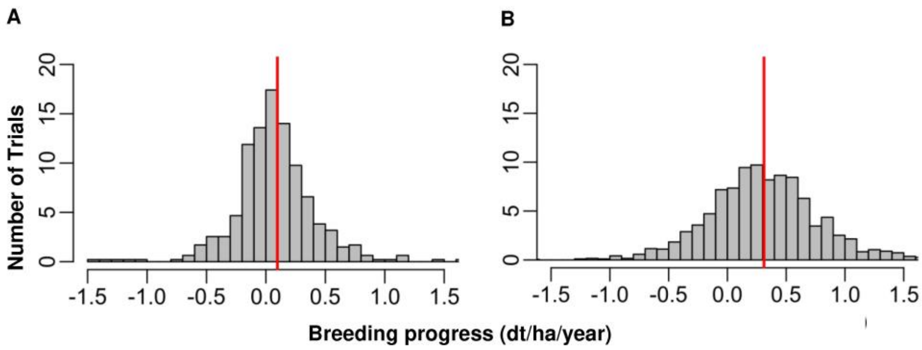

Figure 1. Histograms depicting the estimated breeding progress in the single experiments; A: Organic B: conventional trials

Network for the dynamic management of winter barley genetic resources

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1 Introduction

Genebanks apply static *ex situ* management systems to conserve plant genetic resources for food and agriculture. By doing so, genebanks facilitate users' access to germplasm and related data. While genebanks maintain accessions, i.e. a spatial and temporal part of the evolutionary process, dynamic management strategies aim at promoting the continued adaptation of crops to changing environmental conditions (Bretting and Duvick, 1997). An effective and efficient approach for a dynamic management system with wheat was described by Goldringer *et al*. (2001) and is being developed by INRA at Le Moulon (France) towards an on-farm management system involving farmers (Enjalbert *et al*., 2011). The transfer of this approach to barley was recommended by the German Federal Ministry of Food and Agricultural in its expert program for plant genetic resources. The Julius Kühn-Institut was subsequently requested to develop an institutional network for the dynamic management of winter barley genetic resources. Populations and sub-populations are cultivated at different locations and exhibit a wide genetic variation within and between populations, adapted to regional agricultural conditions, and with potential for future adaptation to climate changes.

2 Materials and Methods

From a total of 227 German winter barley varieties released between 1914 and 2003, a set of 58 varieties was genetically analyzed using SSR markers. Among these, 32 genotypes representing the genetic diversity of the whole set were selected to produce a highly recombinant winter barley population. In the years 2008 to 2015, the 32 selected winter barley varieties were crossed according to the Multi-parent Advanced Generation Inter-Cross (MAGIC, Cavanagh *et al*., 2008) scheme resulting in a set of lines with each line being a descendent of all 32 initial varieties and thus harboring parts of all 32 initial genomes. Aliquot amounts of seeds from 324 of these lines were combined in 2015 to form a highly heterozygous population and grown for multiplication.

3 Results

In order to promote the development of differently adapted germplasm, 12 ecogeographically contrasting locations within Germany were selected to form a network for the dynamic management of winter barley genetic resources. These include 3 locations under organic management practices. Since 2016, sub-populations of the material have been continuously cultivated under high and low input conditions at these locations. Adaptation of winter barley sub-populations to different climatic, soil and agricultural input conditions will be monitored over a period of 6 to 8 years. Based on samples taken in each year, changes in the allele frequencies within and between locations will be monitored at the DNA level. Simultaneously, ROBUSTUM has been developed as an information system for the consistent documentation of varieties and lines, crossing schemes, composition of (sub)populations, cultivation conditions, characterization and evaluation data, and for subsequent data analysis. The complex pedigree of the initial winter barley population has already been recorded within ROBUSTUM. All data as well as plant genetic resources developed by the network will be publicly available according to the rules of the Multilateral System of the International Treaty.

4 Discussion and Conclusions

The present approach enables a continuous and dynamic adaptation of the natural genetic diversity present in our crops to changing climatic and agronomic developments. The evolutionary plant breeding concept actually translates the breeding of landraces by farmers and the functions of traditional seed supply systems of the past into science-supported crop diversity management practices of today. Evolutionary plant breeding approaches may play a role in solving the many problems related to the increasing pressure on finite natural resources caused by a growing human population and changing consumption patterns (Steffen *et al*., 2015) and increasing insecurity in agricultural production systems caused by climate change. The creation and development of the winter barley population can be considered as course of action in plant breeding and contribution to a genetic diversification of agricultural production systems. Thus, dynamic management will contribute to the development of sustainable agricultural production systems.

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ECOBREED - Increasing the Efficiency and Competitiveness of Organic Crop Breeding

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1 Introduction

Organic production has been increasing across the EU28 (11.14 M ha in 2015 which represents a 21% increase over 2010 (Eurostat 2015) and accounts for 6.2% of the agricultural used area. Organic production is limited by some agronomic and management requirements but particularly by the lack of organic seeds and varieties bred for organic conditions, organic farmers use the permitted derogations for using the untreated conventional seed material for their production. Modern plant breeding programmes use methods which is not compatible with the organic principles, i.e. GMO, (IFOAM, 2017). On the other hand, traditional plant breeding involving quantitative genetic/phenotypic selection approaches, which compare genotypes for a wide range of traits over a range of contrasting environments is time consuming, expensive and thus difficult to fully exploit especially for the smaller organic and low-input market sectors. There is therefore an urgent need to develop improved genotyping, phenotyping and farmer-participatory breeding approaches which are more efficient, reduce costs and/or can be used to target traits suited to an organic production environment.

The H2020 ECOBREED project aims at increasing the availability of seed and varieties suitable for organic and low- input production. Activities focus on four crop species, selected for their potential contribution to increase competitiveness of the organic sector, i.e. wheat (both common *Triticum aestivum* L. and durum *Triticum durum* L.), potato (*Solanum tuberosum* L.), soybean (*Glycine max* (L). Merr), and common buckwheat (*Fagopyrum esculentum* Moench.).

- **Wheat** is the most important single crop among 1.54 M Ha of organic cereals in Europe (EUROSTAT 2015). Most modern cereal varieties are semi-dwarf which provides a higher potential yield under a high input environment but have negative effects because of reduced competitiveness against weeds and increased sensitivity to *Septoria tritici* and *Fusarium* spp.
- In **potato** production, the yield gap between organic and conventional production systems is much greater (up to 60% lower yields in organic systems) and has been mainly attributed to inadequate control of pests and diseases that can be effectively controlled by fungicides, particularly late blight caused by *Phytophthora infestans*. The potential future exclusion of copper fungicides from organic potato production is likely to have further negative effects on late blight control and yields.
- **Soybean** is an important source of protein especially for livestock feed. The total area of soybean grown globally in 2014 was 117.7 million ha, with less than 4% of this grown in Europe (FAOSTAT 2017). Within Europe, soybean cultivation is mainly situated in Eastern (3.9 million ha) and Southern Europe (0.4 million ha) with limited production in Western Europe (0.13 million ha) and no recorded production in Northern Europe (FAOSTAT 2017). Increased organic soybean production in Europe requires development of genotypes with increased; drought and cold tolerance, competitiveness against weeds, capacity for symbiotic N fixation, and resistance/tolerance to pests and economically important diseases.

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- **Buckwheat** is an underutilized crop that currently accounts for less than 3% of the area and 1% of wheat production in Europe. It was grown widely in the past and has been identified as having clear nutritional benefits and being suitable for the manufacture of gluten-free products. The demand for buckwheat, and in particular organic buckwheat has increased rapidly in recent years and is largely met by imports from outside the EU, particularly from Russia and China. There are very few climatic constraints on buckwheat, which means that it can be grown in most European countries, although the availability of buckwheat varieties is a key factor limiting this potential growth.

2 Materials and Methods

The project will develop (a) methods, strategies and infrastructures for organic breeding, (b) varieties with improved stress resistance, resource use efficiency and quality and (c) improved methods for the production of high quality organic seed. The objectives of the project are:

- To increase the availability of seeds and varieties for the organic and low-input sector
- To identify traits and combinations of traits suited to organic and low-input production environment including high nutrient use efficiency and weed competitiveness/allelopathy
- To increase breeding activities for organic and low-input crop production.

Specific activities include:

- Identifying genetic and phenotypic variation in morphological, abiotic/biotic tolerance/resistance and nutritional quality traits that can be used in organic breeding
- Evaluation of the potential of genetic variation for enhanced nutrient acquisition
- Evaluation of the potential for increased weed competitiveness and control
- Optimisation of seed production/multiplication via improved agronomic and seed treatment protocols
- Developing efficient, ready-to-use farmer participatory breeding systems
- Pre-breeding of elite varieties for improved agronomic performance, biotic/abiotic stress resistance/tolerance and nutritional quality
- Development of training programmes in (a) genomic tools/techniques, (b) PPB and (c) use and application of improved phenotyping capabilities.
- Ensuring optimum and rapid utilisation and exploitation of project deliverables and innovations by relevant industry and other user/stakeholder groups.

3 Results

ECOBREED will enhance the portfolio of wheat, potato, soybean and buckwheat varieties suitable for organic farming in Europe and identify traits and combinations of traits suited to organic and low-input farming. The primary target of the H2020 ECOBREED project is the organic farming and food sector in Europe. However, activities also support other low-input production systems and will provide solutions for potential future challenges in the conventional farming sector (e.g. reduction of pesticide use, restrictions on the use of NPK fertilisers and climate change).

Acknowledgement

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Nutritional characteristics of common buckwheat (*Fagopyrum esculentum* Möench) genetic resources

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1 Introduction

The genus *Fagopyrum* (family Polygonaceae) includes several different species, among which common buckwheat (*Fagopyrum esculentum* Möench) is the most known and cultivated worldwide (Bonafaccia et al., 2003). From nutritional point of view buckwheat represent a rich source of high quality proteins with a balanced amino-acid composition, dietary fibre, retrograded starch, essential vitamins, minerals and antioxidants (Giménez-Bastida et al., 2015; Pongrac et al., 2010). The aim of the present study was to determine the chemical (crude proteins, fibre, ash and fats), fatty acids, free amino acids and multi-elemental composition in different common buckwheat genetic resources obtained from Slovenian Plant Gene Bank. Knowledge of nutritional characteristics is of key interest for breeding programmes since the buckwheat is considered as promising functional food due to a rich variation of phytochemicals and potential health benefits.

2 Materials and Methods

Eight common buckwheat accessions (i.e. CBW KIS SRGB 1-8) were grown in the experimental fields of the Infrastructure Centre Jablje, Agricultural Institute of Slovenia, Slovenia (304 m above sea level; 46.151°N 14.562°E). The dried grain samples, containing on average 12.8 % of moisture, were homogenised using laboratory mill (Retsch ZM 200). The methods used for analysis of buckwheat samples were those used for analysis of animal feed, either for raw components or compound feed. Moisture was determined by heating the samples at 103°C for 4 h (EC 152/2009 App. III A). Crude proteins were analysed by method ISO 5983:2, using factor 6,25; modified method ISO 6865 using FiberCap was applied for the determination of crude fibre, for crude ash ISO 5984 was used, and crude fats were analysed with petroleum ether extraction (152/2009 App. III H). Fatty acid composition was determined using gas chromatography (Agilent 6890N, USA) of fatty acid methyl esters (FAMEs). Separation was carried out on column SPB PUFA (30m×0.25mm×0.2µm column; SUPELCO). Identification of fatty acids was carried out using a reference standard mixture of methyl esters of higher fatty acids (Lipid standard Sigma 189-19). The content of the fatty acids was expressed as mg/100 g dry weight (DW) and as the mass ratio of all of the fatty acids analysed. Free amino acids were determined using high-performance liquid chromatography. The multi-element analysis was performed non-destructively using EDXRF spectroscopy. Pellets made from 0.5 g to 1.0 g of powdered sample material were prepared using a pellet die and a hydraulic press. The pellets were analysed using an energy dispersive X-ray spectrometer composed of XR-100 SDD silicon drift detector (Amptek), PX5 digital pulse processor (Amptek) and lap top based digital acquisition software (DPP MCA, Amptek). The analysis of complex X-ray spectra was performed using the AXIL spectral analysis program and quantification using the Quantitative Analysis of Environmental Samples software (Nečemer et al., 2008). The estimated uncertainty of the analysis was 5 %. The data are expressed as µg/g DW.

3 Results

Table 1. Chemical, fatty acids and multi-mineral composition of common buckwheat accessions

Buckwheat accession	% DW				Fatty acid composition (wt. %)							Total fatty acids	Multi-mineral composition (µg/g DW)								
	Proteins	Fibre	Ash	Fats	C14:0	C16:0	C18:0	C18:1	C18:2	C18:3	C20:0	mg/100 g FW	K	P	Si	S	Ca	Fe	Cl	Ti	Zn
CBW KIS SRGB 1	14.4	15.3	3.1	2.2	0.4	15.6	1.9	37.4	40.1	2.7	1.9	237.0	5850	4850	2720	1600	676	184	128	23.6	21.5
CBW KIS SRGB 2	14.2	17.3	3.1	2	0.3	15.8	1.9	36.6	40.6	2.9	1.9	226.7	6200	4310	1850	1380	481	167	113	17.6	20.1
CBW KIS SRGB 3	13.2	15.7	2.6	1.8	0.2	13.5	1.8	39.6	39.9	2.8	2.1	254.9	5210	4050	686	1270	694	86	122	3.5	19.9
CBW KIS SRGB 4	14.3	16.3	3.4	2	0.2	15.6	2.0	37.7	39.7	2.7	2.1	252.0	5790	4320	1920	1290	1140	196	201	23.9	19.2
CBW KIS SRGB 5	13.7	15.9	2.7	2	0.2	16.0	2.2	36.0	40.9	2.7	1.8	315.6	5400	3990	942	1270	855	102	133	11.8	16.8
CBW KIS SRGB 6	15.8	19	2.8	2	0.3	15.5	1.8	37.7	39.9	2.8	2.0	267.5	4560	4120	1390	1620	1150	136	145	10.5	19.9
CBW KIS SRGB 7	12.6	14.7	2.8	2	0.3	16.2	1.9	35.8	40.9	2.9	1.9	238.3	5410	3410	675	998	853	118	158	6.7	18.9
CBW KIS SRGB 8	14.4	17.3	3.1	2	0.3	15.9	1.9	35.7	41.5	3.0	1.8	230.8	4960	3440	2690	1120	1040	162	109	22.0	24.4

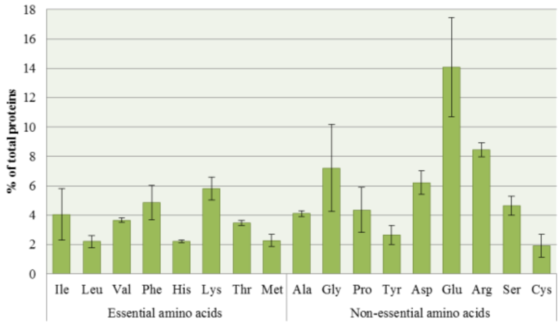

Figure 1. Free amino acids composition of common buckwheat accessions

4 Discussion and Conclusions

The average crude proteins content among eight common buckwheat accession grains was 14.1 % DW, while the crude fibre represented 16.6 % DW. The crude ash content was on average 3 % and crude fats 2 %. The total fatty acid content varied considerably, from 1643 mg to 2081 mg/100 g DW. Seven fatty acids were identified and quantified: saturated myristic (C14:0), palmitic (C16:0), stearic (C18:0) and arachidic (C20:0); and unsaturated oleic (C18:1), linoleic (C18:2) and α-linolenic (C18:3). Prevailing fatty acid in common buckwheat grains was linoleic acid (40.8 %), followed by oleic (33.7 %), palmitic (16.8 %), α-linolenic (3.6 %), arachidic (2.9 %), stearic (1.8 %) and myristic acid (0.3 %). Eight elements were obtained in common buckwheat samples, and these elements are Si, K, P, Al, S, Ca, Cl and Ti. The highest levels among elements was seen for K (from 4720 to 6480 µg/g DW), followed by P (from 3750 to 5380 µg/g DW) and Si (from 636 to 10400 µg/g DW), which varied the most among all elements. The less abundant elements in buckwheat grains were Ca (on average 747 µg/g DW), Cl (on average 150 µg/g DW) and Ti (on average 51 µg/g DW). The following 17 free amino acids were identified and quantified: aspartic acid (*Asp*), threonine (*Thr*), serine (*Ser*), glutamic acid (*Glu*), proline (*Pro*), glycine (*Gly*), alanine (*Ala*), cysteine (*Cys*), valine (*Val*), methionine (*Met*), isoleucine (*Ile*), leucine (*Leu*), tyrosine (*Tyr*), phenylalanine (*Phe*), lysine (*Lys*), histidine (*His*) and arginine (*Arg*). These amino acids can be divided into two groups: the essential amino acids of *Ile*, *Leu*, *Val*, *Phe*, *His*, *Lys*, *Thr* and *Met*, and non-essential amino acids of *Ala*, *Gly*, *Pro*, *Tyr*, *Asp*, *Glu*, *Arg*, *Ser* and *Cys*. The highest content in common buckwheat grains was shown for *Glu* (> 14 % of total proteins), followed by *Arg* (> 8 % of total proteins) and *Gly* (> 7 % of total proteins). The results show significant differences between buckwheat accessions for analysed nutritional characteristics. Nutritional characteristics data of common buckwheat genetic resources are the basis for breeding new varieties with traits of interest (e.g. higher Fe, Zn content) combined with higher productivity in terms of improvement of agro-biodiversity and profitability within the food value chain.

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Harnessing crop diversity of common bean to preserve its nutritional quality under a changing climate

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1 Introduction

The Anthropocene has brought tremendous pressures to our planet, and we are currently facing a scenario where in the course of food production, we are impacting the resources of our sole food-producing land. In fact, global food production methods are the largest pressure caused by humans on Earth, and we are currently feeding monotonous, climate damaging diets which in turn, due to elevated CO_2 (eCO_2) emissions, are also lowering the intrinsic nutritional content of plant foods. With the global demand for nutritious, high yielding crops expecting to more than double by 2050, it is important to underpin the different regulatory mechanisms that explain why crops are losing nutrients due to climate change, and how crop biodiversity and diversification can help address this burden. Here we will focus on the global impacts of eCO_2 and Fe deficiency on the nutritional value of common bean (*Phaseolus vulgaris* L.) from an agronomical and physiological point of view.

2 Materials and Methods

Changes in the nutritional status of legumes may have a major impact on the nutritional status of populations which are heavily reliant on these crop as a major nutrient source. To understand the individual and combined effects of eCO_2 and restricted Fe supply on mechanisms relevant to common bean nutrient uptake and accumulation, plants were grown under Fe sufficiency (Fe+, 20 µM Fe-EDDHA) and Fe deficiency (Fe-, 0 µM Fe-EDDHA) combined with eCO_2 (800 ppm) or ambient CO_2 (aCO_2, 400 ppm) in hydroponics until maturity. We will showcase some of the existing evidence linking the effects of eCO_2 and iron (Fe) deficiency on nutrient content of common bean, presenting published and unpublished data of a diverse set of genotypes of common bean grown under future predicted levels of atmospheric CO_2. Results from a field trial conducted under Breed-FACE elevated CO_2 conditions will also be presented.

3 Results

When looking at individual responses of different common bean cultivars to eCO_2 it was noticeable that intraspecific variability exists for the effect of eCO_2 on grain accumulation of several mineral nutrients, including Fe (Figure 1). In depth studies looking at the mechanisms that may be underlying these differential responses show that elevated CO_2 (Fe+/eCO_2), stimulated photosynthesis and stomatal closure, decreasing leaf and root soluble protein and highly affecting Fe metabolism: root reductase activity was stimulated by 6-fold while the expression of root FRO1 and IRT1 were down-regulated by about 4-fold. In the leaves, citrate and oxalate increased but ferritin expression decreased by 9-fold. Such changes may have determined: i) lower levels of Fe (62%) and Mn (73%) in the roots, ii) lower Fe (38%) and higher Zn (25%), Mg (34%) and K (28%) levels in the leaves, and iii) the lower P (30%) and Fe (50%) and higher Ca (40%) levels in the seeds. The combination of Fe deficiency and eCO_2 doubled the effect of a single factor on FCR activity up-regulation, balanced internal pH of Fe deficient plants and resulted in the lowest accumulation of Fe in all plant parts (significantly lower in roots), and the highest accumulation of Zn in grains.

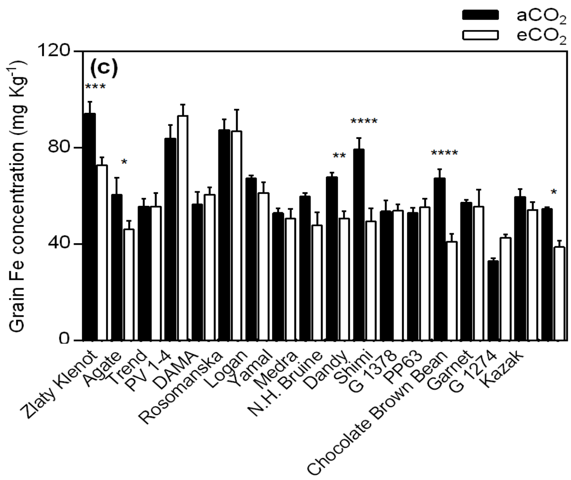

Figure 1. Grain concentration of Fe of 18 bean cultivars, grown under ambient -aCO_2 and elevated -eCO_2. Data presented are the means ± standard errors of n = 4 plants. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.005$; **** $P < 0.0001$ significance level.

These results suggest that eCO_2 directly affects Fe uptake mechanism having a negative impact on Fe concentrations in all plant parts and that it may highly interfere on Fe uptake and accumulation in plant cultivars sensitive to Fe deficiency, but other nutrients such as Ca and Zn maybe less affected by climate change in the future.

4 Discussion and Conclusions

The results of this study show that eCO_2 has a highly negative impact on Fe accumulation in all plant parts including the grains and that, although there is an important interaction of eCO_2 and Fe deficiency leading to a sharp up-regulation of FCR activity, this regulation was not sufficient to ensure an efficient Fe uptake, with the plants exposed to eCO_2 having lower Fe levels. This may highly interfere on Fe uptake in plant cultivars sensitive to Fe deficiency. Mechanisms that helped us understand the causes of nutritional losses include impacts on root Fe reductase activity, shifts in photosynthesis, alterations in cytoplasmic acidification, organic acid and sugar concentrations; changes in nutrient accumulation patterns, and expression of key enzymes involved on mineral uptake. The goal is to propose a preliminary model which insights some of the mechanisms which are impacted by eCO_2 and Fe deficiency that may be responsible for the reported nutritional losses. The wealth of research on the nutritional impacts of climate change is new, and considering the general findings gathered here, we propose sustainable strategies to be put in place for future mitigation and adaptation practices, harnessing both agro ecological farming practices and crop diversification.

Acknowledgments

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Greenhouse gas emissions of diverse wheat populations vs. varieties

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1 Introduction

Future farming systems have to reduce their dependence of external inputs in order to mitigate their effects on climate change and fossil resource use while being more resilient against adverse effects of changing growing conditions. Among other means, functional diversity at the within- and between-species levels can be a major component in order to use less external inputs while maintaining high yield levels (Wolfe&Döring 2016). Composite cross populations (CCP, Döring et al. 2015) are one way to achieve a higher functional diversity. With regard to the impact of a farming system on climate change, energy balances as well as nutrient and greenhouse gas balances are often utilized to assess the use and effects of external inputs (Simon 2018). Models that describe the complex interactions between production processes as well as matter and energy flows are used to calculate these balances. By assessing e.g. the carbon dioxide emissions of every system input and production process, the carbon dioxide emissions of the whole process chain can be evaluated. This method can be used analogous for every other impact category. As an example, greenhouse gas emissions of a CCP and a reference variety (Florian) was compared with and without pesticide use.

2 Materials and Methods

The calculations were based on a 3-year field experiment in southern Germany. In 4 repetitions, winter wheat CCP and varieties were grown with and without pesticide use (herbicides, fungicides, insecticides, growth regulators). The crops were fertilized with 110 kg ha^{-1} N, management included tillage, sowing, fertilizing, pesticide use (where applicable), harvest and transport. Yield and management data were averaged across the 3 trial years for the calculations. At field level, all inputs and outputs were assessed in order to calculate greenhouse gas emissions. The total greenhouse gas emissions of a plant production system consist of emissions from energy use, soil organic carbon turnover and from nitrous oxide emissions, each modelled. Greenhouse gas emission equivalents of all inputs were adjusted to state of the art production processes in Western Europe (Hülsbergen et al. 2001, Küstermann et al. 2008, Frank 2014).

3 Results

The production of the line variety emitted more greenhouse gases in total compared to the composite cross populations, both with and without pesticide use (with pesticide use: Florian 38.5 kg CO_2-eq GJ^{-1}, CCP 34.2 kg CO_2-eq GJ^{-1}, without pesticide use: Florian 33.0 kg CO_2-eq GJ^{-1}, CCP 30.1 kg CO_2-eq GJ^{-1}). The difference between Florian and CCP was caused mainly by the higher soil organic carbon turnover of the line variety (with pesticide use: Florian 17.0 kg CO_2-eq GJ^{-1}, CCP 11.9 kg CO_2-eq GJ^{-1}, without pesticide use: Florian 10.3 kg CO_2-eq GJ^{-1}, CCP 7.2 kg CO_2-eq GJ^{-1}). The higher straw yield of the CCP paired with comparable kernel yields (with pesticide use: Florian 9.5 t ha^{-1}, CCP 9.1 t ha^{-1}, without pesticide use: Florian 8.3 t ha^{-1}, CCP 8.0 t ha^{-1}) resulted in a lower soil organic carbon turnover. The other parts of the greenhouse gas balance (GHG emissions from energy use, nitrous oxide emissions) were comparably high for both varieties with little differences.

4 Discussion and Conclusions

The results of our study indicate that the main advantage of CCPs compared to varieties regarding greenhouse gas emissions could be due to their lower harvest index. The lower soil organic carbon turnover is linked to a higher supply of carbon due to the amount of straw that remains on field. Interestingly, omission of pesticides had little effect on the greenhouse gas emissions from energy use. Both emissions from energy use and nitrous oxide emissions were similar for CCP and Florian, indicating few effects beyond emissions from soil organic carbon.

Acknowledgement

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On-farm winter wheat variety trials in organic farming

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1 Introduction

Among small-grain cereals, wheat cultivation has the highest acreage in Hungary both in conventional and organic agriculture. The climate extremes of 2010 and 2011 with the highest amount of precipitation and the driest year of the century, however, drew attention to the vulnerability of the production and quality of organic wheat. Searching for possible causes shed light on the lacking information on variety usage, inadequate variety assortment and difficulties in the acquisition of suitable sowing seeds, especially organic ones, although choosing the right variety is essential in organic farming (*Lammerts et al*. 1999). The above reasons lead to the participatory on farm variety trials begun by ÖMKi in 2012, as a substitution for the official variety trials missing in organic farming. These types of tests provide unique opportunities to alloy experimentation with practice and obtain reliable information on the performance of a great number of varieties under various climatic and environmental conditions on the organic farms all over Hungary. The aim is to exclude the inappropriate varieties and find the economically profitable, best yielding, stably producing high quality ones, which might of course change with site and location. Farmers can compare several promising varieties each year, which encourages them to choose more than one variety to further grow. This increases biodiversity and might contribute to better yield stability at the same time. Based on the data acquired on cultivation, performance, weed suppression and disease resistance, variety recommendations can be made more efficiently taking into account the environmental and climatic issues, resulting in a more diverse and optimized variety usage.

2 Materials and Methods

At start in 2012, four varieties of two breeding companies were sown on five volunteer organic farms together with the varieties the farmers usually grew on each site. These initial varieties have been replaced with more suitable accessions in the following years during which both the number of the varieties and that of the farms increased gradually. The investigated varieties originate from local breeding centres in Hungary and partly from the neighbouring Austria. A characteristic of the on-farm trial is that not all of the varieties are sown in all locations but most varieties are grown in various places, partly based on the farmers' choice. To allow comparisons between sites, a standard variety (KG Kunhalom) is used in all testing sites. Varieties producing above average without restricting characteristics (such as e.g. poor disease resistance, weed suppression or quality) have been repeatedly included in the tests so that the most suitable ones could be selected for cultivation by farmers. Although the farms participating might vary with time there is a core of farmers (5-7 farms) who take part in several subsequent years. Sowing seeds (typically 30-50 kg from each variety) are provided for the farmers who are requested to sow them in lanes (usually in the width of their sowing machine) side by side, in the most homogenous part of their piece of land. During field surveys, each variety on each site is evaluated and data on the incidence and coverage of various diseases are recorded. Yield is determined via estimation (collecting the spikes with a sickle from 3×1 m^2 representative plots) and, when possible, with machine-harvesting of the plots. Grain quality is measured on the threshed grain samples with the NIR method (Mininfra Scan-T Plus, Infracont) according to the relating standards.

3 Results

Up till now, more than 20 farms and 40 varieties have been involved in the experiments. Variety assortment is regularly revised because of unsuitability, distribution expiry or inaccessibility. This implies it is improved over time and that the last years are the essence of experiences from previous years. Due to lack of space and the rather complex test situation, only the main findings of 2018 are presented here, when wheat cultivation was severely influenced by drought. Rates of disease infection, such as e.g. Septoria tritici, leaf and yellow rusts were also significant. 9 sites and 19 varieties were involved; in average 8.8 varieties per site and 4.3 sites per each variety, from which there were 4 varieties tested in one place, 2 in 2, 2 in 3, 1 in 4, 2 in 5, 4 in

6, 3 in 7 and 1 in 9 sites. Differences between sites were great as the average grain yield varied between 1.5 and 4.2 t/ha, with the mean value of 2.5 t/ha. Taking into account only varieties which were grown in at least three locations, the differences between accessions were also considerable; the grain yield, averaged over the sites, varied between 1.9 and 3.0 t/ha. With its mean yield of 2.7 t/ha (on 9 sites), the standard variety, KG Kunhalom adapted well to poorer and moderate environments and performed acceptably in farms with the best capacities. In Tiszasziget, however, where soil conditions are outstanding and the highest yields are usually obtained, top conventional varieties (e.g. Mv Nádor) had the highest yield and quality. Besides KG Kunhalom, GK Körös, Lukullus, Capo and Adesso produced better under moderately high growing conditions. Though yield was lower, quality was higher in 2018, compared to the wet year of 2017 (shown here in one example of one location, Fig.1), when a lot of varieties reached only feed quality. The moderately yielding old landrace, Bánkúti 1201 had, however, high quality under all conditions, which might explain why it is still so esteemed by organic farmers.

4 Discussion and Conclusions

In organic farming, where the use of artificial fertilizers and pesticides is prohibited, biological bases – choosing the most suitable variety - have outstanding importance (*Lammerts et al*. 1999). Despite this, information on the variety usage, especially on the accessible ones, is rather scarce. Experiences of conventional farming can poorly be adapted to organic conditions (*Murphy et al*. 2007), due to their contrasting circumstances; the same variety is very unlikely to thrive equally well under both cultivation types (*Carr et al*. 1971). This is in accordance with our findings, which suggested that organic breeding has a great potential. Some Austrian varieties, which are recommended or bred under organic conditions performed also well in several locations of Hungary. The Hungarian variety, KG Kunhalom, which was used as a standard, exhibited, however, the widest adaptation ability with respect to both yield and quality.

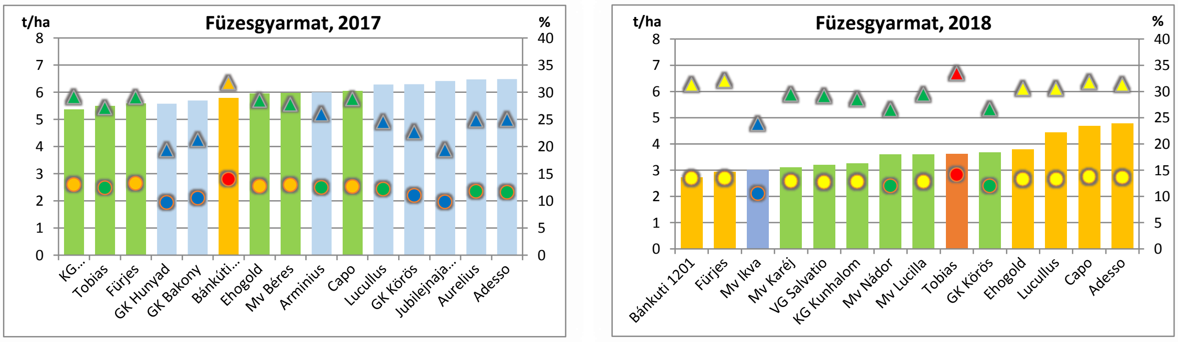

Figure 1. Grain yield in Füzesgyarmat (2017-18).

Columns, dots and triangles refer to the average grain yield, protein and gluten content, while blue, green, yellow and brown/red colours represent feed, milling II, milling I, and premium quality, respective-ly, indicating grain quality levels according to the Hungarian MSZ 6383 2017 standard.

Although the results of the first years' trials suggested that either grain quality was high but yield was low or yield was high but coupled to poor quality, some varieties have been since found to be able to produce both high yield and quality, providing thus locally adapted solutions.

The high interest from farmers' side and the wide range of varieties tested during the seven years of the experiments underline the success of our on farm system, which we intend to carry on with extended investigations aimed at high quality organic production, including the needs of handcraft bakeries.

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Session 13. Breeding for interspecific mixtures

Chairs: Charlotte Bickler (ORC, United Kingdom),
Johannes Timaeus (University of Kassel, Germany)

ORAL PRESENTATIONS

- Selection of the best adapted legume types for relay intercropping in durum wheat
  Speaker: Federico Leoni, Sant'Anna School of Advanced Studies, Italy
- Promoting long-term durability in disease control: a framework for managing varietal diversity and identifying varieties with potential durable resistance
  Speaker: Florence Dubs, INRA, France
- On-farm research to explore the impact of increasing diversity: the case of soft wheat combining intra-varietal diversity with legume association for modern and landrace varieties
  Speaker: Antoine Marin, INRA, France
- Development of genetic models to breed for mixed cropping systems
  Speaker: Benedikt Haug, FiBL, Switzerland
- An interdisciplinary approach to increase wheat within-field diversity and promote agro-ecosystem services
  Speaker: Jérome Enjalbert, INRA, France

POSTERS

- Examining wheat-pea mixtures to define specific selection traits for targeted winter wheat breeding
  Presenter: Péter Mikó, Hungarian Academy of Sciences, Hungary
- Experimental screening of pea and wheat genotypes for mixture-performance in a baking-wheat cropping system
  Presenter: Johannes Timaeus, University of Kassel, Germany
- Performance of durum and soft wheat in a mixed cropping system with a faba bean population in Germany
  Presenter: Odette Weedon, University of Kassel, Germany
- Screening of perennial and annual self-reseeding legume cover crops for their potential application as permanent living mulch in organic vegetable system
  Presenter: Mariateresa Lazzaro, Sant'Anna School of Advanced Studies, Italy

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Selection of the best adapted legume types for relay intercropping in durum wheat

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1 Introduction

Weed presence in cereal-based cropping systems may be markedly reduced increasing temporal and spatial diversification (Liebman *et al*., 2001). Relay intercropping is an application of spatial diversification and consists of growing two or more crops simultaneously, during part of their life cycle (Vandermeer, 1989).

In the current study, legume subsidiary crops are intersown in an already established durum wheat crop stand. The delayed legume establishment is expected to maintain grain yield by limiting the legume-wheat interspecific competition, avoid the fallow period between wheat harvest and the following crop (up to 10 months in Mediterranean agroecosystems) and support weed control.

However, the simple delay in sowing may not be sufficient to prevent yield loss and contrast weeds; the appropriate choice of the associated legume, with specific morphological and phenological characteristics, is also essential for a successful application of this system (Uchino *et al.*, 2011).

Perennial, annual and annual self-reseeding legumes can be used for relay intercropping. During the intercropping period, the three groups can support weed control by establishing a living mulch. After wheat harvest, weed control capacity changes according to the group. Perennial legumes, traditionally used in this practise, can be used as forage crop for 2-3 following years. Annual legumes with high self-reseeding capacity, may be able to re-germinate by their seeds in autumn and serve as cover crop until the subsequent cash crop, while, annual legumes support weed control as dead mulch until the following crop.

The objective of this study is the agronomic evaluation of legumes and the selection of the most suitable ones for relay intercropping with durum wheat in central Italy. The study focused on wheat performance and weed control before and after crop harvest.

2 Materials and Methods

The legumes evaluated in this experiment include perennial (*Medicago sativa*, *Medicago varia*, *Medicago lupulina*, *Trifolium repens*, *Hedysarum coronarium*), annual (*Trifolium alexandrinum*, *Trifolium incarnatum*, *Trifolium resupinatum*, *Vicia villosa*) and annual self-reseeding (*Medicago polymorpha*, *Medicago rotata*, *Medicago scutellata*, *Medicago truncatula*, *Trifolium michelianum*, *Trifolium subterraneum*) species. For each species, we tested one commercial cultivar except for *T. subterraneum*, particularly promising for the target region, that was included with six cultivars for a total of 21 legume types in the experiment.

Legumes were undersown between the already established durum wheat rows (18 cm inter-row) before the wheat stem elongation phase. The experiment, organised in a randomised complete block design, with four replicates for each legume type and the sole wheat crop as control, was carried out in 2017/18 and repeated in the 2018/19 cropping season at the Centre for Agro-Environmental Research "Enrico Avanzi" in Pisa (Italy, 43°40'48.0"N+10°20'45.5"E). Wheat, legume and weed growth were monitored during the intercropping period and, at harvest, their biomass was measured. Legume and weed biomass were also sampled during the following autumn and spring. Wheat grain yield, legume and weed biomass related to 2017/18 experiment were analysed by ANOVA, using a mixed effect model with the intercropped legume type included as fix factor and the blocks as random factor. Tukey test was used as post-hoc test ($p\text{-value} \leq 0.05$).

3 Results

Results at wheat harvest show that, despite the different performance of annual, self-reseeding and perennial legumes in terms of biomass accumulation, grain yield was not affected by the legume presence (1.48 ± 0.06 t ha^{-1}). Legume presence decreased weed biomass on average by 56 % in comparison with the control (201.73

± 27.91 *vs* 457.07 ± 76.28 g m^{-2}). The effect of each legume on weed biomass varied considerably among types, with a higher weed suppression capacity for legumes with a higher biomass. In fact, a significant correlation between legume and weed biomass was detected (r= -0.41, $p < 0.05$).

In autumn, biomass accumulation of perennial legumes and weeds was evaluated, showing that perennial legumes reduce the average weed dry biomass by 70% in comparison with the control (35.94 ± 11.76 g m^{-2} vs 118.47 ± 33.76 g m^{-2}).

In the following spring, perennial legumes continue to affect weed biomass. In particular, *H. coronarium* showed the stronger suppressive effect against weeds, reducing their dry biomass by 50 % in comparison with the control (96.66 ± 15.31 *vs* 196.84 ± 13.34 g m^{-2}).

At this stage, no significative effects against weeds was detect for annual legume.

The situation is very diversified for the annual self-reseeding legumes in the trial. Despite the high amount of seed production, some self-reseeding legumes were unable to regrow in a sufficient way (e.g. *M. rotata*, *M. scutellata*, *M. truncatula*) with no effects against weeds. Other self-reseeding legumes such as *M. polymorpha*, *T. subterraneum* cv Antas, instead, had a good regrowth and biomass accumulation, reducing weed biomass in the following spring respectively by 35% and 49 % in comparison with the control (128.35 ± 18.48 and 100.75 ± 12.41 *vs* 196.84 ± 13.34 g m^{-2}).

The experiment is repeated in a nearby field in 2018/19 to prioritise legume types suitable for relayintercropping.

4 Discussion and Conclusions

Relay intercropping of legumes in durum wheat seems a suitable practice to preserve wheat grain yield and improve the weed control before and after wheat harvest.

Wheat grain production, during this first-year experiment, was on average below the local production level. This was mostly due to low wheat germination (192 plants/m^2 instead of 350 plans/m^2) and the unusual rainy season, which facilitated weed growth.

The use of perennial legumes allowed to cover the soil and compete against weeds immediately after wheat harvest and this effect can potentially be exerted for the following 2-3 years. The perennial legumes had a good biomass accumulation in the following autumn and spring and this confirms their potential use for forage production or pasture.

After wheat harvest, residuals of the annual legumes remained on the soil. However, their residual biomass was not sufficient to establish a suppressive dead mulch against weeds, making them less suitable for this system.

Instead, annual-self reseeding legumes such as *M. polymorpha* and *T. subterraneum* cv Antas were interesting for this system. These legumes showed the best re-growth capacity in comparison with all the other self-reseeding legumes in the trial. They ensured a good soil coverage and biomass accumulation until the following cash crop. Self-reseeding legumes could be managed as green manure or as dead mulch in which the following spring crop can be sown by direct drilling. Other annual self-reseeding legumes, despite the high amount of seed production, were unable to regrow in a sufficient way, suggesting that also the seed hardness may be a barrier to regrowth of these legumes. Results from this first-year experiment seem to confirm that the relay intercropping of legumes in wheat may support weed control, if suitable legumes are used. However, additional replications of this experiment are needed to confirm the weed suppressive capacity of legumes in this system.

Acknowledgment

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Promoting long-term durability in disease control: a framework for managing varietal diversity and identifying varieties with potential durable resistance

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1 Introduction

Since the mid-twentieth century, European agroecosystems have undergone profound changes, including the erosion of crop diversity making agricultural production vulnerable to pathogens, and can lead to devastating epidemics. To limite their importance and increase the durability of resistance genes, we need to better manage varietal deployment. The monitoring of spatio-temporal crop diversity may be a way to promote the diversification of sources of resistance. To do so, we propose a framework for the identification of varieties with durable resistance, effective for at least ten years in an epidemic context, based on several kinds of information collected routinely by Wheat Board authorities, phytopathologists and agricultural advisory services. To illustrate this framework, we use the bread wheat varieties deployed in France over the period 1985-2015, and study the yellow rustresistance.

Yellow rust, caused by *Puccinia striiformis f. sp. tritici* (*Pst*), has become a major disease in Europe due to the emergence of new *Pst* pathotypes from the near-Himalayan region that have replaced the previously dominant European pathotypes. This replacement calls into question yellow rust control, which is currently based on the use of fungicides and major race-specific resistance genes. These race-specific resistances, inherited monogenically, are very efficient but, because of their wide deployment, they are usually broken down in few years by the evolution of new virulent *Pst* populations. To lower both the frequency and impact of these replacements, a more parcimonious deployment of these resistances is needed. But it is also critical to breed and promote varieties with durable resistance, a complementary strategy as their durable resistances often rely on a set of Quantitative Trait Loci (QTLs) rather than a single major gene. A more efficient identification of commercially successful varieties with durable resistance is certainly a good way to promote their use as sources of durable resistance in breeding programs.

2 Materials and Methods

France is an important production area of bread wheat, subject to the recurrence of yellow rust epidemics. Information on the acreages of bread wheat varieties, the level of field adult-plant resistance, the race-specific resistance genes of varieties and the occurrence of *Pst* pathotypes are available. In France, the varietal composition, the yellow rust pressure and the pathotypes composition have a strong and well described spatio-temporal structure. It allows to define homogeneous areas of bread wheat production and disease pressure, in a first step. Within a homogeneous area, we then retained all the varieties sown over a significant acreage (> 50,000 ha) over the entire period studied and computed the longevity of varietal resistance for resistant varieties to yellow rust at the time of their registration, which is the number of year between the registration year and the year before the epidemic episode following the last year of field adult-plant resistance notation. . Then, the interpretation t of the longevity of varietal resistance to yellow rust is done by using information available on the presence of race-specific resistance genes and *Pst* pathotypes at the time of the level of field adult-plant resistance change.

3 Results

Considering the North region of France (de Vallavieille-Pope *et al*., 2012), on the 1083 varieties deployed between 1985 and 2018, only 240 have a total crop rotation area of more than 50,000 hectares and available information on year of registration, and their field adult-plant resistance notation. Among them, 15 may have a potential durable resistance based only on acreage data. One of them is known to have lost this durable resistance (Renan). Some of them (Apache, Camp Remy, Claire and Soissons) were already known for their durable resistances but other (Isengrain, Scipion) were not known to be durable, but their pedigrees suggest that they may have inherited a high level of resistance from older lines known to be sources of durable resistance.

4 Discussion and Conclusions

In the current context of yellow rust pressure in Europe, a good strategy would be to combine the use of varieties with durable resistances and varieties carrying diversified race-specific genes. A better knowledge of the pedigree of the varieties and their particular sources of resistance could also make it possible to diversify these breeding sources. Indeed, the combination of multiple sources of partial resistance due to QTLs and one or more race-specific resistance gene(s) is complex for breeders and may conflict with other objectives. Even though handling a portfolio of resistance sources constitutes a constraint for breeders, it could nevertheless limit the importance of the epidemic and the fungicide use. The use of the framework proposed here by various actors could thus contribute to improve the deployment of varieties and resistance genes.

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On-farm research to explore the impact of increasing diversity: the case of soft wheat combining intra-varietal diversity with legume association for modern and landrace varieties

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1 Introduction

In a context of agroecological transition answering the global ecological crisis, climate change and global nutrition problems, nutrients deficiencies and allergies, what cereals should we eat and how to grow them [Newton et al., 2010, Tokatlidis and Vlachostergios, 2016]? In recent years, in France and overall Europe, the interest in local and traditional productions is increasing, especially in the agro-food sector. For economic, social and nutritional reasons, this trend has led to the rediscovery and reuse of landraces for both wheat and other crops. Higher price are offered to farmers for these local productions. Many recent studies have shown the high quality and nutritional value of landraces, both for high amount of antioxidant compounds and for their natural aptitude to organic production [Pasqualone et al., 2014, Migliorini et al., 2016].

Joining questions from regional actors and farmers about diversity to increase crop resilience (stability over time and space), yields and quality, on farm research has been experienced to study several levels of diversity in diversified real conditions [Ceccarelli, 2012, Chable et al., 2014]; intra varietal and inter specific diversities have been combined and studied in a long term experiment through which was initiated during a regional project, SAFARI[1] (four years from 2014 to 2017). The co-evolution process has been investigated thanks to the sowing of seed harvested year after year. The objectives were (1) to learn about on farm plant breeding for crop associations and (2) to measure the respective abilities of modern pure lines and ancient populations?

2 Materials and Methods

The SAFARI experiment took place in four organic farms and one conventional farm. No inputs were used during cultivation. Three modern pure line varieties (Chevalier, Renan, Pireneo) and three landrace population varieties (Bladette de Provence, Redon roux pâle, St Priest et le Vernoix rouge) were used. The varieties were cultivated according to three treatments: (1) single crops, (2) mixtures, one obtained with 'modern' varieties, and one with 'landraces' mixtures, (3) both 'modern' and 'landrace' mixtures intercropped with legumes. The legumes were clovers (white clover or clover mix) or fababean ('Diva', a modern variety). The legume species had been chosen by the farmers. Each plot was 30 meters long and 3 meters wide (adapted to farm sowing machine) and was replicated three times on each site. Trials were implemented using the machinery available on the farms according to the current practices of the farmers. Thus, the experimental design was simplified to be easily managed by farmers, so the treatments were replicated but not randomized. A statistical analysis was done to check homogeneity across repetitions. We present and discuss results collected for the following criteria: grain yields, grain & straw yields, grain protein contents, plant health and arbuscular mycorrhiza fungi colonization.

3 Results

This on farm experiment allows us to confirm several statements: 1) an overall wheat grain yield around 3 t/ha, like the French national mean for organic agriculture; 2) the intercropping of wheat with legumes decreases wheat grain yield from around 25%; 3) the overall wheat grain protein content is around 13% (around 11.5% in France, probably more in organic agriculture); 4) intercropping wheat with legumes increases wheat grain protein content from 12.5 to 13.5%; 5) wheat lodging was 40% on overall with

[1] SAFARI: « Agro-diversités génétique et spécifique pour la Santé des plantes, la Fertilité des sols, l'Adaptation et la Résilience des systèmes de culture ». The project was funded by the PAO, an inter-regional structure of two regions, Brittany and Pays de la Loire. It developed collective programs with several local actors.

landraces varieties while it is around 1% with modern varieties. The trial design based on mixtures and intercropping with legumes offers new insights on the differences between modern and landrace varieties: (1) landraces varieties yielded around 2.8 t/ha whilst modern varieties yielded around 3.1. The landraces were more stable over sites and years, they have shown less competition with legumes when intercropping with legumes; (2) total dry matter yields including straws and legumes reached 11.4 t/ha for landrace varieties and only 9.3 t/ha for modern varieties, thus showing a great interest for carbon production / fixation, soil improvement; (3) the rate grain protein of landraces populations was 13.3% whilst it was only 12.1% for modern varieties, thus landraces have shown interest as source of proteins; (4) on overall, plant health was better for landrace varieties than for modern varieties; (5) arbuscular mycorrhiza fungi wheat root colonization was 6% higher for landrace varieties than for modern ones.

4 Discussion and Conclusions

It is clear that landraces varieties have shown great interest for several characters but the bottleneck to their expansion is their lodging susceptibility and to a lesser extent their lower yields. Specific breeding programs and agronomic knowledge are needed to reduce lodging impact. On-farm research has shown its relevance by the verification of knowledge already demonstrated elsewhere. The diversified conditions of the network of farms also offered the opportunity to observe the contrasting potential of modern varieties and landraces. On farm experiment is always a compromise between what is possible (time, place) and what we need to answer. Regarding these results, a lot of other pending questions remains, like a qualitative analysis of arbuscular mycorrhiza fungi or the impact of these practices onto soil life, one of the main objective of organic systems. The continuation of this work is currently on-going in the frame of EU H2020 ReMIX[1] project where our team focus on the co-evolution ability of wheat and fababean to increase the efficiency of intercropping systems. Meanwhile, this study will question whether it is possible to breed wheat specifically for growing with fababean. In the context of the SAFARI project, regional authorities have funded the project and were also particularly interested in the multi-actor process. They aimed to encourage legume cultivation for protein self-sufficiency in the farms and to better connect conventional and organic sectors in matter of research. At several levels of the experimental design (choice of the species, varieties and practices), the methods and tools have been specified within an iterative process from dialogue between farmers and researchers.

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[1] A four years project, 24 partners from 13 countries, since 2017.

Development of genetic models to breed for mixed cropping systems

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1 Introduction

Mixed cropping, i.e. mixing different crops in the same field, provides agronomic advantages as increased productivity under low inputs conditions (e.g. for organic farming: Bedoussac et al. 2015) and higher yield stability (Raseduzzaman and Jensen 2017). In mixed cropping, choosing the right cultivars is critical for the performance of the mixture, as shown for pea-barley mixtures (Hauggaard-Nielsen and Jensen 2001) and maize-bean mixtures (Hoppe 2016). As performance in pure stand can strongly diverge from performance in mixture, estimating the ability of a cultivar to be mixed with another crop is therefore of utmost importance. For this purpose, concepts of General and Specific Combining Ability in hybrid breeding (Griffing 1956) have been adapted to cultivar and crop mixtures. Thus, these effects are called General Mixing Ability (GMA) and Specific Mixing Ability (SMA) (Federer 1993). In contrast to intraspecific mixtures, interspecific mixed cropping experiments often provide additional information, since harvested lots can be separated into their different grain fractions. Until now, statistical developments mobilizing the additional information provided by separated harvest lots to estimate mixing abilities in intercropping experiments have been neglected. The concept of Producer- and Associate-effects (abbreviated *Pr* and *As*, respectively) describes interactions between varieties sown in alternate row trials (Forst 2018). The producer effect *Pr* is the average performance of a cultivar grown in mixture with other crop-species, whereas the associate effect *As* is the average effect of a cultivar on the performance of the mixing partner. We used the fraction yields of a spring-pea (*Pisum sativum* L.) and spring-barley (*Hordeum vulgare* L.) mixed cropping experiment to determine *Pr* and *As* effects of different pea genotypes. The additional information provided by this approach is biologically more informative than GMA/SMA estimates, since it better reflects competition and facilitation occurring between different cultivars of the two crop-species.

2 Material and methods

Plant material comprised of 28 (plus 4 mixtures) and 7 (plus 1 mixture) morphologically diverse pea and barley cultivars, respectively, from European breeding programmes to compose bi-specific pea-barley mixtures. Fifty-six bi-specific pea-barley mixtures were arranged in an incomplete factorial design (Figure 1) and sown in 7.5 m^2 plots with two repetitions at two locations in Switzerland (Figure 2). Harvested grains were separated into pea and barley components. Variance components for both the GMA/SMA and the *Pr*/*As* model were estimated within a mixed model framework with best linear unbiased prediction. GMA of pea cultivars, SMA (interaction of pea cultivar with barley cultivar) and the error term were set as random variables with the assumptions for random effects of having a mean of 0 and being normally distributed. Similarly, *Pr* and *As* effects were estimated with the pea and barley component yields as dependent variables, respectively. Potential functional traits, such as early vigour of pea, were measured and evaluated using correlation analysis to relate them to GMA, *Pr* and *As* effects. When prerequisites for parametric test procedures were not fulfilled, non-parametric tests (e.g. Spearman rank-correlation) were applied.

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	peas	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32
barleys	No barley (pure stand pea) / No pea (pure stand barley)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
B1	1	1				1					1				1					1			1				1			1			
B2	1	1					1			1						1		1					1						1		1		
B3	1				1	1				1					1						1	1				1						1	
B4	1			1					1				1				1	1						1					1			1	
B5	1				1			1				1		1					1					1				1					1
B6	1		1				1					1		1							1	1				1					1		
B7	1		1					1			1						1		1						1		1						1
B8	1			1					1				1			1				1					1			1		1			

Figure 1. Incomplete factorial design with 8 barley pure stands (7 cultivars and 1 mixture), 32 pea pure stands (28 cultivars and 4 mixtures), and 56 bi-specific mixtures of those.

Figure 2. Aerial image of one of the two trial locations.

3 Results

The proportion of GMA variance of pea, i.e. the variance in mixture yield explained by the presence of a given pea cultivar in mixture, was predominant over SMA variance, i.e. the variance due to interaction of pea and barley cultivars: GMA pea ≈ 50%, SMA ≈ 10%, residual ≈ 40%. There was a significant negative correlation between the pea *Pr* effects and it's *As* effects with Spearman's rho= -0.47. However, few individual genotypes were found with positive *Pr* and positive *As* effects. *As* effects of pea were correlated over locations (R^2=0.48). The GMA of pea was not significantly correlated with early vigour of pea (Spearman's rho=0.21), whereas *As* effects of pea were significantly negatively correlated with this trait (Spearman's rho= -0.36).

4 Discussion and conclusions

The GMA approach, based on the testcross methodology from hybrid breeding is a valuable tool to determine mixing ability in pea-barley mixtures. This potential is further pronounced by our finding that pea GMA variance is predominant over SMA variance, indicating the potential for breeding for mixed cropping. The GMA approach can be extended using the *Pr/As* concept for understanding trait influences on mixture behaviour. We observe a negative correlation between *Pr* and *As* effects, indicating a trade-off between a cultivar's performance and its companion-crop's performance as observed also by Forst, 2018, for wheat cultivar mixtures. However, our data suggests room for genetic improvement, e.g. by selecting deviating genotypes with both positive *Pr* and *As* effects. *As* effects were correlated over locations, indicating an underlying heritable component. Early vigour of pea was not correlated with GMA, however, it significantly negatively correlated with pea's *As* effect (its effect on the barley yield), indicating the surplus of precision and information on trait-performance relationships that the *Pr-As* concept gives compared to the GMA concept. The results allow to seize the effects of cultivar choice in the performance of crop mixtures and to propose breeding schemes and experimental designs for improving pea-barley mixtures.

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An interdisciplinary approach to increase wheat within-field diversity and promote agro-ecosystem services

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1 Introduction

One major challenge for increasing agricultural sustainability is to better mobilize crop genetic diversity, as promoted by agroecology. A simple way to increase within-field diversity is to use cultivar mixtures, and this has been successfully applied to a few crops in the past. Despite numerous scientific papers documenting the value of cultivar mixtures in wheat and other cereals, especially to control diseases, their cultivation has remained marginal throughout the world. To understand the origin of this gap between scientific knowledge and agricultural practices, the French project Wheatamix explored the synergies mobilized by cultivar mixtures, their impact on various ecosystem services, and their potential to reinforce the sustainability, resilience, and multi-functionality of agriculture. It focused on the agro-ecological and socio-economic impacts of variety associations at different scales, from the plant level up to the wheat supply chain. The project aims at developing new blending and breeding methods to design performing mixtures.

2 Materials and Methods

To understand how plant-to-plant interactions shape wheat mixtures performances, Wheatamix has set five objectives: 1) describe the variability of morphological and ecological traits in a panel of 57 varieties; 2) explore variability by blending 16 contrasted varieties from the panel into 72 mixtures, composed of 2, 4, and 8 components; 3) study the ecosystem services provided; 4) assess the technical and economic performances in farmer conditions; 5) evaluate the impact of cultivar mixtures on the wheat supply chain. To achieve these goals, this project has developed an interdisciplinary approach, mobilizing agronomy, ecology, economics, ecophysiology, epidemiology, genetics, and management sciences. The project brought together scientists from 10 labs, as well as agricultural advisers and farmers from 6 French counties.

3 Results

The project first described the functional diversity of 57 varieties, highlighting the effects of modern breeding on trait variability, that lowered phenotypic variation for traits subject to direct selection, and impacted both plant architecture, physiological traits as nutrient absorption, but also trade-off between traits. Wheatamix then surveyed how variation in mixture diversity impacted wild communities. A first result highlighted the low abundance of macro-organisms in this experiment: no relationship was found between the number of varieties in a mixture and the diversity/abundance of earthworms, weeds, mycorrhizae, springtails, beetles, nematodes. However, a significant effect of mixture diversity on the abundance of some spiders, and on nitrifying bacteria, was observed. Coming to ecosystem services, disease regulation (rust and septoria) has been confirmed as the most strongly and positively affected by varietal associations, raising also the strong effects of architectural variability of the canopy (septoria). Diversity also contributed to higher predation rates on aphids. Lastly, soil nitrification and denitrification activities were significantly affected by mixture diversity on 4 surveyed sites, contributing to a shift in plant nutrition and positive effect of greenhouse gas emission. Co-design of variety mixtures was carried out with farmers, technical advisers, and scientists. For three years, 30 farmers in the Paris basin proposed varietal blends and measured their performance on their farms. This exchange first highlighted that the first goals for farmers was to i) secure their production ii) simplify plot management. Then co-design workshops allowed to propose assembly rules and design mixtures, resulting in a wide diversity of sown mixtures. Field trials revealed that in more than 70% of the cases, the mixture had a higher yield than the mean of its components. This work highlighted farmers needs and resulted in a Multicriteria Evaluation Tool, helping farmers and advisers to design mixtures. The survey of the wheat supply chain finally highlighted the need for a concerted innovation among the various actors. Finally, Wheatamix also developed new statistical method to infer mixing ability, allowing both to blend the best mixers, and also to propose new breeding methods.

4 Discussion

Coupling various disciplines and approaches, such as ecophysiological modeling of plant competition (FSPM WALTer), field and controlled experiments, theoretical framework in ecology (sampling vs complementarity effects, functional traits and trade-off), and mixture co-design and surveys with stakeholders, Wheatamix has allowed to understand the interest of cultivar mixtures for farmers. Wheat cultivar mixtures are experiencing an exponential growth: they only represented 2% of bread wheat sown in 2010, and are presently at 8%, raking at the first position on the cultivar list.

5 Conclusions

Wheatamix emphasizes the need for an interdisciplinary approach when addressing agroecological subjects, and illustrates the strong mutual benefices between agronomic and ecological sciences.

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Examining wheat-pea mixtures to define specific selection traits for targeted winter wheat breeding

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1 Introduction

Lack of sustainability in agriculture negatively affects the yearly grain supply, which could be effectively overcome by implementing and improving intercropping practices that enriches biodiversity above- and below-ground in the fields. However, targeted breeding programmes on suitable varieties for crop mixtures are seldom found. To define specific selection traits for winter wheat, a 3 years long trial has been started in 2018 at the Centre for Agricultural Research, Hungary in the frame of EU H2020 project ReMIX.

2 Materials and Methods

Altogether nine winter wheat genotypes having different types and diversity levels (5 varieties: dwarf-intensive, tall-extensive, robust-organic, normal-milling, premium quality; 2 mixtures: a 2-way (extensive+premium) and a 4-way (all mixed except dwarf type) mixture; 1 landrace and 1 composite cross population (CCP)) are examined using two different sowing densities (300 and 500 germs/m^2) with and without a winter pea cultivar intercropped. The trial was established under organic and conventional growing conditions using randomised complete block design of small plots (6 m^2) in three replications. A control trial was also set up with herbicide treatment in conventional field to check the effect of weeds. Several agronomic, phenotypic and resistance traits were assessed during the first year (see Table 1). Grain yield of the wheat genotypes in mixed plots was measured after separation from the pea seeds.

3 Results

Based on the results of the first year, we have found that in most cases the entries responded negatively to the presence of pea, unlike grain yield of the landrace in conventional field (Table 1). Most of the varieties and variety mixtures headed 1-2 days later in mixed plots than in pure plots, and they developed significantly less ears in the presence of pea. Comparing the pure and the mixed stands in both management systems, only the landrace and the CCP developed similar number of ears. However, significantly different ear-numbers were found between the entries only in the organic pure stands. Pea intercrop had negative effect on early soil coverage and weed suppression, especially in conventional field with lower sowing density. Few significant differences were observed for the effect of pea on resistance of wheat to the main leaf diseases: in the presence of pea, only the robust, the extensive variety and the 2-way variety mixture showed significantly higher susceptibility to yellow rust in organic field with low sowing density. No significant effect of sowing density was found for disease susceptibility. In the case of flag leaf area and plant height, significant effect of the pea intercrop was not observed.

In general, the dwarf (intensive) winter wheat cultivar was the most sensitive to intercropping in the case of grain yield, while the extensive (relatively tall) modern cultivar and the 4-way variety mixture had the highest grain yield in conventional field, harvested both from pure and mixed stands. The landrace had the lowest yield in conventional field, while no significant difference between the entries was found for grain yield in organic field. Regarding the dwarf intensive variety, grain yield was negatively affected also by weeds, while only the extensive variety drilled with high density responded with significantly higher plant stand to the presence of weeds.

Table 1 Winter wheat genotypes in organic and conventional sites showing significantly different respond to mixing with pea compared to their pure stands (2018, Martonvásár)

Trait	organic site	conventional site
Grain yield	1 , 6 , 10	1 , 8* , 10
Heading date	2, 4 , 7 , 9 , 14 , 16	3 , 4 , 6 , 7 , 13
Powdery mildew resistance	not assessed	N.S.
Leaf rust resistance	N.S.	N.S.
Yellow rust resistance	11 , 12 , 15	3
Soil coverage at tillering	N.S.	6 , 9 , 10 , 11 , 12 , 13 , 14 , 15 , 16 , 17 , 18
Weed coverage	14 , 15	1 , 2 , 4 , 5 , 9 , 10 , 11 , 13 , 17
Number of ears/m2	1 , 4 , 5 , 6 , 7 , 8	1 , 4 , 10 , 12
Lodging	N.S.	N.S.
Flag leaf area	N.S.	N.S.
Plant height	N.S.	N.S.

*positive response to pea intercrop (all others showed significant negative response at $p<0.05$)
N.S.: no significant difference between the pure and the mixed stand regarding each trial entry. Variety 1-9 and 10-18 were sown with 500 and 300 germs/m2, respectively. Winter wheat variety types: 1+10: dwarf intensive, 2+11: robust (good for organic), 3+12: extensive, 4+13: normal milling, 5+14: premium quality, 6+15: 2-way variety mixture (extensive×premium), 7+16: 4-way variety mixture (all mixed except dwarf type), 8+17: landrace with good quality, 9+18: composite population YQCCP.

4 Discussion and Conclusions

The trial will be continued for two more years, and results from three years will be aggregated and evaluated to select those traits that show significant effect for pea intercropping. After the first year we could assume that the companion species affects negatively the performance of wheat genotypes of any type and diversity levels in intercrops. However, the results of first year highlights the importance to examine grain yield, ear-number, heading date, yellow rust sensitivity and weed suppression ability also in mixed crop in order to select those lines that do not show significant negative effect of the pea intercropped. These traits could be the primary target of selection that will be carried out in mixed cropping growing system. Therefore, a targeted breeding program has been started already, where selection of lines occurs in crop mixture, taking into account specific selection traits highlighted above and searching also for new ones.

Acknowledgements

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DiverIMPACTS
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Experimental screening of pea and wheat genotypes for mixture-performance in a baking-wheat cropping system

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1 Introduction

A key challenge in low-input organic agriculture is low protein content due to low nitrogen fertilization rates. Experimental studies showed that wheat-pea mixtures can improve protein content of wheat (Bedoussac et al. 2015) and can increase energy efficiency up to two times measured in energy harvested per ton of grain (Pelzer u. a. 2012). However, the pea-wheat mixture cropping system still requires optimization with respect to finding the best pea and wheat genotypes and trait combinations. A key factor to identify the best variety combinations is competitive balance as this allows complementarity effects between crop species to become effective (Annicchiarico u. a. 2017), such as overyielding, nitrogen efficiency or increased wheat quality. Research indicates that plant height, leaf type (semi-leafless, normal-leafed) and growth habit (indeterminate, determinate) of peas influence mixture performance in barley-pea mixtures (Hauggaard-Nielsen und Jensen 2001) or in triticale-pea mixtures for fodder production (Annicchiarico u. a. 2017). Much less is known about traits of wheat cultivars relevant for mixture performance. Another trait of crucial importance for cereal grain production for human consumption is simultaneous grain maturity to enable combine harvesting. Further significant factors are sufficient frost tolerance of peas and traits conferring lodging resistance for effective harvest.

2 Materials and Methods

To screen how genotypes and their traits contribute to mixture performance we established two complementary experiments in autumn 2018 at the research fields of University of Kassel in Neu Eichenberg, Germany. The first experiment is a split plot design (mixture/monoculture) with four replicates. Sixteen wheat varieties and populations were sown as sole crop and in mixture with a single pea variety. In the second experiment, with two replicates, seven pea varieties with contrasting phenotypes were sown in monoculture and in mixture with a single wheat variety. Data are gathered for plant height, stand height, stem strength, phenology, biomass, diseases and yield data.

3 Results

Overwintering of all genotypes was successful due to a mild winter. So far only preliminary data for stem strength of peas was analysed. Stem strength varied between 2 mm and 6 mm. Cultivar Kolinder and Pandora had on average a smaller stem diameter (3,3 mm, 3,5 mm) then cultivars Fresnel (4,8 mm), Enduro (4,5 mm), Balltrap (4,4 mm), Jagger (5 mm) and James (4,8 mm). Between monoculture and species mixture stem diameter varied not much for Kolinder and Pandora. For James, Fresnel, Jagger, Enduro and Balltrap the stem diameter decreased in mixture compared to monoculture between 0,5 and 1 mm. In addition, increased internode length was observed for these varieties in species mixtures. This provides some support for plasticity of some pea cultivars, likely due to light competition that differs between monoculture and species mixture.

4 Discussion and Conclusions

Trait plasticity with respect to stem diameter/internode length is present in some pea varieties. Consequently, stem diameter/internode length cannot simply be predicted from trials in monoculture for species mixtures potentially complicating design of species mixtures. In contrast, trait plasticity itself could be an interesting trait for species mixtures. Peas that are capable of adapting to the plant height of the cereal crop partner would allow to mix it with different cultivars that vary in plant height contributing to general combining ability. Further data accumulating during this season will be presented at the conference.

Aknowledgments

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Performance of durum and soft wheat in a mixed cropping system with a faba bean population in Germany

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1 Introduction

Nitrogen is often a limiting factor in organic farming systems, not only due to lower overall N input levels, but also due to limited N availability during critical growth phases. Legume-cereal mixed cropping systems are of particular interest due to differential and in large part complementary nitrogen niches (Hauggaard-Nielsen et al. 2008; Bedoussac and Justes 2010;). Durum wheat (*Triticum durum*) production in Germany currently only meets around 20% of the local demand due to climatic limitations. Changing climatic conditions present the opportunity to screen previously unused species for suitability to new regions. Durum wheat has a high nitrogen demand and high grain protein content is important to ensure production quality (13-15% protein content). In order to test the suitability of durum wheat as an alternative cereal crop for the state of Hessen in Germany and to improve grain protein content within an organic farming system, a two-year field trial was started in May 2018, with the second experimental year planned for spring 2019.

2 Materials and Methods

The field experiment (randomised block design with four replicates) included two durum wheat varieties ('Doridur' and 'Duramonte') and a spring wheat variety ('Quintus') grown as monocultures, as well as in mixtures with a faba bean population ('Detpop'), with a sowing rate of 80% faba bean to 40% cereal variety. Assessments included cereal heading dates, plant height, biomass, cereal foliar and foot diseases, agronomic parameters such as yield, TKW (Thousand Kernel Weight), HI (Harvest Index) and grain protein content.

3 Results

The experimental season of 2018 was extremely dry (total precipitation for the growing season 123mm). After sowing the experiment was irrigated twice to ensure adequate germination (30mm). Nevertheless, emergence of wheat was poor, particularly in the monoculture stands (range of 44% to 48% emergence). Emergence in mixtures (56% to 66%) was considerably higher. The extreme drought and low plant emergence led to low yields. The cereal monocultures ranged from only 0.9 t/ha in the variety 'Doridur' to 1.2 t/ha in the spring wheat variety 'Quintus'. Yields of the cereal varieties in mixed stands raged from 0.6 t/ha in 'Doridur' to 0.9 t/ha in 'Quintus' and not significantly lower than expected their monoculture counterparts considering the sowing density. Overall LER (Land Equivalent Ratio) of the mixtures ranged from 1.28 to 1.50 compared to pure stands (LER).

4 Discussion and Conclusions

The fact that at lower sowing density and lower number of tillers per m^2 the cereals in mixed stands yielded similar to their monoculture counterparts most likely reflects the advantages of a lower planting density in such extreme conditions (drought), where less competition for resources would be advantageous. The experiment will be sown again in the spring of 2019, and results from the two experimental seasons will be presented at the conference.

Acknowledgement

This experiment has been supported by the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N. 727217 (ReMix).

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Screening of perennial and annual self-reseeding legume cover crops for their potential application as permanent living mulch in organic vegetable system

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1 Introduction

The objective of this experiment is to screen perennial and annual self-reseeding legumes cover crops for investigating their potential role as permanent living mulch in organic vegetable systems. This study focuses on the screening of legumes based on their morphology, phenology and weed suppression capacity. This is the first phase of a trial in which 28 different legume cover crops are tested as sole crop in order to select the most interesting ones for the local environmental condition. A reduced number of selected legumes will then be tested as permanent living mulch in a vegetable cropping system. Both perennial and annual self- reseeding legumes may be suitable for the target system. Perennial legumes are expected to exert weed control all over the year as living mulch. Annual self-reseeding legumes are able to re-generate from the soil seed bank in autumn and therefore improve weed control during winter as living mulch, while during summer they act as dead mulch, hence limiting the potential water competition during this season. This preliminary experiment was necessary because one of the main challenges to establish successfully a permanent living mulch is the appropriate choice of legume species and/or varieties. Indeed, specific morphological, physiological and phenological traits are crucial in order to obtain the benefits of living mulch and avoid over- competition with the main crop (Ciaccia *et al*., 2017). Unfortunately, the availability of suitable legumes for this system seems limited, because the cultivars available on the market are normally selected for other uses, e.g. high biomass production and, hence, they are likely highly competitive with the main crop. A specific legume ideotype selection is therefore necessary.

2 Materials and Methods

In this experiment we used 28 legumes (21 self-reseeding annuals and 7 perennials), including (i) commercial cultivars (5 of *Trifolium repens*, 4 of *T. subterraneum*, 3 of *Medicago polymorpha*, 2 of *Lotus corniculatus*, and 1 cultivar of *M. rigidula*, *M. truncatula*, *T. vescicolosum* and *T. michelianum, respectively*) (ii) wild ecotypes (8 *of M. polymorpha* collected in Central and Southern Italy) and (iii) mixtures of wild ecotypes (1 of *M. polymorpha* and 1 of *M. orbicularis*). The experiment was set-up at the Centre for Agro-Environmental Research "Enrico Avanzi" in Pisa (Italy) in autumn 2017 and will be monitored until spring 2020. Perennial and annual self- reseeding legumes were tested in plots of 4.5 m^2, replicated 4 times and arranged in a randomised block design, with spontaneous vegetation plots used as control. Legume development and weed suppression were evaluated by a series of visual estimations and three destructive sampling performed in spring (2018 and 2019 seasons) and autumn (2018 season). Phenology, canopy height and growth habit of legume were repeatedly evaluated during the experiment. Germination capacity and seed hardness of self-reseeding legumes were also evaluated.

3 Results

Biomass sampling in early spring of 2018 showed that, in general, legume presence reduced weed biomass by 49 % in comparison with the control (80.8 ± 20.8 vs 159.0 ± 21.8 g m^2). Biomass sampling in autumn highlighted a strong effect of perennial legumes able to decrease the weed biomass by 71% in comparison with the control (14.1 ± 7.2 vs 49.5 ± 11.5 g m^2). At this stage, among the group of annual self-reseeding legumes, dead mulch of *T. subterraneum* cv Fontanabona affected weed biomass decreasing it by 73 % in comparison with the control (13.44 ± 3.60 vs 49.5 ± 11.5 g m^2). Germination capacity of self-reseeding legumes in the first autumn after sowing showed that, despite the high amount of seed production, some legumes were unable to regenerate a dense green mulch (e.g. only 1% of *M. orbicularis* seeds germinated). Instead, *M. polymorpha* ecotypes from Principina (GR), Pitigliano (SI), and Talamone (GR), had a good regeneration rate.

4 Discussion and Conclusions

Cultivars of T. *repens* used in this experiment, showed in general a good weed control all over the year, even if they had a slow growth during the early stages. *T. repens* cv Rivendel seems the best compromise between weed control capacity and suitable morphological traits, making it interesting to be used as permeant living mulch. Among the group of annual self-reseeding legumes, cultivars of *T. subterraneum* sub. Brachycalicinum, and in particular cv Fontanabona, seem the most interesting for the target system (Ilnicki *et al*., 1992). These legumes are able to establish rapidly a dense and suppressive living mulch against weeds until spring. During summer, a dense dead mulch still effective against weeds, is left on the soil. All cultivars of *T. subterraneum* sub. Brachycalicinum showed a good regrowth in the following autumn. Furthermore, these legumes are characterized by a very prostrate habitus and a contained canopy height (maximum height in average 14.7 ± 2.1 cm), both important characteristics to get good weed control and potentially avoid competition with the transplanted vegetables (Ciaccia *et al*., 2017). Cultivars and ecotypes of *M. polymorpha* showed in general a fast growth and good weed control. Despite the high amount of seed production, regrowth capacity varies considerably among the ecotypes of *M. polymorpha* in the trial, probably due to the seed hardness (Porqueddu et al., 1996). In general, M. *polymorpha* seems unsuitable for our target system due to their high biomass accumulation and excessive canopy height.

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SESSION 14. DESIGNING AND OPTIMISING INTERSPECIFIC MIXTURES

Chairs: Lars Kiær (University of Copenhagen, Denmark),
Odette Weedon (University of Kassel, Germany)

ORAL PRESENTATIONS

- Design and assessment of diversified low input cropping systems in southwestern France: an application of agroecological principles aiming at decreasing pesticides and N-fertilizer use
  Speaker: Eric Justes, CIRAD, France
- Can the APSIM crop growth model simulate the growth of pure cultures and intercrops of wheat and faba bean in temperate zones in Europe?
  Speaker: Herman Nicolaas Cornelis Berghuijs, Swedish University of Agricultural Sciences, Sweden
- Soybean as a diversification crop for western France: using intercropping to mitigate risks linked to the introduction of a new crop
  Speaker: Timothée Cheriere, INRA, France
- Optimizing organic lentil crops in Sweden
  Speaker: Nicolas Carton, Swedish University of Agricultural Sciences, Sweden
- Analysis and design of strip cropping systems
  Speaker: Dirk van Apeldoorn, Wageningen University & Research, The Netherlands

POSTERS

- Using multifunctional subsidiary crops to reduce tillage in organic farming
  Presenter: Elsa Lagerquist, Swedish University of Agricultural Sciences, Sweden
- Evaluation of the Land Equivalent Ratio index in barley-pea and bread wheat-faba bean intercropping.
  Presenter: Stefano Tavoletti, Università Politecnica delle Marche, Italy
- Management of white clover living mulch to allow the development of winter cereals
  Presenter: Didier Stilmant, CRA-W, Belgium
- Pulses intercropped with cereals to secure the pulse production in organic and conventional farming in western France
  Presenter: Aline Vandewalle, Chambre d'agriculture des Pays de la Loire, France
- Organic vegetable cropping system diversification: effect of strip cropping on productivity and soil N availability in Mediterranean conditions
  Presenter: Elena Testani, CREA, Italy
- Crop diversification with aromatic herbs below
  Presenter: Felix Dittrich, Trier University, Germany
- Using the complementarity with cereals to overcome weaknesses of sole-cropped winter white lupin
  Presenter: Nicolas Carton, Swedish University of Agricultural Sciences, Sweden
- Lentil-oat mixtures: stronger together by complementing each other?
  Presenter: Katrin Rehak, Agroscope, Switzerland

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Design and assessment of diversified low input cropping systems in southwestern France: an application of agroecological principles aiming at decreasing pesticides and N-fertilizer use

Noémie Gaudio[±1], Catherine Bonnet [1], Didier Rafaillac [1], Lionel Alletto [1,2], Laurent Bedoussac [1,3], André Gavaland [4], Magali Willaume [1], Philippe Debaeke [1], Eric Justes*[1,5]

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1 Introduction

Spatial and temporal diversification of cropping systems (CS) is recognized as a relevant alternative to move towards sustainable agriculture (Duru et al. 2015). It could be achieved by several agronomic levers, and more particularly by lengthening and diversifying crop rotations notably by the introduction of legumes, crop mixtures and multi-services cover crops. In this study, we assumed that diversified CS could reduce the use of pesticides and N fertilizers in South-West France context, while maintaining the economic profit and improving the overall performances of CS in terms of ecosystem services. After designing CS varying by their degree of agro-ecologization, our objective was to illustrate their strengths and weaknesses and discuss the possible way to improve their performances for favoring their adoption by farmers in the future.

2 Materials and Methods

The experiment was located at INRA station in southwestern France (43°53'N, 1°51'W) and was carried out on two rotation cycles of three years each (2011-2013, 2014-2016), each crop of the rotation being present each year. The CS were designed as alternatives to the local two-years reference rotation of durum wheat and sunflower (REF) and were designed based on a lengthening of the rotation (3 years instead of 2), a pesticides reduction of 50%, and a variable reduction of N-fertilizer:

- LI: low-input CS aiming at reducing N-fertilizers by 25%, relying on a rotation of sunflower-durum wheat-sorghum,
- VLI_CM: very low-input CS aiming at reducing N-fertilizers by 50%, relying on a rotation of sunflower-fababean-durum wheat and including cultivar mixtures (CM),
- VLI_IC: VLI composed of three successive intercrops (IC): sunflower+soybean, then triticale+fababean (2011-2013) or durum wheat+winter pea (2014-2016), and then durum wheat+winter pea (2011-2013) or soft wheat+fababean (2014-2016).

Each CS was tested with and without cover crops (CC) during the fallow period. Thus, six CS were designed covering an agroecological gradient of reduced inputs use and increased diversification.

ANOVAs were run to compare the six CS and the reference at the rotation scale, considering 4 indicators calculated for each rotation at the year scale: i) the mean semi net margin (€.ha^{-1}, =[Grain yield x Crop price + Subsidies] - [Operational charges + Mechanical charges + Fuel]) as an integrative indicator, ii) the mean yield (t.ha^{-1}), iii) the gross proceeds (€.ha^{-1}, = Grain yield x Crop price, which is for intercrops the price of the mixture) and iv) the N-fertilizer amount (kg N.ha^{-1}).

3 Results

The CS (reflecting plant diversification and input effects) and the rotation cycle (reflecting mainly a climate effect) had a significant ($p < 0.05$) impact on semi net margin (Figure 1A). The effect of the rotation cycle was predominant, and involved a global decrease of semi net margin during the second rotation cycle, highlighting the importance to consider the environment through modelling in order to assess its impacts.

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Semi net margin decreased following the diversification gradient, with a lower semi net margin for VLI_IC and intermediate values for VLI_CM, partly because no additional costs are linked to grading of grains. Moreover, for a given CS, the presence of CC had globally no significant impact on semi net margin.

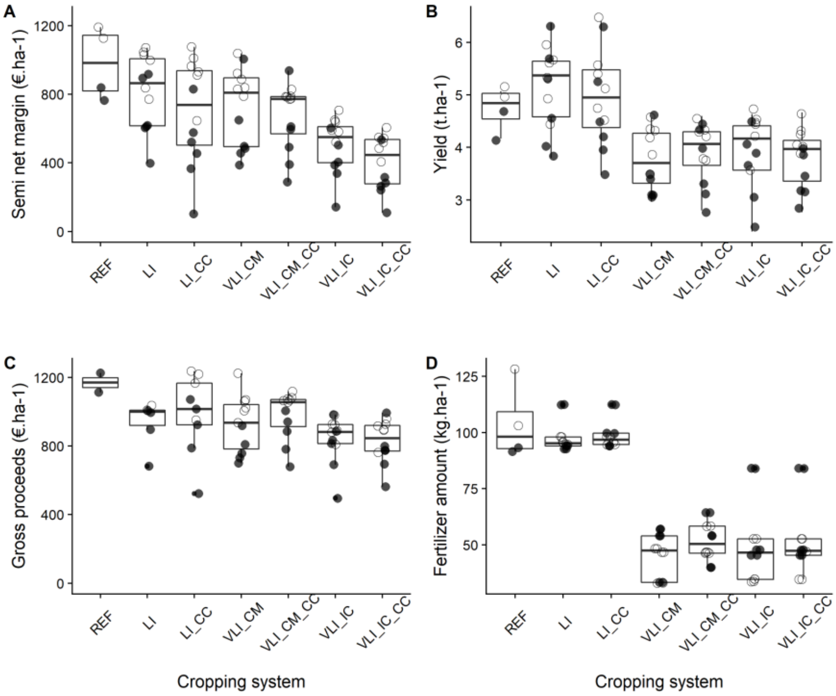

Figure 1. Semi net margin (A), yield (B), gross proceeds (C) and fertilizer amount (D) of seven cropping systems differing by their level of diversification: REF (standard local system), LI (low input system), LI_CC (LI with cover crops CC), VLI_CM (very low input system with cultivar mixtures), VLI_CM_CC (VLI_CM with CC), VLI_IC (VLI with intercrops) and VLI_IC_CC (VLI_IC with CC). White dots: rotation 2011-2013, Black dots: rotation 2014-2016.

4 Discussion and Conclusions

When focusing on agro-economic indicators, diversification and the related reduced inputs use were not profitable. Despite the input cost reduction in VLI systems, lower yields (Figure 1B) and gross proceeds (Fig.1C) penalized these diversified CS. In order to study such innovative CS and highlight their potential benefits, new indicators should be taken into account, considering an economic value of the ecosystem services provided by diversification. For example, the strong decrease of N-fertilizer amount in VLI systems (Fig.1D) suggests that they could have a reduced environmental impact compared to LI systems or the REF considering both greenhouse gases emissions and water pollution, as ever demonstrated (Plaza-Bonilla et al. 2018). For this reason, agroecological CS able to deliver on reduce N-fertilizer inputs would require reward. Additionally, soil fertility and biodiversity could also be valuable indicators to highlight the ecosystem services brought by these diversified CS and in particular, the benefits of multi-services CC. In addition, these results suggest that the choice of the crop species and cultivars is crucial. When the CS is less productive, partly because of the decrease in chemical inputs use, choosing species that are characterized by a high price could be relevant, *e.g.* lentil dedicated to human consumption vs fababean. Finally, intercrops grain products were sold as a mixture while the improvement of agricultural machinery, able to separate grains, could increase their selling price.

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Can the APSIM crop growth model simulate the growth of pure cultures and intercrops of wheat and faba bean in temperate zones in Europe?

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1 Introduction

Arable farming in Europe relies heavily on external inputs like synthetic fertilizers to achieve high productivity. These inputs lead to a variety of environmental problems such as water pollution and greenhouse gas emissions. Intercropping of cereals and legumes has been suggested as a promising approach to reducing the use of synthetic fertilizers while maintaining high yields, as legumes can fulfil most of their nitrogen demand by fixing atmospheric nitrogen. Moreover, cereal-legume intercropping systems can even increase and stabilize the total yield relative to the yield that would have been obtained if cereals and legumes were grown in pure cultures in the same region. However, designing the most suitable intercropping system for a certain location is challenging, as crop yields are determined by the interplay of many factors (e.g., weather conditions, soil texture and fertility, cultivar traits, and field management). Crop growth models are capable of accounting for these factors and their interactions, and hence can help to identify the most suitable cropping systems for specific environmental conditions and management goals. One example of such a crop growth model is the Agricultural Production SIMulator APSIM. It has been developed in Australia and has been used extensively to investigate cropping systems in tropical and subtropical zones, but has been comparatively little used in temperate zones. One particularly interesting feature of APSIM is the option to simulate intercropping systems, by accounting for the competition and complementarity for resources. How competition and complementarity play out depends on pedoclimatic factors, cultivar traits, and management, particularly sowing dates, spatial configuration of the intercrop and the application of fertilizers. Here we explore the use of APSIM as a tool to identify suitable cultivars for productive intercropping systems in Europe. The study aims at:

i) calibrating and validating APSIM for wheat and legumes grown under temperate conditions;
ii) assessing the ability of the newly calibrated APSIM to simulate the yields in intercropping systems across Europe.

2 Material and methods

We successfully calibrated and validated APSIM for spring wheat and faba bean using published Dutch data on monocultures of these crops. Next, we used the newly calibrated APSIM Wheat and APSIM Fababean crop modules to simulate intercropping experiments on well fertilized and lowly fertilized plots that were conducted throughout Europe as a part of the EU Horizon 2020 project DIVERSify.

3 Results

We found that the newly calibrated APSIM was capable of simulating wheat and faba bean grain yields in pure culture on well-fertilized fields reasonably well (Figure 1A). However, APSIM underestimated the crop yield of the lowly fertilized treatments for pure cultures of both crop species (results not shown). When considering wheat-faba bean intercrops, APSIM was capable of explaining quite a high percentage of the yield variation of crop yields of wheat (42%) and faba bean (40%) in the intercrops grown on well-fertilized fields. However, it systematically underestimated the grain yield of wheat and systematically overestimated the grain yield of faba bean (Figure 1B), possibly due to the simulated shading of wheat plants by taller faba bean plants in the model.

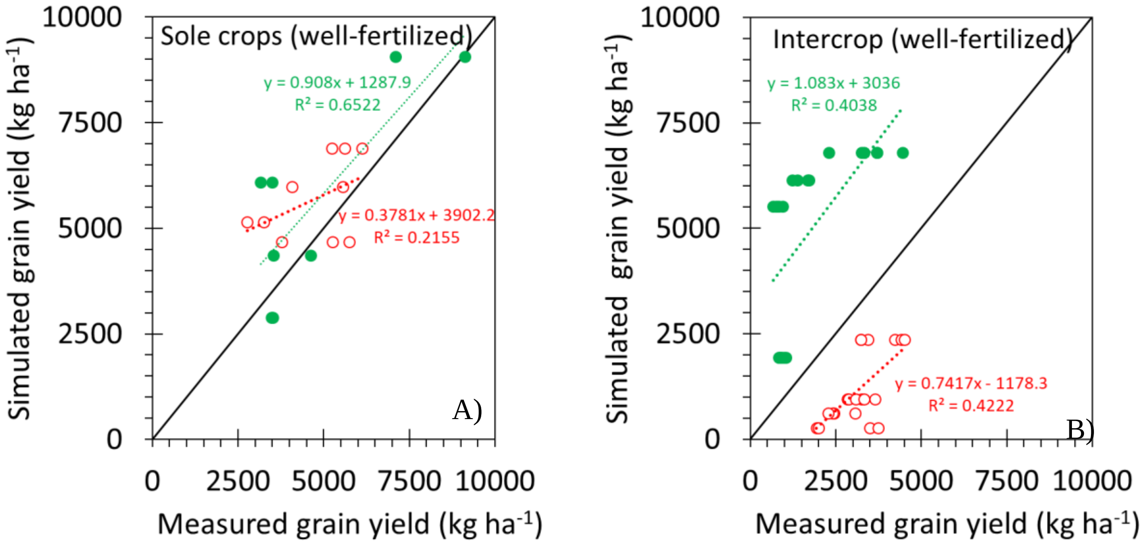

Figure 1: Measured versus simulated grain yield in pure cultures of wheat and faba bean (panel A) and in a wheat-faba bean intercrop (panel B) on the well-fertilized plots. The straight line is the one-to-one line. Wheat yields are represented by red, open circles and faba bean yields by filled, green circles.

4 Discussion and conclusions

APSIM explained the variation in yield well for well-fertilized wheat-fababean intercrops. However, it overestimated the performance of faba bean and underestimated the performance of wheat. Possible explanations for this are that: (1) APSIM overestimates the plant height of faba bean relative to that of wheat, or that (2) the radiation use efficiency of faba bean was overestimated, or (3) the light interception by faba bean in the upper part of the canopy was overestimated, or (4) a combination of these. Based on these results and additional literature research, we conclude that in order to improve APSIM's capability of simulating wheat-faba bean intercrops in Europe, it would be necessary to:

i) validate and, where necessary, re-estimate APSIM parameters that describe crop-nitrogen relations for both wheat and faba bean;
ii) validate the relation between stem weight and crop height that APSIM employs.
iii) validate the light interception module Canopy of Apsim for wheat-faba bean canopies.
iv) introduce a more mechanistic description of radiation use efficiency for faba bean in APSIM.

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Soybean as a diversification crop for western France: using intercropping to mitigate risks linked to the introduction of a new crop.

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1 Introduction

There is a growing interest in soybean in Europe. In western France, using soybean as a diversification crop would address several problems at once. First, it would act as a break crop in crop rotations mainly composed of cereals and could build up soil fertility through N_2 fixation. Secondly, it would lower the dependency on soybean imports for this region highly specialized in animal husbandry, providing locally produced plant proteins with easy traceability. However, soybean yields are highly variable in this region [1] and soybean is known to be a poor competitor against weeds. Therefore, as for other grain legumes, crop failure risk and poor weed competitiveness constitute two common barriers to its adoption by farmers and thus cropping systems diversification. To overcome these barriers, we propose to use intercropping as a facilitator for new crop introduction in cropping systems. Indeed it has been shown that intercropping improved stability of crop production and that intercrops (IC) were more resilient to stresses and could provide insurance to harvest at least one crop. Also, intercropping can facilitate weed control and improve global production per unit of area [2].

The introduction of a new crop such as soybean in a cropping system is difficult, thus keeping IC management relatively simple is important. Therefore, sowing and harvesting both crops at the same time was a primary criterion in the choice of crops to be paired with soybean.

Comparison of contrasting species to be intercropped with soybean should help understand the functioning and response of soybean in IC and later facilitate the choice of intercropped species in relation to their traits and expected services (weed control, productivity, pre-crop effect). Moreover, few references are available on the effect of spatial arrangement of IC but it could influence the growth of each component and the outcome of the IC.

Thus, this study aims at quantifying grain production of soybean in sole crops and its pre-crop effect and comparing the effect of different species intercropped with soybean in combination with the effect of spatial arrangement on the performances (grain production, nitrogen fixation, competitiveness toward weeds, pre-crop effect) of the various IC.

2 Materials and Methods

A two factors analytical experiment was carried out near Angers, France. The species intercropped with soybean were lentil, sorghum, buckwheat and sunflower and were chosen for their contrasting traits and their ability to be sown and harvested at the same time than soybean. IC were sown in a substitutive design (50:50). Spatial arrangements of IC were Within row IC with both crops mixed in the same row and Alternate row IC with each specie sown separately one row out of two.

Grain and residues dry matter (DM) samplings where done at soybean maturity. Then, wheat was sown on every plot yield was quantified.

3 Results

In the 1st year of experiment sole crop soybean produced 3.17(±0.3) t/ha of grain DM with a protein content of 50% of grain DM. Total grain Land Equivalent Ratio (LER) varied from 0.76(±0.2) for soybean-lentil to 1.13(±0.2) for soybean-buckwheat. Soybean partial LER was significantly influenced by spatial arrangement with higher average partial LER for alternate row IC (0.49±0.2) than for within row IC (0.37±0.2). Partial LER of soybean also varied according to the species intercropped. Partial LER of soybean IC with lentil

(0.63±0.2) was not significantly different from that of soybean IC with sorghum (0.52±0.1) but was higher than that of soybean IC with sunflower (0.37±0.1) and all three were significantly higher than partial LER of soybean IC with buckwheat (0.20±0.1). Second plant's partial LER was not affected by spatial arrangement but was affected by specie with buckwheat partial LER significantly greater than sorghum and lentil partial LERs.

Weed DM in soybean sole crop at harvest was 253 (±20) g/m². Comparing IC ability to control weed development, it appeared that soybean-buckwheat (35±34 g/m² weed DM) and soybean-sorghum (132±87 g/m² weed DM) IC were better at weed control than soybean-sunflower (177±99 g/m² weed DM) and soybean-lentil (367±205 g/m² weed DM).

4 Discussion and Conclusions

Climatic conditions were favorable for the crops studied in this experiment leading satisfactory yields, even for soybean. The composition of the grain mixture harvested was highly dependent on the species intercropped and the spatial arrangement. Soybean-lentil IC favored soybean yield but was not efficient for weed control. Other species such as buckwheat were too competitive and reduced soybean productivity. Using alternate rows helped to reduce the competition. These first results show the key role of the choice of intercropped species but also the major effect of spatial arrangement on productivity and competitiveness against weeds. Pre-crop effect, related to soil mineral nitrogen concentration and wheat yield will be studied.

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Optimizing organic lentil crops in Sweden

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1 Introduction

Lentil is considered healthy, tasty and easy to cook by many consumers. Sweden, like the majority of European countries, imports almost all current consumption of lentils, even though the crop can be grown in the local soil and climate conditions of Southern Sweden. The transition towards diets relying more on local plant products and less on imports and animal products is a way to reduce greenhouse gases emissions and to increase resource use efficiency of food systems (Röös *et al.*, 2018). Thanks to the relatively high price of organic lentils for food, introducing lentil could be an economically profitable way to increase the proportion of legumes in crop rotations, thereby contributing to crop diversification. Lentils are prone to lodging and have a low competitive ability against weeds. Intercropping is thus a way to avoid weed infestation (Wang *et al.*, 2012) and loss of grains at harvest (Viguier *et al.*, 2018). Our research aims at increasing the basis of knowledge in order to improve the yield and yield stability of organic lentil in Swedish conditions, to give the opportunity for more farmers to benefit from the increasing demand in local and organic pulses.

2 Materials and Methods

We conducted factorial block experiments on two sites in the Scania region in southern Sweden in three seasons (2017, 2018 and 2019). The impacts of lentil variety, intercropping with oats and/or lupin, oat sowing density and mechanical weeding practices were assessed in terms of crop and weed biomasses, grain yield and lodging. An additive design was used for lentil-oat intercrops, sowing lentils at their full sole-crop density and adding oat at 10 or 20 % of its sole-crop density. We will quantify lentil dinitrogen fixation and preceding effect in sole crop and in intercrops as these important crop features are unknown in the Swedish growing conditions. Our results will help to identify cropping practices that optimize competitive ability against weeds, preceding effect and economic return. We will also assess the nutritional quality of lentils (nitrogen concentration, folate, nutritional fibers and minerals) and a potential effect of intercropping on these parameters.

3 Results

The results of the first years of experiments confirmed that additive intercrops consisting of the full density of lentil and 20% of the full density of oats allowed a weed biomass reduction of 60-85% in conditions of high weed pressure. Mechanical weeding showed inconsistent effects on weed reduction. Intercropping with lupin or with 10% oats did not improve weed control even in the situations with high weed pressure. Sole-cropped lentil yielded between 0.2 and 0.9 T/ha, with strong differences between years. Intercropping with oats had a positive effect on lentil yield in 2017 on two sites, even though total lentil biomass was lower in the intercrop. Very interestingly, the Swedish lentil landrace Gotlandslins, brought back to cultivation in the recent years after almost disappearing, produced as high or higher grain yields than the French reference cultivar Anicia ('Puy-type' green lentil), in sole crop and in intercrops. In the intercrops, oats sown at 20% of its sole-crop full density produced on average 2.2 T/ha, corresponding to 54% of its sole crop yield.

4 Discussion and Conclusions

Lentil can be successfully grown in organic Swedish conditions and could have an increasing role to play in cropping systems diversification. Additive intercropping with 20% oats appeared more reliable than mechanical weeding to control weeds in organic lentils. The higher grain yield observed in intercrop in some conditions can presumably be explained by a higher harvest efficiency, as the companion crops reduced lentil lodging (Viguier *et al.*, 2018). When reintroducing a crop, the potential of local landraces should not be underestimated. The approach of using intercropping to facilitate adoption of legume crops that are difficult to cultivate in sole crop can inspire actors to adopt crop diversification, in Sweden as well as in other European regions.

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Analysis and design of strip cropping systems

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1 Introduction

The global collapse of insects, the mismatch between human dietary needs and food production, and global environmental change all contribute to the growing recognition that there is urgent need to diversify agricultural systems. It is also clear that a variety of approaches and methods to promote diversification are needed, however, many of these approaches are underdeveloped. Ecological intensification is one such approach, which supports the premise that agricultural systems can be designed to meet both food production and ecosystem service demands. Within the ecological intensification paradigm, diversity is seen as an asset to agriculture, and as a means to create healthy and resilient farming systems.

Strip cropping—the practice of growing two or more species in alternate, multi-row strips wide enough to allow independent cultivation but narrow enough to support interaction between crops—is a management practice that utilizes spatial principles to leverage the benefits of diversity. A meta-analysis on intercropping showed that strips result on average in a land equivalent ratio of 1.25 (Yu et al., 2015). Another advantage is that strip cropping can be implemented by farmers today, as the concept is based on current on farm available machinery. While strip cropping is a technologically accessible practice, its unique spatial structure introduces a new dimension to agricultural systems management and research. Informing farmer and policy makers of best practices for strip cropping will require new knowledge, generated through systems experiments and on-farm trials.

The objective of our study is twofold:

1) Evaluating and designing systems experiments that include spatial structure in its design criteria
2) Designing novel cropping systems based on obtained insights from objective 1

2 Materials and Methods

Wageningen University & Research has been experimenting with strip cropping since 2010. In fall 2017, the decision was made to start a new systems experiment. Design criteria were a representative organic crop rotation at a practice and ecological relevant scale. Based on the long term experience a minimum of 50 m strip length and 50 X 50 m large scale reference was set to sufficiently represent field conditions for machinery and ecological processes. Moreover, to mimic field conditions best, the same crops should be close to each other.

Spring 2018, 278 soil samples were taken over 2 locations and soil organic matter (SOM) (%) was determined by loss-on-ignition. Using ordinary kriging a spatial explicit map of SOM of two locations and fields was obtained. The within-field variability was modelled by using the SOM content, being an accepted indicator for soil quality. Combined with long term data on potato yield variability of both locations, a random effects model was fitted to obtain variance components. These variance components have been used to simulate different experimental designs and have been evaluated on their efficiency and power.

By using treatments shared between separate experiment locations, we were able to compare strip cropping effects across the Netherlands. Our current strip cropping network of 25 farmers and researchers covered a diverse set of farming practices (conventional/organic, large/small scale, cereal/vegetable based, etc.). From this network, we have accumulated several years of data; the next step in bringing this knowledge to farmers and society is to create design rules for establishing new strip cropping systems.

3 Results

Based on simulations of 20 increasing effect sizes, each for a 1000 times, the power was determined for randomized complete block design (RCBD) and incomplete block designs (IBD). We found that IBD is as efficient as RCBD in homogeneous environments, but with increasing variability IOB increases in power and facilitates connections to other experiments.

Two models were explored for suitability in the strip cropping design process. To explore the influence of crop choice on various farm objectives the static bio-economic farm model FarmDESIGN (FD) was used (Groot et al., 2012). This model was used to explore crop area configurations for optimizing selected farm parameters. Furthermore, the crop rotation model ROTAT was used as a starting point for generating crop rotations with the crops selected with FD (Dogliotti et al., 2003). A new app *StripRotation* was developed in which different layouts can be evaluated, following the theory of multifunctional crop rotations. The associated scoring system from ROTAT was expanded with scores on combinability of crops based on a database collected for the SureVeg project (Figure 1).

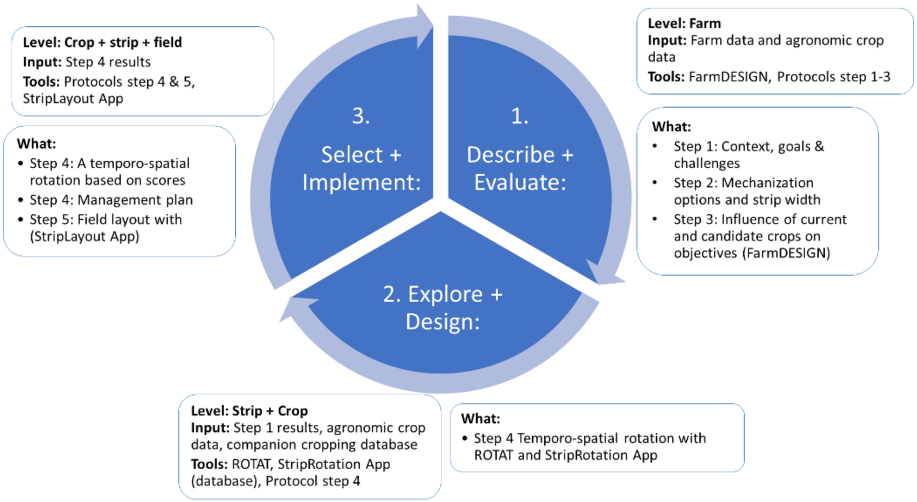

Figure 1. A schematic of the design cycle. The aggregation level, inputs for each step and the tools that are used are listed as well as what aspects are dealt with and the connections to the formalisation of design method via protocols.

4 Discussion and Conclusions

Integrating the analysis and design of strip cropping with this methodology allows farmers to start incorporating diversity now. However, a finer grain of diversity is needed to make use of its full potential. As a next step in the research, we are linking strip performance to within-field heterogeneity by using remote sensing. Our aim is to design 'pixel cropping' systems: highly diverse, fine-resolution cropping systems where the right plant is sown at the right place in the field at the right time. With current developments in autonomous mobility, deep learning, energy sources, ruggedization of electronics, and modularity, strip cropping is a first key step for the transition to a highly diverse farming future.

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Using Multifunctional Subsidiary Crops to Reduce Tillage in Organic Farming

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1 Introduction

There is an increasing awareness that agricultural lands need to cover multiple ecosystem services to provide long-term sustainability in food production (Foley *et al.*, 2005). Producing not only human goods, but also environmental regulating and supporting services (MA, 2005), to contribute to the mitigation of climate change and keep soils fertile. Reducing tillage and using subsidiary crops (SCs) has shown the potential to provide such services to agricultural systems, although the results vary depending on e.g. climate, soils and crop rotations (Palm *et al.*, 2014). Hence, management methods to foster and utilize ecosystem services has to be adapted to local climatic and environmental, as well as cropping systems (Garnett *et al.*, 2013). In Sweden, the use of SCs are limited by the length of the growing season, with short and cold days in autumn. In this project we replace the common soil management techniques ploughing and stubble cultivation with an innovative cropping system design where cereal are intercropped with three different mixtures of forage legumes from early summer. The objective is to optimize the cropping sequence spring cereal – winter cereal with regards to yield, nitrogen use and weed control.

2 Materials and Methods

Field experiments were carried out in Östergötland (OG) and Skåne (SK), mid - southern Sweden, 2017-2018 and 2018-2019. The experiments were two factorial, (1) system of under-sowing, including sowing time, placement of SC and equipment used (Figure 1), and (2) legume species mixture. In OG the novel intercropped- direct seeded (I-DS) systems were compared in main plots with systems using inversion or non-inversion tillage. These systems are common practices for organic farmers in the regions. Legumes where placed either in the cereal row, centred between two cereal rows or adjacent to the cereal row, allowing for one or two row-hoeing events during the first growing season. In the second growing season, row-hoeing was done twice in all treatments. When sown in the cereal row, the legumes were sown at the same time as the spring cereal crop, while for the two other placements the legumes were sown roughly one month after sowing of spring cereals. The species mixtures were *Trifolium squarrosum* and *T. resupinatum* (annuals), *T. incarnatum* and *Vicia villosa* (annuals), and *T. pratense*, *T. repens* and *Medicago lupulina* (perennials). The winter cereal is sown between the rows of legumes with the goosefoot.

3 Results

The weather conditions greatly affected SC performance. SC biomass in OG was 50 and 25% of that in SK for annuals and perennials, respectively. SK receiving 58 mm of rain in July, compared to 17 mm in OG. In 2018, the growth and development of all plant species, especially the legumes, were greatly affected by the dry and hot weather. The exception was *V. villosa* that even produced more biomass this year. The late-sown legumes did not even emerge until July–August, due to the lack of water.

In SK oat yields were reduced by about 10% by early sown SCs (P=0.01), whilst in OG yield reduction was only seen with *V. villosa* as SC (15%) (P=0.04). Wheat yields were greatly affected by the dry summer 2018. However, in SK wheat performed better when grown after an intercrop compared to the control, yielding on average 400-700 kg/ha more, this was not significant. In ÖG, wheat yields in the I-DS systems were 30-76% lower than the reference plots ($P < 0.0001$).

The effect of SCs on weeds varied between sites and part of the cropping sequence. High biomass was not always correlated with low weed biomass, and this could probably be due to technical factors also influencing the results.

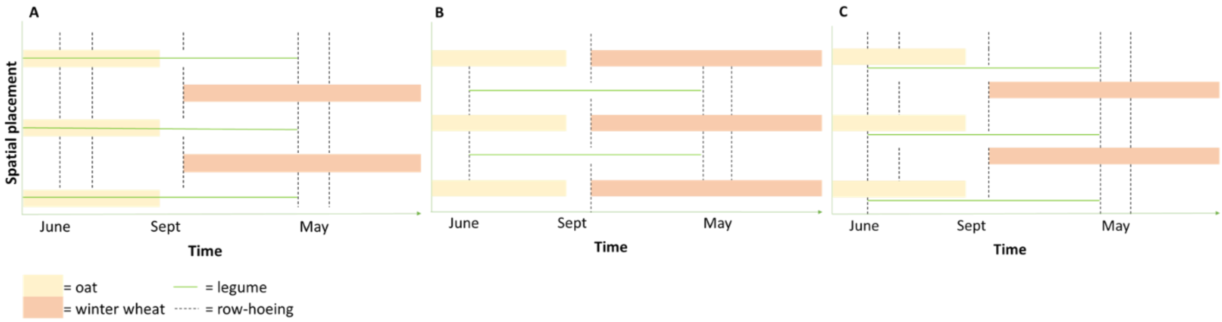

Figure 1. Schematic drawing of the system. A=early sowing of subsidiary crops (SCs) in oat row, B=late sowing of SCs between oat rows, C=late sowing of SCs adjacent to oat row. The figure also show the placement of winter wheat and the frequency of row hoeing.

4 Discussion and Conclusions

The novel I-DS system showed large variation in SC biomass production, oat and wheat grain yields and weed biomass. The effect of SCs on yield and weed suppression varied and was not always related to SC biomass. Furthermore, the system showed to be much influenced by the weather and environmental conditions. Biomass production of the SCs showed large variation due to the amount of rain fall. Wet weather in the autumn 2017 prohibited sowing of winter wheat in ÖG due to that the plots with direct seeding did not dry up sufficiently. Instead spring wheat was sown. The delayed sowing allowed weeds and surviving SC plants to grown to a large size, and were hard to remove in spring. In SK, the soil was lighter and dried up faster, so here winter wheat was successfully sown, and weeds did not become a major problem here. Timing and establishment of a competitive wheat crop is key to make this system work. Some plots with the I-DS system performed as well as the reference systems and hence we see a development potential in this system. More studies and practical experiences are needed to get a better understanding of when intercropping with forage legumes is beneficial. How different functional groups, sowing techniques, weather conditions and fertilization regimes affect cover crop growth and hence the competition with the main crop.

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Evaluation of the Land Equivalent Ratio index in barley-pea and bread wheat-faba bean intercropping

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1 Introduction

To improve agricultural sustainability, a valuable strategy could be the increase of biodiversity of cultivated fields through intercropping (Bedoussac *et al*., 2015; Brooker *et al*., 2015; Yu *et al*., 2016). Cereal-legume intercropping exploits the complementarity between these two groups of crops. In 2017, a field trial showed that the Mix1(50-50) was not effective because barley was too much competitive against pea, and faba bean plant density could have been increased. In the present research, new barley-pea and bread wheat-faba bean combinations were evaluated to increase the Land Equivalent Ratio (LER) and to reduce weed competition in mixed vs sole legume crops.

2 Materials and Methods

2.1 Trial 1- WP2 Barley-Pea trial: conventional farming – no herbicide treatments.

At the UNIVPM Experimental Station a split-plot design (4 replicates, sub-plot size 9x1.2m^2) was performed including one barley (Tea) and two pea (Hardy, Astronaute) varieties as sole crops and mixed crops: Mix1(50-50), Mix2(33-67), Mix3(25-75), Mix4(20-80). Nitrogen fertilization (whole-plots) was applied as shown in Table 1, amount of N in mixed crops being proportional to the barley seed density. The trial was sown on February 1st, 2018, and harvested on July 3rd, 2018.

Table 1. Trial 1: Nitrogen fertilization plan (N kg/ha).

	Pea sole	Barley sole	Mix1 (50:50)	Mix2 (33-67)	Mix3 (25-75)	Mix4 (20-80)
High N	20.0	80.0	40.0	26.4	20.0	16.8
Low N	0.0	40.0	20.0	13.2	10.0	8.4

2.2 Trials 2 and 3 –WP4 Barley-Pea trials: organic farming – no nitrogen fertilization.

Two trials were performed with participatory farmers at 2 locations: Monte San Martino – MC (Trial 2) and Sterpeti - PU (Trial 3). At each site, a randomized complete block (4 replicates) was applied (Plot size: 50x4.5m^2 for Trial 1 and 50x4.2m^2 for Trial 2. One barley (Tea) and one pea (Hardy) varieties were included as sole crops and as Mix2(33-67) and Mix3(25-75). Trials were sown on February 1st, 2018 (Trial2) and March 28th, 2018 (Trial3), and harvested on July 3rd, 2018 (Trial2) and July 9th, 2018 (Trial3).

2.3 Trial 4 – WP4 bread wheat-faba bean trial: organic farming.

The trial was performed at Rocca Priora – AN as a randomized complete block design (3 replicates, plot size 10x1.2m^2). Three bread wheat (ACA320, Bologna, Marcopolo) and two faba bean (Chiaro di Torre Lama, Prothabat69) varieties were evaluated as sole crops and as Mix1(50-50), Mix2(50-65), Mix3(50-80), Mix4(33-75) and Mix5(33-80). The trial was sown on January 31st, 2018 and harvested on July 19th, 2018.

3 Results

3.1 Trial 1: Barley-Pea

In mixed crops, LERbarley was always much higher and LERpea was always much lower than expected (Table 2). Even though LERtotal was always higher than 1, Mix1 showed the highest values because of the high yielding ability of barley in mixed crop combinations. As frequently observed in mixed cropping trials, the LERtotal values were higher at low than at high nitrogen fertilization levels.

Table 2. Trial 1: LERbarley (LERb), LERpea (LERp) and LERtotal (LERt) values.

Barley-Pea Mix	Expected LER			HIGH Nitrogen			LOW Nitrogen		
	LERb	LERp	LERt	LERb	LERp	LERt	LERb	LERp	LERt
Tea-Astronaute Mix1	0.50	0.50	1.00	0.87	0.26	1.13	0.87	0.30	1.17
Tea-Astronaute Mix2	0.33	0.67	1.00	0.71	0.36	1.08	0.74	0.37	1.11
Tea-Astronaute Mix3	0.25	0.75	1.00	0.57	0.44	1.01	0.62	0.49	1.11
Tea-Astronaute Mix4	0.20	0.80	1.00	0.54	0.49	1.03	0.59	0.48	1.07
Tea-Hardy Mix1	0.50	0.50	1.00	0.80	0.26	1.06	0.83	0.32	1.16
Tea-Hardy Mix2	0.33	0.67	1.00	0.64	0.41	1.05	0.71	0.41	1.12
Tea-Hardy Mix3	0.25	0.75	1.00	0.56	0.52	1.08	0.61	0.45	1.07
Tea-Hardy Mix4	0.20	0.80	1.00	0.50	0.52	1.01	0.55	0.51	1.06

3.2 Trials 2 and 3: Barley-Pea.

Both trials showed LERtotal>1 values, ranging between 1.22 and 1.31 (Table 3). Moreover, Trial 2 confirmed the allelopatic effect of barley against weeds, mainly wild mustard in Trial 2, as already described in Central Italy (Ciaccia *et al*., 2015: Trinchera *et al*., 2015).

Table 3. Trials 2 and 3: LERbarley (LERb), LERpea (LERp) and LERtotal (LERt) values.

Barley-Pea Mix	Expected LER			Field Trial 2			Field Trial 3		
	LERb	LERp	LERt	LERb	LERp	LERt	LERb	LERp	LERt
Tea-Hardy Mix2	0,33	0,67	1,00	0,72	0,59	1,31	0,55	0,67	1,22
Tea-Hardy Mix3	0,25	0,75	1,00	0,60	0,69	1,29	0,43	0,81	1,24

3.3 Trial 4: Bread Wheat-Faba Bean. LERwheat values were higher than expected, whereas faba bean LER values were slightly higher than expected for MIX1, MIX2 and MIX4, and lower than expected for MIX3 and MIX5 (data not shown). However, LERtotal was always high, ranging between 1.22 and 1.39 (Table 4).

Table 4. Trial 4: LERtotal values of each mixed crop combination.

Mixed crops	faba bean	Chiaro di Torre Lama			Prothabat69		
	wheat	ACA320	Bologna	Marcopolo	ACA320	Bologna	Marcopolo
Mix1(50:50)		1,32	1,36	1,28	1,22	1,37	1,26
Mix2(50:65)		1,39	1,43	1,37	1,36	1,40	1,33
Mix3(50:80)		1,35	1,43	1,43	1,39	1,39	1,30
Mix4(33:65)		1,27	1,32	1,28	1,38	1,32	1,29
Mix5(33:80)		1,39	1,43	1,28	1,34	1,28	1,33

4 Discussion and Conclusions

Overall results showed that, in Central Italy, intercropping could be a valid alternative to sole crops, especially for bread wheat – faba bean in organic farming. The barley-pea mixed crop must be further investigated to optimize the harvested barley-pea mixed grain for animal feeding.

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Management of white clover living mulch to allow the development of winter cereals

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1 Introduction

Living mulches are cover crops planted either before or with a main crop and maintained as a living ground cover throughout the growing season. As for other cover crops, their integration into a cropping system may serve to provide and conserve nitrogen for companion or following crops, reduce soil erosion, reduce weed pressure, and increase soil organic matter content (Hartwig and Ammon 2002), leading therefore to a reduction of inputs need. In previous studies (i.e. Jones and Clements 1993, Deguchi et al. 2015), white clover has been tested as potential living mulch. Nevertheless, even if white clover can contribute to fix nitrogen within the cropping system, it can also be a strong competitor for available resources. Indeed, when annuals are established in white clover, the clover has a competitive advantage from being established earlier. Therefore, recorded yield of the main crop is usually lower in association to the living mulch even when harvested as whole crop for silage.

In order to reduce competitive advantage form white clover, different levers could be mobilized. Bergkvist (2003) explored the impact of white clover traits on its competitive potential, looking for varieties with small shoot biomass at flowering of the annual crop and with a lower vigor at spring.

In the current approach, we explored the potential offered by different reduced tillage techniques to limit white clover vigor when sowing the winter cereal with a special attention for the ability of the living mulch to recover later in order to limit weed development. This approach was performed on two soil types during two cropping seasons with a spelt (*Triticum spelta* L.) followed by a triticale (×*Triticosecale* Wittm.) crops.

2 Materials and Methods

The experiment was carried out at two Belgian sites, Libramont (loamy-rocky soil; 490 m above sea level; 1200 mm average annual rainfall and 7.2°C as average annual temperature) and Mussy-la-Ville (loamy-clay soil, 270 a.s.l., 900 mm average annual rainfall and 8,5°C as average annual temperature). The crop succession was a Spelt–Tritical–Spring barley one. White clover, CV Barbian, was under-sown in the spring cereal.

The techniques compared, to limit white clover competition during the implementation of the winter cereals, were (1) a classical ploughing as reference, (2) the use of a rotating harrow (horizontal axis), (3) the use of a cultivator, (4) the use of a disc harrow and (5) a direct sowing without white clover destruction.

White clover cover was chopped before the implementation of these different techniques.

This trial only received 30000 kg ha^{-1} of cattle manure before spelt crop. This corresponds to 150 kg of N with 25 to 30% expected to be available during the first year.

The experimental disposal was, within each trial, in complete random blocks design with three blocks. Recorded parameters were the cover recovery after cereal implantation, cereal tillers density, biomass growth and characterisation during the vegetative phase, cereal grain yield in quantity and quality, residual inorganic-N in the soil.

3 Results and Discussion

During the first year, in comparison to the classical ploughing scheme, there was a decrease of the number of spelt tillers, by 20 and 50% respectively in Libramont and Mussy-la-Ville, only under the direct sowing scheme. Under this scheme, weed and white clover biomasses were also the highest (20 and 50% of the total biomass, respectively in Libramont and Mussy-la-Ville) while they were halved following the different harrowing schemes.

This competition of the white clover cover against the cereal limited its yields. In comparison to the classical ploughing scheme (4400 kg ha^{-1}), at Libramont, spelt yield decreased, in average, by 19, 25 and 27% after the use of a rotating harrow, the use of a cultivator or of a disc harrow and a direct sowing, respectively. At Mussy-la-Ville, always in comparison to the classical ploughing scheme (3200 kg ha^{-1}), these reductions were of 41, 49 and 74%, respectively.

The results obtained with the triticale intensified the observation of the first year. Yield decrease was, in average, of 88% under the direct sowing scheme, in comparison to the yield under ploughing while it decreased by 43 and 17%, in Libramont and Mussy-la-Ville, respectively, under the intermediate soil preparation schemes.

4 Conclusions and perspectives

The approaches based on soil preparation through harrowing, with yield decrease of 20 to 50%, allow to limit white clover competition but not in a way as efficient as cover ploughing that also allow to the cereal to take profit of the N carry-over effect provided by this leguminous. Now a special attention has to be paid to the selection of less aggressive white clover varieties (Bergkvist 2003), on the one hand, and to the opportunities offered by strip cropping, on the other hand.

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Pulses intercropped with cereals to secure the pulse production in organic and conventional farming in western France

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1 Introduction

Global soya prices are increasing and fluctuating. Imported soya is also linked to environmental impacts and is not traceable. At the same time, crop diversification is being more and more put forward to tackle many issues as disease or pest management. In that context, pea, lupin and faba bean are three interesting protein crops for the future, regarding both subjects. They could contribute to enhance protein autonomy of breeding farms in the western part of France and also to diversify crop rotation. However, those crops are facing a number of technical issues, among them weed management and yield instability. To solve those issues, the intercropping of the pulse with a cereal was tested. The goal was to improve weed management and to secure the yield.

2 Materials and Methods

The trial network was set up during three years (2016-2018) in two different regions in the west part of France (Britany and Pays de la Loire), both in conventional (84 trials) and organic farming (57 trials).

The two main factors studied were the choice of the cereal species (oat, wheat, barley, rye) and the choice of its sowing density The pulse was sowed at the same density as a sole pulse and the cereal between 30 and 165 grain/m² (e.i. 10 to 30% of sole sowing doses).The trials were arranged in a randomized block design with 4 replicate blocks. Results presented here are only on the choice of the cereal which is sowed at 30%.

3 Results

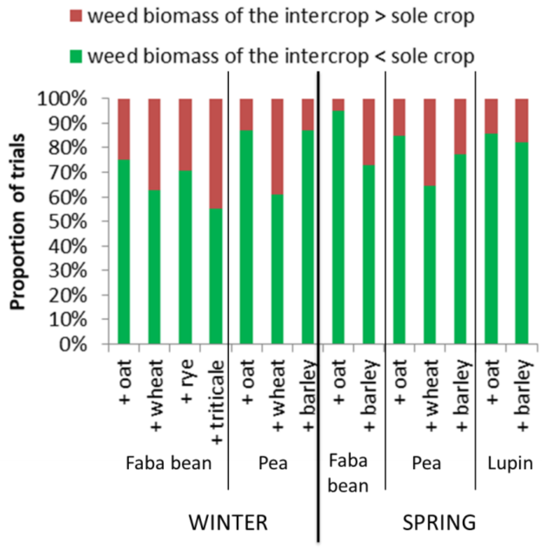

Figure 1. Impact of the intercrop on weed biomass at flowering stage in organic farming

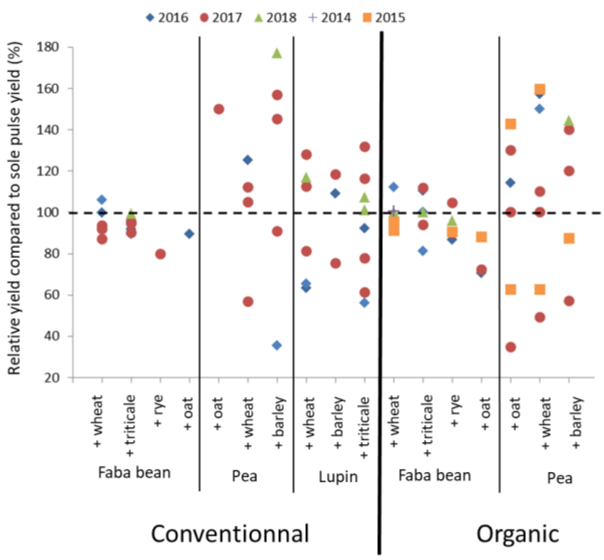

Figure 2. Relative pulse yield in

4 Discussion and Conclusions

4.1 An interesting effect on weed control for organic farming

Regarding weed management, results are promising, especially for organic farming. Intercropped plots have less weed biomass at flowering stage than the sole pulse, for at least 60% of plots. After winter, soil cover is higher on plots with the cereal intercropping, which develops at higher speed than the pulse and is more competitive. Those trends are of course to be nuanced, depending on the site context.

Results are quite variable, which prevent from confirming those trends by statistics. However, at least 55% of plots in winter pulses and 65% of plots in spring pulses showed a better weed control than the sole pulse.

Oat shows the best results in that regard, for all the pulses tested. With oat sowed at 99 grain/m² (30% of sole density), the weed biomass decreases from 27% to 83%, depending on years and trial sites. Barley is also interesting with spring pulses.

The positive effect of the associated cereal on weeds is more visible on spring pulses than winter pulses. Those last ones have a better soil cover and are less sensitive to competition.

Results are also interesting for conventional farming. However, here the question is different. Intercropping cereals and pulses also brings restrictions in availability of pesticide solutions (combination of homologation on both crops) and makes weed control more technical.

4.2 A variable impact on yield

The intercrop impact was also studied on pulse yield, protein production and total yield (pulse + cereal). Several trends could be observed. Winter faba bean, for example, is less impacted than spring faba bean. In the case of pea, the cereal can be a vertical support for the growth of the pea. Harvest is therefore easier and yield higher in risky situations.

The choice of the intercropped cereal is also important: oat is more competitive whereas wheat has difficulty to develop under a pulse crop. However, total yield is mostly higher than the sole pulse, thanks to the additional cereal production. The cereal could secure the harvest in case of an accident on the pulse.

Concerning protein production, protein content is not influenced by the intercrop. However, protein production of the intercrop is higher than the one of sole crop when considering protein from the cereal.

Finally, the economic impact of the intercrop compared to a sole pulse has been analysed. Two indicators were used: semi-net margin and technical management cost per protein unit. They mainly vary with the pulse yield. The additional cereal allows an economic compensation for the yield loss of the pulse and intercrop over-costs, but only in lower decrease cases.

To conclude, the construction of the association should be done based on the objectives, the context and should be the result of a compromise between weed management and grain yield.

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Organic vegetable cropping system diversification: effect of strip cropping on productivity and soil N availability in Mediterranean conditions

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1 Introduction

In recent years, there has been a trend towards industrialization and specialization of agro-food systems in several regions of Europe with the aim to intensify their efficiency. These simplified systems have amplified the negative impacts on both environment and society, by generally reducing the provision of ecosystem services and the societal benefits associated with the agro-ecosystems (Lemaire et al., 2014).

Crop rotation, intercropping and multiple cropping are the most common practices implemented to diversify agro-ecosystems. To date, there is still a lack of knowledge on the effects achieved by combining the three strategies. Accordingly, the DiverIMPACTS project has set up a network of ten Field Experiments (FEs) under different pedoclimatic conditions in Europe to assess the effects of combination of diversification strategies and test new temporal and spatial arrangement of species and management. This abstract presents some of the results obtained in the first year (2017-2018) of the FE hosted within the MOnsampolo VEgetables organic Long-Term Experiment (MOVE-LTE), run by CREA (Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria), in the Adriatic coastal area of the Marche Region (Italy), since 2001.

2 Materials and Methods

The MOVE-LTE (Campanelli & Canali, 2012) is based on a four-year rotation with six vegetable cash crops and three agro-ecological service crops, belonging to different plant families.

Since rotation and multiple cropping were already implemented in the MOVE-LTE, the strip cropping was introduced in combination with no-till. Two field experiments were carried out to test strip cropping (S) *vs* pure stand (P):

Experiment 1. From the existing rotation, vetch was replaced by faba bean (*Vicia faba* L.) to obtain a multiple cropping system based on faba bean-tomato (*Solanum lycopersicum* L.). Faba bean cultivated in strips 2.8 m wide was harvested (May) for fresh product. Simultaneously, the residues were flattened by a 'In-Line Roller Crimper' (ILRC; Canali et al., 2010) and tomato was no-till transplanted into the mulch (harvest in August). Faba bean for dry grain was left growing until harvest (July) in alternate 2 m wide strips. Strip cropped faba bean and tomato yields were compared with those of P.

Experiment 2. We used the same design as Experiment 1, though an evolutionary population of common wheat (*Triticum aestivum* L.) was introduced instead of faba bean and harvested in July. At flowering (April-May), the cereal was flattened by the ILRC in strips, and zucchini (*Cucurbita pepo* L.) was no-till transplanted on the mulch. Wheat and zucchini yields in S were compared with those of P.

A series of traits were assessed including: total biomass production of crops at harvest, weed biomass at harvest and soil mineral nitrogen (SMN) at mid-cycle of the vegetable crop. Moreover, Land Equivalent Ratio (LER) index, declined on total biomass production of crops, was computing.

3 Results

The results of total biomass production of crops and SMN were reported in Figure 1.

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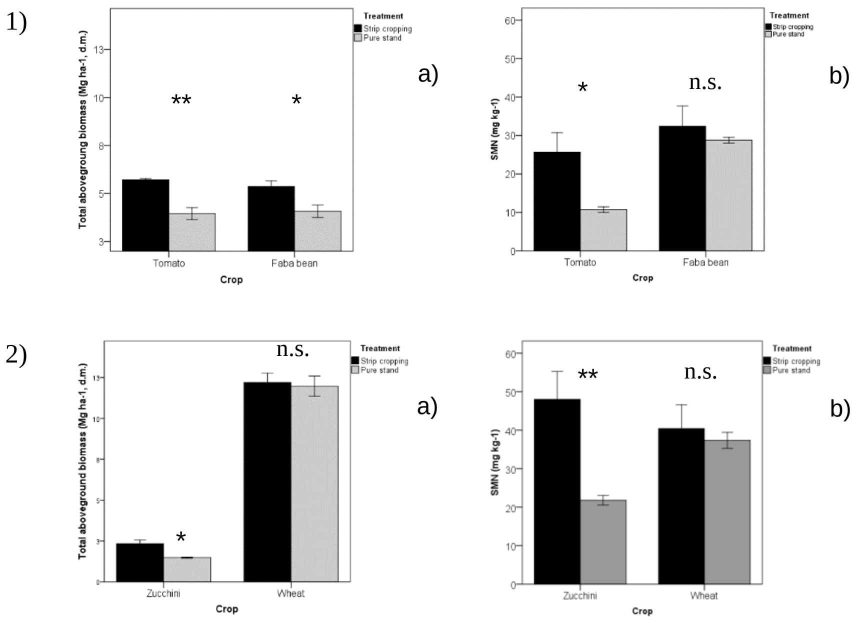

Figure 1. Results of ANOVA comparing stripcropping (black) and pure stand (grey) for total biomass of crops (a), soil mineral nitrogen (SMN) (b), at mid-cycle of vegetables, for faba bean-tomato (1) and wheat-zucchini (2) systems.

Note: n.s. =not significant; * $p \leq 0.05$ probability level; ** $p \leq 0.01$. Bars = standard error.

Experiment 1: tomato total biomass (fruits and residues, d.w.) was significantly higher in S with faba bean than P (+44.5%). Tomato strips also showed significantly higher weed dry biomass (+62.8%) than P (data for weeds not shown). A significant total biomass production (total crop and weed biomass) increase for S was also observed for faba bean (+31.9% and +29.7%, respectively). The LER index value was 1.37.

Experiment 2: zucchini total biomass and weed biomass were significantly greater in S with wheat than in P (+58.1% and + 47.5%, respectively), the same was observed for SMN (+120.1%). No significant differences were found for wheat or weed biomass compared to the S arrangement. LER index value was 1.25.

4 Discussion and Conclusions

Though one field-experiment year is not enough to draw robust conclusion, the performances of strip cropping in faba bean-tomato and wheat-zucchini systems seem highly promising.

Experiment 1: the general increase in production (total crop and weed biomass) of S compared to P was reflected by the SMN results. This implies, for tomato strips, a positive effect of N-building by neighbouring legume during the vegetative growth-stage, as found in other crops (Viguier et al., 2018). The same increased production of faba bean strips could be due to greater availability of resources in strip arrangement. The LER index value higher than one confirmed the advantage of the S arrangement compared to P.

Experiment 2: the zucchini system showed similar behaviour to that found for tomato in response to strip-cropping. It is also the case that higher productivity of S seemed to be associated to significantly greater SMN. LER index value above one confirmed the productive advantage of S arrangement respect to P.

Further investigations are needed to better understand the mechanisms that ameliorate productivity and nutrient (N) availability in strip cropping.

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Crop diversification with aromatic herbs below

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1 Introduction

The EU-funded project DIVERFARMING (Horizon 2020) aims to develop and deploy innovative farming and agribusiness models based on crop diversification.

In Germany, research focusses on organic steep slope viticulture. A fundamental issue of steep slope viticulture is related to vegetation management below the vines. In order to overcome problems of soil erosion and soil organic matter depletion, an increasing number of winemakers are establishing cover crops such as grasses and legumes in driving lanes. However, the area underneath the vines is typically still kept free of vegetation to avoid fungal diseases and competition for water. As cover crops do not benefit to the value chain and may compete with vines on water or have other adverse effects on vine performance, an alternative strategy for vegetation management underneath vines in steep slope viticulture is required.

Therefore, intercropping vines with perennial herbs growing underneath is a promising cropping practice to adress the abovementioned issues. Mediterranean herbs appear to be appropriate since they are economically valuable and originate from dry and warm environments, which are typical for most viticultural areas. Furthermore, their relatively low need for water and flat-growing habitus is assumed to be suitable to cover the soil underneath the vines in order to protect against erosion and suppress weeds without having adverse effects on vine growth and -health.

2 Materials and Methods

During the 5-year project, researchers from Trier University and ETH Zurich together with Winery Dr. Frey investigate impacts on and interactions between crops, soil ecological and physicochemical properties as well as erosion and greenhouse gas emissions to comprehensively evaluate ecological as well as economic benefits of crop diversification. In addition, abundance and diversity of insects will be monitored. Intercrops i.e. *Thymus vulgaris* and *Origanum vulgare* were planted in May 2018 in a commercial vineyard. Vine monocrop with regular tillage and bare soil underneath is considered as control.

3 Results

Due to severe drought after planting aromatic herbs in 2018, seedling establishment and growth was limited. Besides planting, irrigation of aromatic herbs was carried out twice, leading to increased management intensity for the diversified cropping system. Most of the soil erosion in 2018 was caused by a single extreme rain fall event. Soil tillage prior to planting of aromatic herbs, increased soil erosion as compared to vine monocrop. Soil quality parameters were not altered during one season of growing aromatic plants. Nitrous oxide fluxes are generally low, but the emissions increased after the extreme rain fall event without significant differences among the treatments.

4 Discussion and Conclusions

Restricted growth of aromatic herbs in the first year limited possible impacts on plant-soil interactions. We assume the effects of intercrops to become more pronounced as aromatic herb biomass increases over time. Furthermore, we expect a reduction of soil erosion due to intercropping after consolidation of herbs in 2019. Harvest quality and quantity of aromatic herbs will be measured in order to determine marketing opportunities and economical valuation.

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Using the complementarity with cereals to overcome weaknesses of sole-cropped winter white lupin

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1 Introduction

Increasing the adoption of grain legumes in crop rotations requires alternative cropping practices to secure their productivity and improve weed control while reducing herbicide use. Additive intercropping with a cereal as a companion crop can be a way to buffer yield variability of grain legumes (Raseduzzaman and Jensen, 2017) and to increase competitive ability against weeds (Corre-Hellou *et al.*, 2011). Lupins are known for their high yield variability and low competitive ability against weeds. Winter white lupin (*Lupinus albus* L.) produces protein-rich seeds that can be used in feed to reduce the dependency on soybean imports and in food for the increasing demand in plant-based protein. It is not known how intercropping with a cereal alters the weed suppression and productivity in a crop like winter white lupin which requires 11 months from sowing to harvest. To improve cropping practices for maximal weed suppression, maximal lupin yield and total yield stability, a deeper understanding of resource acquisition by the lupin, the intercropped cereal and the weeds is needed.

2 Materials and Methods

This contribution combines results from two experimental setups:

- A network of eleven agricultural study sites during a two-year period in western France. For each site-year, a winter white lupin sole crop was compared to a winter white lupin-triticale intercrop, focusing on weed biomass and crop yield.
- A field experiment replicated in 2016 and 2017 in Western France, where we measured crop and weed biomass as well as nitrogen and light acquisition dynamics over the season in combinations of two lupin varieties with two varieties of wheat (*Triticum aestivum* L.) and one triticale (×*Triticosecale*) and compared them with lupin and triticale sole crops.

In both setups, the intercrops were additive, with lupin grown at the same density as in sole crop and 30% of a full sole-crop density of cereal.

3 Results

In the field network, we found that intercropping winter white lupin with a cereal reduced weed biomass at lupin flowering by an average of 63%. Competition from triticale generally reduced lupin grain yield, but intercropping produced a higher total grain yield than did lupin sole cropping while maintaining protein yield. Differences between sites gave useful indications on optimal practices and agro-ecological conditions.

In the plot experiment, both lupin varieties showed a slow early growth and very low soil nitrogen acquisition, causing virtually no weed suppression in the lupin sole crops from sowing (early October) until flowering (April). Intercrops increased crop total biomass and soil nitrogen acquisition dramatically compared to the lupin sole crops. Competition from the cereals on lupin around lupin flowering lead to a reduction of the number of lupin fertile stems per unit of area. However, this effect was significant only for the combination of triticale with the shortest lupin variety tested and in the year during which cereals were more dominant in the intercrops. In the intercrops, cereal yield was much more affected than lupin yield by differences between years in terms of climate and competition from the weed flora. Triticale produced more early biomass, acquired more soil mineral nitrogen, was higher and had a higher LAI than wheat at lupin flowering, thus it competed more than wheat with lupin and with weeds.

4 Discussion and Conclusions

Intercropping winter white lupin with a cereal has the potential to circumvent two shortcomings of sole-cropped lupin (low competitive ability against weeds and high yield variability) especially for situations with high weed infestations. It is thus a relevant strategy in order to integrate lupin in organic cropping systems and to reduce dependence on herbicides in conventional systems.

We showed that the difference between sole crops and intercrops was larger for the acquisition of mineral soil nitrogen than for that of light. During the early growth stages, the contrast between lupin and cereals in N and light acquisition strategies allowed for low competition between the two crop species but concurrently the cereals competed with the weeds.

We propose a lupin and a cereal ideotype for maximal complementarity in the intercrop and a set of recommendations for practitioners. This work is an illustration of the way intercropping can help to overcome difficulties related to the low resource use of legume sole crops.

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Lentil-oat mixtures: stronger together by complementing each other?

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1 Introduction

Lentil (*Lens culinaris* Medikus) belongs to the legume family and is considered as one of the oldest domesticated grain legume crops (Cubero *et al*., 2009). Although its main cropping areas are outside of Europe (India, Canada), lentil is grown in some European countries on more than 10 000 ha (Turkey, Spain, France; FAO, 2016). The average grain yield in Europe is 7.6 dt ha^{-1}, which may vary depending on the region and cultivation method. To meet the increasing demand of consumers in Switzerland, the import of lentil seeds has increased from 2004 (1300 t) to 1900 t in the year 2014 (FCA, 2016). Although the area cropped in Switzerland with lentil increased during the past years it remains modest (estimation: 100 ha) and potential exists to increase surface.

Due to the comparatively low need for mineral nutrients, lentil is suitable for extensive cropping systems and is an interesting crop, due to the ability to fix nitrogen. Because of its poor early vigor, lentils competes poorly with weeds, which leads to a major challenge for the successful production of organic lentil (Gruber *et al.*, 2012). Additionally, the poor resistance to lodging causes further efforts for eliminating stones and soil particles after harvest if lentils are established as monoculture. Intercropping is an interesting option to combine the advantages of two crops on a field in the same growing season. Aim of the study was to investigate lentil–oat (*Avena sativa* L.)–mixtures at different seeding densities as well as at different proportions in the mixtures.

2 Materials and Methods

The trials were conducted in 2014, 2016 and 2017 in the proximity of Zurich at the Agroscope site Reckenholz. The long-term precipitation and average temperature (1981–2010) between March and August at this site is 592 mm m^{-2} and 13.5°C. A short growing oat variety (cv. Kurt; I.G. Pflanzenzucht GmbH, Germany) and the lentil variety Anicia (Agri Obtentions, France) were established both row by row pure alternating or mixed before sowing in different proportions (100:0, 75:25, 50:50, 25:75, 0:100) and densities (120, 180, 240, 300 seeds m^{-2}). Neither fertilizer nor pesticides were applied. Trials were established as a randomized complete block design with three replicates. Plot size was 1.5m x 6m. Among other scores, lodging was recorded at harvest (evaluation, 1 = no lodging, 9 = complete lodging). Yield was evaluated on dried samples after harvest with an experimental combine (Wintersteiger, Ried Austria) and having separated the material with different lab equipment into pure fractions of lentil and oat, respectively. In order to evaluate the systems' productivity, land equivalent ratio (LER) was calculated (Mead and Willey, 2008). Statistical analysis was done by R-Studio (Version 1.1.463, RStudio Inc., Boston, USA) and for pair-wise comparisons, Tukey's HSD was applied. Figures were established with Excel and R-Studio.

3 Results

Grain yield of both crops strongly depended on the year but variation was bigger for lentil than for oat: in 2016 average yields were lowest (2.5 dt ha^{-1} for lentil and 21.1 dt ha^{-1} for oat) while in 2017 yields were highest (7.3 dt ha^{-1} for lentil and 46.4 dt ha^{-1} for oat; Figure 1a). The seeding density did not

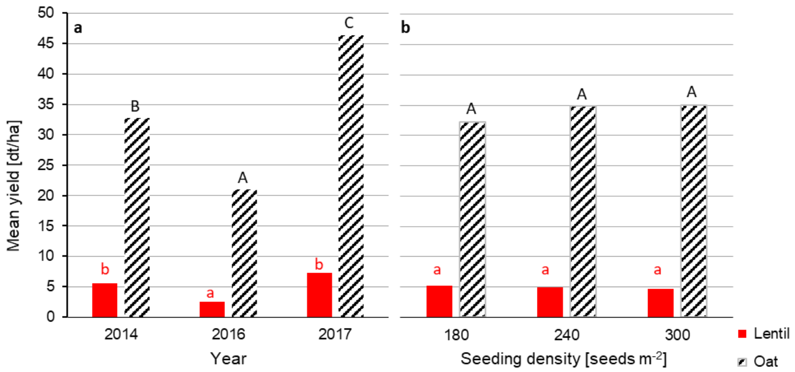

Figure 1. Grain yield of lentil (dt ha^{-1}, *standardized* to 8% H_2O) and oat (dt ha^{-1}, standardized to 14% H_2O) grown at different proportions, densities and arrangement of the partners in the field for (a) the three experimental years and (b) for the three seeding densities (180, 240, 300 seeds m^{-2}) at Zurich. Different letters indicate significant differences at α=0.05.

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influence the yield of neither lentil nor of oat (Figure 1b). Grain yield of pure lentil was 16.0 dt ha^{-1} and significantly higher than in mixed cropping (Figure 2). With decreasing proportion of lentils in the mixtures, yield decreased but the yield reduction was more pronounced in the system with alternating rows when compared to the system where seeds were mixed prior to seeding. For the oat crop, the yield reduction was less pronounced in the mixtures when compared to the pure oat cropping and only significant if the proportion of oats in the mixture was reduced severely (Figure 2).

Within the crop mixtures, highest yield of lentil was observed at the proportion 75% lentil and 25% oat for the mixed seeding structure. Lodging in pure lentil cropping (8.6) was similar to the system with alternating rows (8.5) but significantly higher as in the system with mixed seeds (5.5). The LER was distinctly higher in the system of the seed mixtures (LER = 1.2) compared with the system with alternating rows (LER = 1.0).

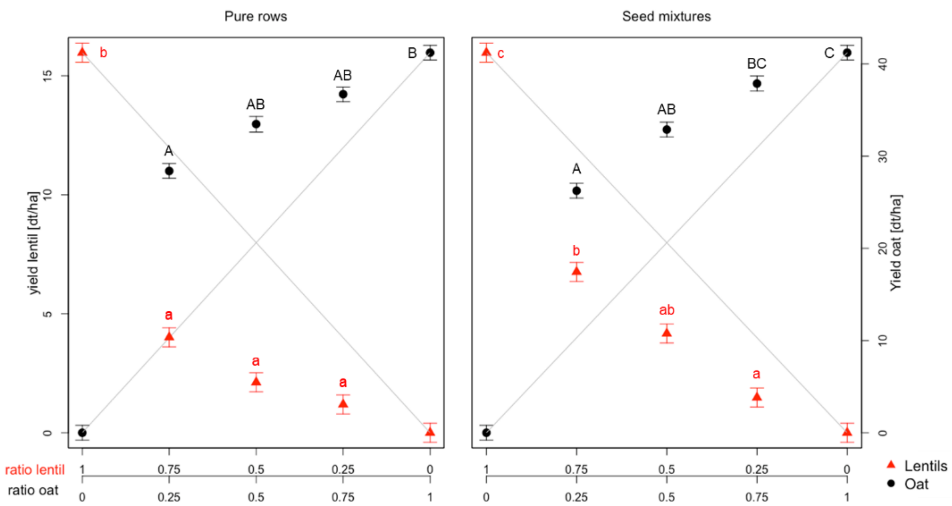

Figure 2. Grain yield of lentil (dt ha^{-1}, standardized to 8% H_2O) and oat (dt ha^{-1}, standardized to 14% H_2O) for different proportions (100:0; 75:25; 50:50; 75:25; 0:100) grown in alternating rows (pure, left) or as seed mixtures (right) at Zurich during the years 2014, 2016, and 2017. Error bars indicate standard error. Different letters indicate significant differences at α=0.05.

4 Discussion and Conclusions

Cropping of pure lentil in the region of Zurich is possible, however rainy summer increase risk of crop failure due to poor drying of the canopy and the risk of rotting in the field due to the tiny pinna. Although intercropping significantly reduces yield of lentil, the mixing of the species prior to seeding is a more promising strategy than the cropping with alternating rows, which allows the well-distributed oat plants better to prevent lentil from lodging and as a consequence to facilitate harvest. On the other hand, reduction of grain yield for oats was less distinct when compared with the pure cropping and the proportion in the harvested material in the respective mixtures was always higher for oats than for lentil. Consequently, oat is more competitive compared with lentil. Results of the LER show, that lentil growing in crop mixtures is a promising option to increase the system output and could help to increase stability of a system. Since additional efforts are needed after the harvest to separate seeds of the species, other partners’ suitability as pea [*Pisum sativum* L.) or cameline (*Camelina sativa* (L.) Crantz] to intercropping with lentil should be evaluated to look for species being less competitive compared to lentils, being more easily separated while maintaining advantages to reduce lodging and suppressing weeds. To allow for overall conclusions of intercropping systems with lentil, economical aspects also need to be considered.

Acknowledgements

Funding by Bio Suisse and Fondation Sur-La-Croix, providing seeds by breeders, as well as inspiring discussions with various persons are gratefully acknowledged.

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SESSION 15. BARRIERS, LOCK INS, ENABLERS AND PRACTICAL EXPERIENCES OF CROP DIVERSIFICATION

Chairs: Alison Karley (The James Hutton Institute, United Kingdom),
Wijnand Sukkel (Wageningen University and Research, The Netherlands),
Martin Weih (Swedish University of Agricultural Sciences, Sweden)

ORAL PRESENTATIONS

- The perceived or realised practical restrictions imposed by plant teams
  Speaker: Laura Tippin, Linking Environment And Farming, United Kingdom
- Emmer and einkorn as the means of diversification in organic farming under marginal conditions
  Speaker: Szilvia Bencze, ÖMKi, Hungary
- Hemp, a borderline crop to diversify Sicilian food systems
  Speaker: Luca Colombo, FIRAB, Italy
- Supporting crop diversification within or outside the dominant agro-food regime: different barriers for different strategies
  Speaker: Kevin Morel, Université catholique de Louvain, Belgium
- Motivations and observed benefits and limits from farmers growing legumes
  Speaker: Elise Pelzer, INRA, France
- Documenting crop diversification experiences across Europe - The DiverIMPACTS Expert Survey
  Speaker: Dóra Drexler, ÖMKi, Hungary
- Implementing applied research and development approaches for crop diversification in French arable farming: a strategic view from the French oil and protein farmers' applied research institute Terres Inovia
  Speaker: David Gouache, Terres Inovia, France
- Why and how farmers change their practices towards crop diversification: examples from a case study in France
  Speaker: Eva Revoyron, INRA, France

POSTERS

- Soil organic carbon sequestration and mitigation potential in a rice based crop rotation systems in Bangladesh - a modelling approach
  Presenter: Khadiza Begum, University of Portsmouth, United Kingdom
- Factors constraining and facilitating crop diversification: results and lessons from a sample of Italian experiences
  Presenter: Luca Colombo, FIRAB, Italy
- Growing cover crops in maize production: the effects of triticale and winter pea
  Presenter: Brankica Babec, IFVCNS, Serbia

- Crop diversification in Pays de la Loire: collect and spread experiences of farmers and local actors to better support farmers
  Presenter: Emmanuel Mérot, Chambre d'agriculture des Pays de la Loire, France
- Getting out of the commodity trap: Enabling diversity through alternative food networks
  Presenter: Katie Bliss, ORC, United Kingdom
- Chances and barriers of crop and value chain diversification from a perspective of an organic case study in Poland
  Presenter: Paweł Radzikowski, IUNG, Poland
- Legume land races in short food supply chains - From small-scale farms to urban gastronomy - A case study of TRUE Project
  Presenter: Attila Králl, Agri Kulti Nonprofit, Hungary

The perceived or realised practical restrictions imposed by Plant Teams

Laura Tippin[1±], Jennifer Banfield-Zanin[2], Alice Midmer[1], Charlotte Bickler[3]*, Andrew Manfield[4], Alison Karley[5], David George[2], Bruce Pearce[3],

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1 Introduction

Plant teams offer promising opportunities to improve yield stability, reduce pest, weed and disease burden, minimise inputs such as fertilisers and enhance the resilience of agricultural systems to stresses such as climate change and market volatility. However, a number of barriers exist which may affect their uptake and implementation. It is therefore imperative that these barriers are identified, and solutions sought and communicated to farmers and advisors. Barriers to the uptake of plant teams have been investigated as part of the DIVERSIfy project, funded through Horizon 2020. These barriers and their potential solutions will help to inform future discussion with machinery and precision agricultural technology providers within DIVERSify, allowing for the production of a barrier 'Trouble- Shooting Matrix' as a future DIVERSify output to help farmers and advisors overcome practical barriers to plant team implementation.

2 Materials and Methods

Fourteen stakeholder workshops were hosted across eleven partner countries in 2017 and 2018 to ascertain previous industry experiences with implementing plant teams and identify stakeholder barriers to plant team implementation (Pearce *et al.*, 2018). Barriers were classified as unsolved (barriers which do not currently have readily available solutions), solved (barriers with readily available solutions that are no longer an issue in plant team implementation) or perceived (seen to be a barrier by stakeholders, but which is not actualised).

Following the stakeholder workshops a number of participatory farmers were recruited to conduct commercial-scale field validation trials on plant teams of their choice. A number of such trials were undertaken in the 2018 growing season and helped to identify and highlight further challenges and barriers to the implementation of plant teams on commercial farms. Furthermore, sister projects to DIVERSify, such as TRUE and DiverIMPACTS, are also investigating, and have identified, barriers to the production of legumes and wider crop diversification approaches.

3 Results

Of the unsolved practical barriers, the most commonly identified was a lack of available advice or knowledge for farmers/advisors to utilise when attempting to implement plant teams on-farm (Pearce *et al.*, 2018). This was identified in all workshop countries except Italy and Kenya, who both identified it as perceived. This suggests that confidence is lacking in plant team implementation and that there is a paucity of freely and readily available advice to facilitate plant team use. Austria and Sweden found lack of advice/ knowledge to be both unsolved and perceived, reflecting that some plant teams may be better supported with available information and guidance. This barrier was also highlighted in the TRUE legume innovation and networking (LIN) workshops. During these workshops, knowledge gaps in cultivating, harvesting and processing legumes were highlighted (Maaß *et al.*, 2018). This is particularly relevant as legumes are often a preferred component within plant teams.

The second most common unsolved barrier identified was harvest complexity, largely as a result of variable maturation of species in plant teams, uneven grain size and required adjustments to combine harvesters. This was identified as a barrier in most stakeholder workshop countries with the exceptions of Austria, Italy and Palestine. Austria and Palestine identified it as a solved barrier and Italy identified it as perceived. As well as identifying harvest complexity as unsolved, Sweden also identified it as solved, Germany identified it as both unsolved and perceived and the United Kingdom (UK) identified it as unsolved, perceived and solved. Variability of the barrier between and within countries may reflect differences in the end uses of plant teams, with plant teams used for animal feed or silage having less complex harvesting requirements than other grain crops. Whilst the majority of participatory farmer trials did not come across any barriers at harvest, one UK participatory farmer trialling beans and oilseed rape found the beans in their plant team plots had higher moisture contents than those within the monoculture crop, due to them being less mature at harvest, suggesting plant teams can affect crop maturation.

Other unsolved barriers included the cost of implementing plant teams, crop management and processing complexity, drilling complexity, crop-crop competition and yield suppression. One participatory farmer particularly struggled with poor establishment and yield of their plant team, with poor variety choice believed to be one of the determining factors for this. Challenges were also reported in determining seed rates and drilling dates in the participatory farmer trials.

Of the perceived barriers, insufficient evidence supporting the effectiveness of plant teams was the most common. Stakeholders noted that while research on plant teams and evidence on their effectiveness is available, it needs to be more widely disseminated to farmers and advisors and any on-farm 'success stories' demonstrated through events.

4 Discussion and Conclusions

The range of barriers identified varied greatly between countries. This suggests that other factors, such as climate, policy, intended end use, farming system or farmer perception may be influencing how a barrier is perceived. It could also suggest that some countries have solutions to barriers which are unknown or not utilised by others. Of the responses from the stakeholder workshops, many identified barriers that were both unsolved and solved or perceived. This suggests that the range of barriers change and are dependent on what plant team mixture is used. In Austria, for example, it was noted that their identified barriers were largely around plant teams using legumes, but not Phaseolus and maize mixtures due to this plant team having a well-established value chain and guidance available.

Barriers related to harvest complexity appeared to be specific to geographic region. This could be the result of differing climates which could affect crop maturity of the plant teams, as well as differences in cropping system and available guidance. The range of machinery or equipment available in each country could also play a role in how harvest, drilling and processing complexity is viewed by stakeholders. Cropping system will also influence these barriers, where some systems are less dependent on machinery and other equipment, opting to hand harvest instead.

The role of machinery and precision agriculture technology in overcoming plant team barriers will be further investigated in future DIVERSify outputs. From the barriers identified, machinery and precision agriculture may be able to solve and overcome practical barriers relating to: soil preparation (tillage), sowing/ drilling (machinery adapted for co-drilling of multiple species at consistent rates across the field), nutrient management (helping to target applications and improve monitoring of soil nutrient availability and plant stress), harvesting (equipment to harvest different grain sizes effectively and minimise breakage of grains during harvest) and processing (effective separation of grains or seed while minimising damage to the grain/seed, plus improved drying and storage).

Other solutions to solving plant team barriers also need to be identified in addition to machinery and precision agriculture solutions. These solutions could include effective communication between researchers, advisors, policy and farmers, increased availability and support for independent advice and guidance, training in how to implement plant teams, initiatives to help with processing and marketing of end products, socioeconomic analysis of plant team implementation and its financial benefits, breeding programs and policy changes to encourage the uptake of plant teams and acknowledge the environmental benefits of plant teams to soil health.

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DiverIMPACTS
European Conference on Crop Diversification
September 18-21, 2019
Budapest, Hungary

Emmer and einkorn as the means of diversification in organic farming under marginal conditions

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1 Introduction

Species diversity is one of the highest in organic agriculture yet arable farming is still characterized by the dominance of a few cereal species. This is unfavourable not only for yield stability reasons but also from the customers' point of view. Ancient wheats, compared to the modern main stream cereals, are rich in minerals, various fibre components, carotenoids, antioxidants, vitamins and microelements (Zhao *et al*. 2009, Shewry and Hey 2015, Čurná and Lacko-Bartošová 2017). Due to their positive health effects, they are recommended for consumption for people suffering from allergies, colitis, diabetes and high blood cholesterol. Within the DIVERSIFOOD H2020 project, starting from 2015, 10 winter and 3 spring emmer (*Triticum turgidum* ssp. *dicoccum*), and 5 winter einkorn (*T. monococcum*) landraces and varieties have been tested in organic farming in order to assess their performance under extensive conditions and evaluate their potential for local cultivation.

2 Materials and Methods

Accessions for the investigations were kindly provided by Pro Specie Rara (Switzerland) and Plant Diversity Centre (NöDiK, Tápiószele, Hungary) in the case of landraces, and by the Agricultural Institute, Centre for Agricultural Research, HAS (Martonvásár, Hungary) and the Louis Bolk Institute (the Netherlands) in the case of registered varieties. At the Research Centre of Nyíregyháza in East Hungary, the experiment was sown in marginal sandy soil on 10 m^2 plots, first in 2015, in 1-4 replications (with respect to the availability of seeds) in an incomplete, and from 2016 in four replicates in a complete block design. Winter survival, weed and disease scores, morphological, phenological and yield parameters were recorded each year. On farm multi-variety tests were also started in 2017 in one location, Füzesgyarmat, and are now on-going, involving three sites from the autumn of 2018. The NIR protein content of the wholemeals of the dehulled on-farm grain samples was determined using Perten Inframatic 8611.

3 Results

Though the plants were exposed to marginal growing conditions, most accessions showed good adaptability but there were also some exceptions. Spring emmer varieties were not well-suited to the environment (e.g. weeds, sand blasts), so they could not be recommended for cultivation under such conditions. Furthermore, one emmer accession, GT-2140, which was proposed for both winter and spring sowing, was lost in the first year due to weak frost tolerance. Most of the winter varieties, both emmer and einkorn, however, were found to thrive and produce grain yield over 3 t/ha in 3-year average (Figure 1). In favourable years (2016 and 2018), the best emmer landraces GT 143, GT 381 and the variety Mv Hegyes produced around 4t/ha. Although four einkorn accessions, GT 2139, Mv Alkor, Tifi, and Nödik einkorn could yield as much as 5 t/ha in the best year (2016), this species reacted to the variability of crop year with higher yield fluctuations than emmer. Mv Menket, a registered einkorn variety, which was bred for short straw and intensive organic cultivation, could not tolerate such marginal conditions.

The most important factors affecting cultivation success besides climatic components were sensitivity to sowing date, frost, weed infestation and diseases. Einkorn proved to be resistant to the occurring leaf fungal diseases (*Septoria* spp., *Drechslera graminea*, leaf rust and yellow rust). Both species were susceptible to *Fusarium* to a varying extent depending on the year and variety, however, the emmer GT 1399 and einkorn GT 2139 landraces had no or only a very low level of *Fusarium* infection.

NIR analyses of the on-farm samples indicated existing variation in the protein content between the emmer accessions (11.2-15.5%), while einkorn had rather constant protein values (13.3-13.7%). The highest protein concentrations were obtained in Nödik emmer and Mv Hegyes (15.5 and 14.2%, respectively).

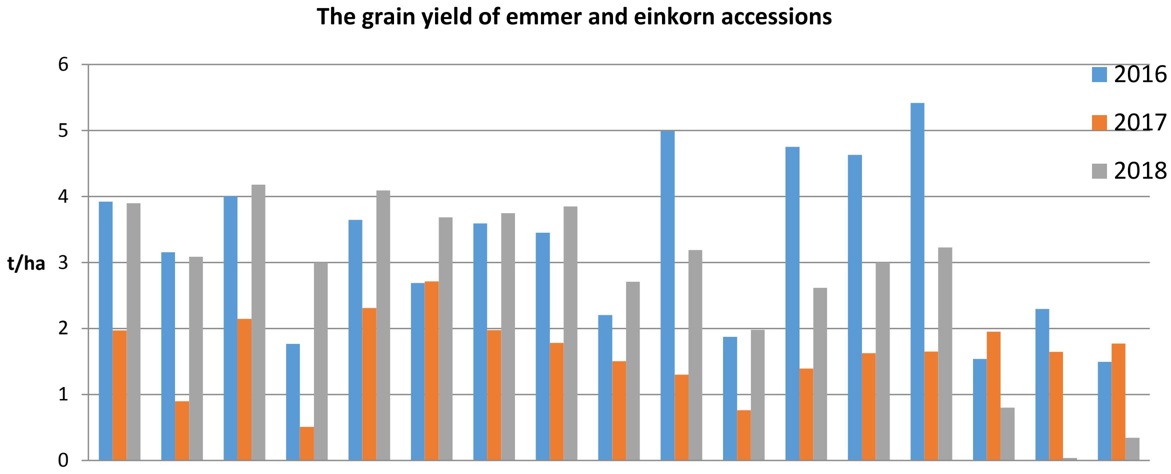

Figure 1. Grain yields of ancient wheats in the three years of the experiment (2016-2018), Nyíregyháza, Hungary.

4 Discussion and Conclusions

Both ancient wheat species with winter growth habit exhibited good adaptation abilities to the marginal sandy conditions, while the spring types were not well-suited to the circumstances of the experiment. Most winter accessions were able to produce around 3 t/ha grain yield in three-year average. Some landraces even had higher or similar yields than registered varieties. Disease resistance was outstanding in most einkorn accessions while yield levels were more stable in emmer. Based on our findings on grain yield and quality traits, and taking into account the market price of ancient cereals, both winter emmer and einkorn can be good alternatives for organic growers, especially on marginal soils.

Acknowledgements

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Hemp, a borderline crop to diversify Sicilian food systems

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1 Introduction

Despite its wide known benefits, crop diversification struggles to be put into practice (Meynard et al., 2018). Such slow development can be explained by a situation of socio-technical lock-in, which means that various interdependent barriers to diversification exist at different level of the food systems and reinforce each other (David, 1985; Vanloqueren and Baret, 2008; Meynard et al., 2018).

The DiverIMPACTS case study on "Diversification of durum wheat cropping systems in semi-arid environment with sulla clover, hemp and chickpea" aims to identify optimal options for the Sicilian arable systems, leading to the identification of crop diversification options to be tested. Notably, the inclusion of hemp in the farm rotation has been considered for its potential at field and value chain scale. Yet, despite its promising agronomic role and marketing possibilities, currently the object of a rediscovery after decades of neglect, hemp development is still limited in Italy because of long-lasting anti-drug policies and suspect at social and institutional levels.

2 Materials and Methods

To determine the case study's room for manoeuvre in relation to hemp cultivation, processing and marketing, a preliminary exploration has been carried out to gather and analyse a typology of possible barriers that could together contribute to a lock-in situation.

3 Results

A first set of barriers relates to the agronomic dimension. As hemp has not been cultivated for decades in Sicily at significant scale, crop-specific expertise lacks among most operators. The genotype (un)suitability represents an additional relevant obstacle as the varietal offer, already limited, is not appropriate to Sicilian pedoclimatic conditions. Similarly, appropriate machinery for harvesting and post-harvesting needs is unavailable: combine harvesters commonly used for wheat are generally adopted for hemp, yet unfit for fresh and tenacious straws, given that the limited scale of cultivation hinder investments.

A second set of possible barriers relates to the 'hysteric' climate still surrounding hemp in Italy. Despite a recent legislative evolution, marked by the law 242/2016[1] regulating the cultivation, transformation and sale of hemp and hemp derived products, uncertainties persist among Italian operators. The law foresees a tolerance threshold for THC inferior to 0.2%, with a tolerance up to 0.6%. Farmers that grow varieties registered in the seed catalogue, showing evidence of the seed purchase, would be considered non-responsible for the possible THC escalation beyond that regulatory perimeter, but they may not sell the produce should the THC content escalate above the tolerance threshold.

These concerns are also in relation with the scientific-politics interface, which represents a third area of uncertainty and aleatory prospects. The National Health Council, the Health Ministry scientific advisory body, issued in April 2018 a recommendation inviting the government to ban the sale of products containing THC in any percentage. Moreover, despite prescribed by the national law 242/2016, only in late 2018 the Italian Health Ministry has notified to the EU Authorities the draft Regulation[2] on THC maximum contents in food, which anyway results quite restrictive for the Italian agro-climatic conditions. Finally, on the scientific-regulatory domain, research has not yet indicated to what extent and in which conditions THC content may escalate in different hemp varieties beyond established limits. This particularly applies to farm

[1] Law 242/2016 - Provisions for the promotion of cultivation and the agro-industrial chain of hemp
[2] Italian Ministry of Health (30/10/2018) Draft Regulation laying down the definition of maximum levels of tetrahydrocannabinol (THC) in food

saved seeds for which a possible THC level increase is expected. As the case study already faced agronomic problems in relation to a late availability of seeds and seed saving has been considered a viable option to test more timely sowings, the case study has engaged a dialogue with the Ministry of Agriculture to get written permission for seed saving as a derogation attributed to a European research project, which was finally conceded with limitations to less than one hectare for each case study farm.

A final category of barriers is related to the fast-developing market for hemp and hemp products that – counterintuitively - represents an additional uncertainty for operators. Hemp-dedicated shops flourished in 2018, mostly due to the smoking attractivity, providing integrative commercial space for food and beverage products based on hemp flowers and grains; thus, in the last two years seed traders and other hemp dealers have disseminated prospects to farmers that promised remunerations up to 30.000 € per hectare for hemp flowers, attracting some improvised operators in the business.

4 Discussion and Conclusions

The variety and unpredictability of all mentioned barriers result in indeterminate conditions for the hemp value chains scalability at regional and national levels. Their market development remains fuzzy and difficult to predict under the current regime, requiring more research and regulatory clarity.

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Supporting crop diversification within or outside the dominant agro-food regime: different barriers for different strategies

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1 Introduction

Adoption of crop diversification is a pillar of agroecological transition (Poux and Aubert, 2018) but faces many barriers, which emerged historically along the specialisation trend of modernisation. These barriers occur at different levels of the agri-food system, reinforce each other and create a situation of socio-technical lock-in (Meynard et al., 2018). They have been described mainly by studies focusing on conventional agriculture, rather oriented to commodity markets and involving temporal diversification (integration of a new crop in the rotation). However, diversification initiatives can involve a wider range of strategies and contexts. Our objective was to investigate whether the presence and conjunction of barriers could be specifically related to some diversification strategies. Developing such understanding would contribute to fine-tune research, innovation and political action in line with the type of crop diversification promoted.

2 Materials and Methods

We studied 25 European case studies (CS) led by local organisations supporting annual crop diversification at food system level in the DiverIMPACTS project. To characterise the diversity of innovation strategies across the cases, we introduced the concept of "food system innovation settings" combining (i) a type of innovative practice promoted at the farm level (temporal diversification with longer rotations, spatial diversification with strip-cropping or multi-species cover crops and leys, intercropping), (ii) a type of value chain supporting that innovation (commodity market, local market, direct arrangements between livestock and arable farmers), and (iii) a type of agriculture involved (organic or conventional).In the initial phase of the project, CS teams attended co-innovation workshops where they used the method of causal analysis and drew a "problem tree" (AUSAID, 2003; Van Mierlo et al., 2010) to explore the different barriers that could limit or imped the diversification process. Further interviews were carried out to deepen the description of barriers they faced. A Multiple Correspondence Analysis (MCA) of the presence/absence of the different barriers to diversification raised by CS was carried out across the 25 case studies. Farming strategies, value-chains and type of agriculture were integrated as supplementary variables in the MCA to explore their relation with groups of barriers.

3 Results

We highlighted 46 different barriers to crop diversification across the cases, at different levels: production, downstream operations from farm to retailing, marketing and consumers, contracts and coordination between actors. We were able to distinguish 3 ideal-types of "food system innovation settings", contrasted in their proximity with dominant food systems, that were linked to different combinations of barriers: (i) "Changing from within" where longer rotations were fostered on conventional farms involved in commodity supply chains, (ii) "Building outside" where crop diversification integrated intercropping on organic farms involved in local supply chains , (iii) "Playing horizontal" where actors promoted alternative crop diversification strategies, either strictly speaking horizontal at spatial level (e.g. strip cropping) or socially horizontal (arrangement between farmers) without challenging directly the vertical organisation of dominant regime value chains. Major challenges faced in each case are presented in the table below.

Food system innovation setting	Main barriers to crop diversification
Changing from within	Current situation is still profitable; power unbalance between the agroindustry and loosely coordinated farmers which constraints innovation at the farm scale with the necessity to fit to existing downstream infrastructures and requirements; cultural inertia and complexity of integrating systemic long term thinking in short term profit-oriented simplified farming systems; belief that technological innovation (machinery) or new phytosanitary products are compulsory to allow change; doubts in the possibility to differentiate new crops based on ecological or health benefits for conventional commodity crops.
Building outside	Actors share strong values and are convinced of ecological practices but struggle in developing new value chains, securing profitability and efficient coordination because of high transaction costs, low and/or uncertain yields/quality of minor crops in organic conditions. Although alternative actors are confident in the possibility to differentiate new local products based on sustainability criteria, doubts remain as far as fair prices are concerned because competition exist with organic products produced cheaper in other conditions.
Playing horizontal	Uncertainties and lack of knowledge on the sustainability and profitability of innovative practices that have been poorly documented; cognitive frames need to be changed to integrate such new practices and support decision making at new scales (strips, territorial collaboration); suitable contracts are required to secure partnerships between farmers and ensure fair mutual benefits; difficulties in communicating to average consumers with no agricultural background of specific implemented practices apart from the positive impact on landscapes.

4 Discussion and Conclusions

This analysis was based on interviews with innovation teams who mostly belonged to farming related organisations (farmer's associations, agricultural R&D, extension or advisory services) at the beginning of the DiverIMPACTS programme. This work thus provides a static initial diagnosis of the challenges faced from farmers' perspective. Innovation and transition are dynamic processes. Further research should explore to which extent this first overview of challenges will condition innovation actions undertaken and how actors' perception of barriers at different levels of food systems change during the process, enriched by other value chain actors' points of view, modified and informed by action. Our work showed that different innovation settings in terms of agricultural practices and value chain can result in contrasted patterns in the combination of barriers. This diversity of challenges has to be taken into consideration to develop targeted research, innovation and policy actions according to the food systems they seek to support. We will formulate specific recommendations in that sense but think that both the characterisation of food system innovation settings (e.g. integrating more detailed variables) and the corresponding adapted action priorities deserve further investigation.

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Motivations and observed benefits and limits from farmers growing legumes

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1 Introduction

The diversity of legume species and management types (e.g. sole crop, intercrop, cover crop) should allow their cultivation in various pedo-climatic contexts. But legume crop areas have strongly decreased since the 1990s in Europe. Yet, some farmers still grow legumes. The aims of our study were (i) to understand the reasons why farmers grow legumes, (ii) to describe the benefits and limits they observe in their field, and (iii) to analyze if they are fully satisfied with their legumes or what kind of additional information they need.

2 Materials and Methods

An on-farm survey was conducted with farmers within the LegValue EU H2020 Project. It concerned (i) the description of their farms and farming systems, (ii) the grown legume species and their management, (iii) the description of cropping systems in which legumes are included, (iv) the motivations of farmers to grow legumes, and the benefits and limits they observe in their fields, (v) their overall satisfaction with legumes and legume-based cropping systems and the criteria on which they based their judgment, (vi) the additional information they need about legumes to improve their practices. Interviewed farmers were not chosen to be representative of European agricultural systems.

3 Results

We received 134 answers, from 10 countries: Denmark, France, Germany, Italy, Lithuania, Latvia, the Netherlands, Portugal, Switzerland, United Kingdom. 40% of the interviewed farmers had an organic farm (among them 55% with livestock) with an average of 3.4 grown legumes species. Conventional farmers (58% of the interviews, among them 68% with livestock) grew an average of 1.5 legumes species. 2% of the farmers had a mix farm (organic and conventional), without livestock, and an average of 3.3 legumes. 14 legume species were recorded in the whole survey. The 6 most cultivated were faba bean (20% of occurrence), pea (19%), clover species (18%), alfalfa (12%), vetch species (7%) and soybean (9%). Legumes were mostly grown as sole crops (67% of the answers), but also as intercrops (25%) or as cover crops, companion crops or relay crops (8%).

The most cited motivations to grow legumes concerned agronomy category: system diversification, soil biological quality (micro-organisms, organic matter, etc.) and structure, N supply, yield and quality of the legume or of following crops, and finally weed, pest and disease control with low pesticide. The second category cited was economy and management: improved farm profit (e.g. feed self-production), input use efficiency (e.g. less fertilizer use). Social and environmental categories came last. Motivations differed slightly between organic and conventional farmers, between farms with or without livestock, and between annual grain and perennial forage legume species. For instance, organic farmers insist on agronomical benefits such as N supply or improved yield and quality whereas conventional farmers insist on economical benefits such as subsidies and reduction of fertilizer inputs.

Concerning observed benefits, they were in accordance with expected ones. The most cited were: yield and quality of the legume or of following crops (e.g. improved yield of subsequent crop), easy-for-tillage soil structure, weed, pest and disease control (e.g. improved weed suppression), N supply, system diversification, input use efficiency (e.g. less fertilizer use), and improved farm profit. Some observed limits of legumes were also mentioned: appearance of new diseases or weeds, lack of outlet for legumes, variability of legume yield, use of additional inputs, negative impact of legume on soil structure and fertility. Again, small differences in benefits and limits appeared between organic and conventional farmers, between farms with or without livestock, and between annual (grain) legume species and perennial forage species. For instance, organic farmers insist on observed improved yield and quality of the following crop, whereas conventional farmers stressed out problem of low legume price.

73% of farmers were satisfied with their legume crop, crop management and crop performance, but only 59% with the benefits brought by legumes at the cropping system scale. Supplementary information needed varied according to the level of satisfaction. Farmers satisfied with their legume crop and cropping system still lack information on crop management, particularly weed, pest and disease control on these crops. Those not satisfied also lack information on crop management, but above all, they require cooperation and information sharing: feedback from other farmers experience, collective discussions and exchanges, particularly at local scale, experiments conducted with researchers in farmer fields, field visits and practical demonstrations, etc.

4 Discussion and Conclusions

This survey allowed us to understand the motivations of farmers growing legumes, the way they grow them, and the benefits they observe in the field. These information will be used to promote crop diversification and spread legume crops in European agriculture. We assume that farmers adapt their legume crop management and insertion in cropping systems to reach their targets, and this will be the next step in analysis.

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Documenting crop diversification experiences across Europe – the DiverIMPACTS Expert Survey

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1 Introduction

Cropping systems can become more diversified if current lock-ins of crop diversification are well assessed, and workable solutions are provided for farmers to overcome them. The DiverIMPACTS EU Horizon 2020 project aims to promote crop diversification by demonstrating its benefits along the value chain, and by providing innovations that can remove existing barriers to practical diffusion. To gain an overview of existing crop diversification experiences (CDEs) in Europe, we conducted an extensive on-line expert survey to identify and analyse factors of CDE success and failure.

2 Materials and Methods

The online expert survey was developed with the programme LimeSurvey. The survey included 72 questions in 3 sections. Section A contained 34 questions for describing the diversification initiative: geographical location, production practice before the initiative, targeted outcome of the initiative, involved actors, certification status, funding, value chain levels etc. In the 24 questions in section B respondents were asked to evaluate the reported diversification initiative: overall success, factors contributing to success or failure etc. Section C explored the dynamics of each diversification experience: the development of the initiative over time, as well as drawbacks and enablers during the process. To make sure respondents could describe their initiative accurately, the questionnaire included several questions with open answers, where potential responses could not be anticipated (e.g. the cultivated crops or the investment volume). January to April 2018 altogether 128 valid responses were received from 12 European countries. The survey was analysed with SPSS Version 22 statistical software package.

3 Results

Results show that rotation was performed singly or in combination with multicropping and/or intercropping in 71% of all reported CDEs, multicropping and intercropping were applied both in around 29% of the initiatives. Most CDEs were reported from arable cropping (86%). Vegetables were cultivated in 25% of the initiatives. Regarding certification statuses of CDE areas non-organic and organic both had a share of around 50%, with slightly more non-organic initiatives reported.

Two thirds of the reported CDEs were evaluated as overall successful or very successful (58% and 8%), while only 1 initiative was rated as not at all successful. The most common targeted outcomes of CDEs were improved environmental preservation (62%), improved crop production stability (52%) and higher economic income (52%). Main factors reported as contributing to failure were market conditions, amount of financial resources committed and availability of inputs (including seeds). The main factors reported as contributing to success were commitment and professional expertise of involved actors. Agronomic expertise was reported as the most relevant professional expertise for success. Respondents were asked whether their initiative encountered any drawbacks or enablers over the course of its lifetime. The most important agronomic drawbacks were climate issues (>20 initiatives), followed by weed management, crop protection and yield of agricultural products (with more than 10 CDEs each), while most important agronomic enablers (>20 initiatives each) were soil type, weed management, quality of agricultural product and expertise available on diversification.

Personal interactions were considered as the most important enablers – knowledge exchange with the actors of the initiative (mentioned >45 times), new skills acquired through the initiative (30 times), new contacts established through the initiative (>25 times), interaction and new cooperations established through the initiative (>20 times each). The fact that personal interactions were mentioned most often as enablers strengthens the finding that knowledge transfer related aspects are core for fostering diversification initiatives.

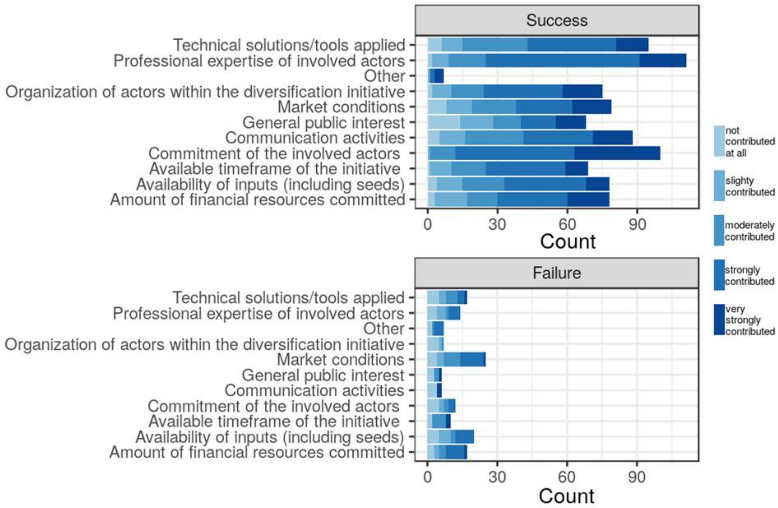

Figure 1. Success and failure factors highlighted by European diversification experiences (Drexler et al., 2019)

4 Discussion and Conclusions

Human resource related aspects, like professional expertise, commitment of actors and personal interactions were crucial for the success of reported crop diversification initiatives. Key drivers for success are thus people, their knowledge, commitment and interactions.

Market conditions were evaluated more important for rotation-only diversification initiatives, while they were hardly relevant for the majority of all crop diversification initiatives that included multicropping and/or intercropping. Rotation alone did not really improve the status of the environment according to respondents, unless combined with other practices, such as avoiding pesticides or with other diversification strategies.

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Implementing applied research and development approaches for crop diversification in French arable farming: a strategic view from the French oil and protein farmers' applied research institute Terres Inovia

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1 Introduction

French arable cropping rotations are dominated by cereals and maize, which represent circa 10 Mha. The majority of diversity in these arable crop rotations comes from oil and protein crops – rapeseed, sunflower, soya, field pea, faba bean, linseed, chickpea, lentil, lupin – that cover a combined 2.5 Mha, of which 2 Mha are rapeseed and sunflower alone. This current level of crop diversification in arable systems is increasingly viewed as insufficient, leading to stagnating or decreasing agronomic performance (Brisson et al., 2010 ; Cadoux et al., this conference), and limiting environmental performance (Recous et al., 2013 ; Lechenet et al., 2016). Following recent French and European agricultural policy initiatives (Etats Généraux de l'Alimentation, European Protein Plan), the French oil and protein crop sector has laid out a strategic roadmap aiming at increasing these crops surfaces by 500 kha, including 400 kha of legumes. This diversification of 5% of cereal and maize cropland will be a key success factor to the contribution of the sector to agro-ecological transition (25% decreases in GHG emissions and use of crop protection products) and national sovereignty for plant proteins ().

To contribute to these objectives, French farming organizations have developed, since the 1950s, their own R&D capability, through "technical institutes" dedicated to applied research and technology transfer to farmers, via levy contributions on crop production. Terres Inovia, one of these institutes, covers oil and protein crops, and has thus been positioned to spearhead the effort of French arable agriculture towards diversification. To do so, many biotechnical challenges must be met, crop by crop, to allow successful cultivation despite many biotic and abiotic stresses. Moreover, the process of diversifying, for growers as well as value chains, is also limited by specific constraints, that can be economical, organizational, social, etc. (Magrini et al., 2016). In this presentation, we will show how Terres Inovia contributes to these 2 types of challenges, and how the institute has organized itself to address them. We will draw on examples of results presented at this conference and elsewhere. Our discussion will focus on how diversification has required organizational change for the institute, and the challenges that lie ahead.

2 Materials and Methods

Terres Inovia, like most French "agricultural technical institutes", are non-profit organizations financed by levy contributions from farmers and grain industry essentially, that aim at producing collective R&D for farmers and the industry. Hence, 70 % of Terre Inovia's 16 M€ budget is contributed from the production of the different grains for which it holds a mandate (oil and protein crops). Terres Inovia was created in 2015 after the merger of 2 separate commodity based institutes, Cetiom (oilseeds), and UNIP (protein rich field crops). This constituted an important diversification for each "parent" institute, and required that the institute significantly rethink its strategy. A participatory approach was developed, at all levels of the organization, from the board to the 150 collaborators of the institute, freely drawing upon methods developed in business strategy (Duplaa, Genton & Simon 2009), organizational change (Laloux 2014), and retro-prospective analysis (Godet & Durance, 2008). This approach was developed in order to maximize the new institute's ability to face up to the new challenges imposed by its own diversification, and the acceptance by all its stakeholders. The results of this analysis and the institute's overall strategy are presented as results, as well as specific projects that illustrate them.

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3 Results

Terres Inovia's applied research strategy has been restructured around 18 "programs", defined as coherent project portfolios. Our focus is on the 9 "agricultural programs", that illustrate Terres Inovia's strategy for and towards crop diversification: among the 9 programs, 5 are dedicated to a crop or group of crops, and 4 are dedicated to transverse actions, all of which contribute to specific aspects of diversification.

This simple structure acknowledges that crop specific R&D must be undertaken to improve the intrinsic performance of each crop. Terres Inovia has allocated 55% of its agricultural programs resources to crop specific programs in such a manner that the larger crops (rapeseed and sunflower) significantly contribute to the smaller ones :while accounting for under 15% of levy funds, legumes and linseed benefit from over 37% of crop specific R&D resources. Despite this, the challenges for these smaller crops are daunting. The R&D required to surpass technical barriers often require multiple decades of investment, as we will illustrate with soya breeding and field pea aphanomyces resistance breeding cases in France: in both cases, over 20 years of investment have been required to deliver sufficient genetic progress. Conversely, regulatory decisions and biological evolutions can create new barriers for a crop in one growing season, as we will illustrate with faba bean weevil and linseed weed management.

Our 4 transverse programs are dedicated to: cropping systems design, improving ecosystem services, organic agriculture, and downstream grain processing. Our general approach to these programs aims at developing successful case studies in locally relevant contexts, from which generic tools and recommendations can be built. We present some case studies in which crop diversification plays a major role. The SYPPRE project (Cadoux et al., this conference ; Tauvel et al., this conference), for example, has demonstrated how the introduction of cover and companion crops, minimum tillage, longer rotation via grain legumes lead to improved productivity (+1-8%) and lower applications of mineral nitrogen (-35 - -26 %) and crop protection(-49 - -34 %) in short rapeseed-cereal rotations of central France. Generic tools, such as guides for companion cropping of rapeseed, built from this case study have contributed to companion cropping of rapeseed increasing from 7% to 12% of rapeseed grown in France from 2014 to 2018. Another project (R2D2; Cerrutti et al., 2019) aims at cultivating rapeseed without insecticides and builds upon these first results adding an ecological engineering approach to a 1000 ha territory with 7 growers. Another major line of projects involves optimizing and valuing symbiotic N fixation of legumes (Schneider et al. this conference, a, b, c ; Smadja et al., this conference).

4 Discussion and Conclusions

Investing in agricultural R&D to support crop diversification is an indispensable step towards a more sustainable agriculture. As some of the cases illustrated here show, these investments can be successful. For success, a convergence of favourable conditions is indispensable:

(1) Crop specific research must exist at a sufficient level of critical mass in terms of plant breeding, crop protection, and crop husbandry. Combined, these sources of progress need to be sufficient to counterbalance different trends that tend to lower a diversification crop's competitiveness: loss of performance relative to major crops with high speed of progress, loss of performance relative to imported commodities from areas, loss of performance due to regulatory and/or biological constraints. Our case studies in plant breeding and crop protection illustrate the oil and protein crops sector's strategy that aims at fostering cooperation between different private entities and upstream (generally public) research to overcome the gap in investment at intermediate Technology Readiness Levels. Currently, circa 500 k€/year are invested in this type of public-private pre-breeding for grain legumes in France: we estimate that attaining 2 M€/year would be necessary to drive sufficient progress for these crops.

(2) At the level of cropping and farming systems, our case studies illustrate that diversification is rarely an objective *per se*: it is in most cases one of the tools used to tackle a specific, local issue (insect resistance, weed management, yield potential, etc.). Hence, diversification comes as part of a process. This process is increasingly well documented, with multiple tools available (or under construction) (Cadoux et al., this conference). In coming years, Terres Inovia aims to provide and disseminate this toolbox through training of crop advisors and agronomists.

(3) Our case studies, as well as many others (Jeuffroy et al. 2018) illustrate that to succeed, the new commodities produced as a result of a diversification process need to find an adequate downstream value chain. In the case studies presented here, in which diversification comes as a tool to tackle specific agronomic difficulties, this factor can be a major constraint : some of our case studies have explicitly had to limit their diversification options linked to downstream feasibility. This has led Terres Inovia to

expand its scope from crop specific and cropping systems R&D. This expansion has occurred in 2 directions. The first direction involves developing projects that contribute to fostering change and diversification in value chains, as illustrated by the FILEG (https://www.fileg.org/) initiative aiming to create a value chain for locally produced grain legumes in the Occitanie region (Vogrincic, 2018). The second direction involves identifying new avenues to value crops and ecosystem services, both for new crops and for existing crops cultivated under cropping practices that use diversification to improve overall durability : one example is ongoing work to leverage carbon accounting as a way to add value to grain legume cropping.

To ensure convergence of these success factors for crop diversification, our institute's approach has had to expand from strictly technical R&D to a project-based approach with multiple stakeholders, involving significant intermediation time and a strong dose of change management. To create this capability, Terres Inovia has used tools and methods brought in from change management and business strategy, and applied them in a participatory approach to its own diversification strategy. The investments and costs incurred by this shift, coupled with the need to increase investment in "traditional" R&D for each crop, highlights current limits in the means dedicated currently to diversification. Commodity based levy financing provides an initial financing based that is essential, as illustrated by the recent investment of the French lentil growers and industry (ANILS) in collective R&D, but it needs to be complemented by a more important contribution of major commodities, i.e. cereals and maize, to the diversification effort that will ultimately benefit these crops as well (Schneider et al., 2019a, this conference ; Brisson et al., 2010). Such a mechanism, that does not exist either in commodity based industry financing or public financing in France, should aim at raising an additional capacity for collective R&D that we estimate at 2.5 M€/year.

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Why and how farmers change their practices towards crop diversification: examples from a case study in France

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1 Introduction

Over the past 50 years, agrifood systems in France and in Europe have been evolving towards a simplification and a regional specialization of crops and cropping systems (Schott et al., 2010). This evolution was originally driven by goals of mass production of food and economies of scale, but its sustainability is now questioned. However, reversing the trend from simplification towards diversification requires redesigning agrifood systems as a whole, considering each component of these systems and their interactions with the other components (Hill and MacRae, 1996; Meynard et al., 2018). While the lock-in effects affecting current agrifood systems have already been studied, there is a lack of literature on the levers that can be mobilised by actors to change their practices towards crop diversification. Some studies (Brodt et al., 2004; Buck et al., 2001; Greiner et al., 2009) provide answers as to *why* some farmers decide to change their practices towards more sustainable or agroecological practices, but they do not examine *how* they are able to implement these changes, or how they interact with their sociotechnical environment as they change (Blesh and Wolf, 2014). Compared to other changes in practices such as input reduction or conversion to no-till systems, crop diversification is not a goal concerning only farmers, as it is strongly dependent on the practices of actors outside the farming system. We hypothesize that analysing how farmers change their practices towards crop diversification, in relation with other actors from the agrifood system, will enable us to better understand the drivers of farmers choices when they diversify their crops (*why?*), and to identify levers for implementing crop diversification more largely in farming and agrifood systems (*how?*).

2 Materials and Methods

We carried out in-depth surveys with farmers that have changed their practices towards crop diversification, in a French region where several minor crops coexist among a few major crops. We traced with these farmers the diversification process they had carried out over time, and we questioned over this process (i) how their cropping systems and the technical management of their crops evolved, (ii) how they took their decisions before, during and after implementing the changes, (iii) what productive resources (land, labour, machinery, inputs), knowledge and learning processes they mobilized, and (iv) how they marketed the new crops. We paid special attention to the influence of the interactions of farmers with other actors from their sociotechnical environment (other farmers, value-chain actors, extension services) on this diversification process.

3 Results

This research provides contrasted examples of farmers' processes of change towards more diversified cropping systems. Our first results show that crop diversification is triggered by technical or economic problems encountered on at least one of the two main crops in local cropping systems, wheat and maize. Farmers who diversify their crops generally replace some or all of their maize area by new crops, but they do not call into question wheat areas. For more than half of the farms in our sample, the crop diversification process follows a similar pattern: during the first steps of the process – 6 to 9 years – the farmers progressively increase the number of crops other than wheat and maize and their share in the utilised agricultural area (UAA), up to ~50% of the UAA. The species and their respective share are then adjusted within this 50% threshold. The choice of the new species is strongly constrained by soil characteristics and outlet opportunities specific to each farm. During the diversification process, most farmers develop strategies in order not to modify in-depth their own workforce, equipment or land: they rather mobilize external resources such as contractors or common machinery. Finally, farmers' performance criteria for crop diversification evolve as they learn about new crops, to include more and more pre-crop/multi-year effects. For example, new crops that decrease weed populations will be kept even with low economic performances.

4 Discussion and Conclusions

This research highlights that crop diversification, at the farm level, is a complex and long-term process which requires farmers to re-design not only their cropping systems, but also their indicators for assessing these cropping systems, and how they mobilise productive resources. A complementary analysis focused on the evolutions of practices of other stakeholders of the region, involved with the farmers in the diversification process, should provide us with a global view of contrasted strategies of crop diversification, and their respective strengths and drawbacks. Our methods will also be replicated to the farms of different regions and contexts in Europe in order to compare our results with varied situations and to identify more generic levers for crop diversification.

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Soil organic carbon sequestration and mitigation potential in a rice based crop rotation systems in Bangladesh - a modelling approach

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1 Introduction

Agriculture is estimated to be one of the largest sources of greenhouse gas (GHG) emissions in Bangladesh. In particular continuous rice cultivation is one of the major sources of GHG emissions. However, diversification in cropping systems such as low input management practises offers substantial mitigation potential. Increasing soil organic carbon (SOC) sequestration in agriculture has been identified as an effective potential strategy for GHG mitigation. However, in Bangladesh research on SOC sequestration under diversified cropping systems is scarce. This study focusses on the consequences of cropping systems diversification in rice by determining SOC sequestration and GHG mitigation from Bangladesh agriculture under various combinations of management practices.

2 Materials and Methods

For this study, an ecosystem model DayCent was validated for monocropping rice-rice (site 1) and wheat-rice (site 2) based experimental sites in Bangladesh. We first tested the model's ability to simulate SOC turnover in two types of cropping systems under different management practices, and then estimated the potential for SOC sequestration by comparing changes in SOC for each management scenario to baseline management (current farmers' practices) including conventional tillage, 5% residue return (Rsd) and nitrogen (N) fertilizer. Predicted yield was also compared at both sites to ensure that yield was not compromised by mitigation measures. A control treatment (no fertilization) was tested at both sites. At site 1, two other treatments of mineral N fertilizer, and combination of farmyard manure (FYM) and N were tested. At site 2, a treatment receiving cowdung (CD) application, and a combination of CD and N were tested. Assuming N fertilizer (180 kg N ha^{-1} yr^{-1}) application for site 1, and CD application (25 t ha^{-1} yr^{-1}) for site 2, respectively, as the baseline, four single, and one integrated, scenarios were implemented in the model to predict SOC and yield at both sites. Two additional scenarios, alternate wetting and drying (AWD) as a single treatment and as part of an integrated approach, were also tested for their mitigation potential at site 1. Net GHG emissions, (methane and nitrous oxide) were estimated using the Intergovernmental Panel on Climate Change (IPCC) tier 1 methods, and country specific emission factors.

3 Results

Both modelled and observed results for two cropping systems of site 1 and site 2 revealed that SOC increased over time under all treatments. Model results under the alternative crop management showed that, among the selected mitigation scenarios, the highest simulated positive impact on SOC development (60% higher than that of the baseline) was observed at site 1 when manure was used in place of mineral N fertilizer (Figure 1a). As there is a yield penalty associated with the use of only FYM, integrated approaches might show more promise, such as inclusion of changes in the residue management (15% Rsd), reduced tillage (RT), less mineral N fertilizer, FYM addition, with or without AWD. This approach shows increased SOC up to 23% while keeping the yield stable (nearly 3.5 t ha^{-1}). The application of CD as manure determined for baseline of site 2, gives a yield of about 1.8 t ha^{-1} yr^{-1}. In contrast, nearly two times higher yield was obtained under

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the scenario associated with integrated management, which also increases SOC by 30% relative to the baseline at site 2 (Figure 1b). Integrated management scenario can reduce the net GHG emissions of 0.82 t carbon dioxide (CO_2)-eq. ha^{-1} yr^{-1} at site 2, while a net reduction in GHGs of nearly 1.21 t CO_2-eq. ha^{-1} yr^{-1} at site 1 was only achieved if AWD was also implemented with the integrated management scenario (Figure 1c).

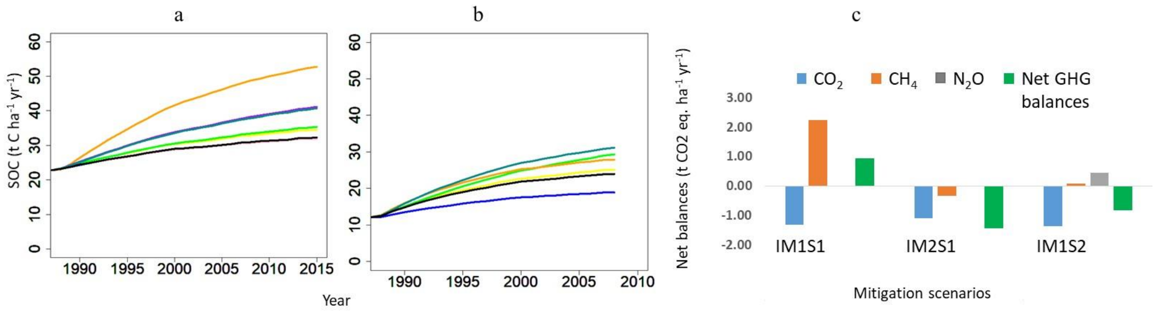

Figure 1. Modelled SOC under different mitigation scenarios for long-term monocropping rice site 1 (a) and wheat-rice site 2 (b) in Bangladesh. The black line denotes baseline and other colours for both sites represents different mitigation scenarios including residue return (yellow), reduced tillage (green), low N fertilizer for S1 and N in place of manure for S2 (blue), manure in place of N fertilizer for S1 and low manure for S2 (yellow), IM1S1 (purple) for S1, IM2S1 for S1and IM1S2 for S2 (Sky) respectively. Some scenarios overlap each other. Fig. 1 (c) represents the net GHG balance estimated with IPCC guidelines under the integrated scenario. S1 denotes site 1. IM1S1 and IM2S1 represents integrated management with and without AWD for site 1 and IM1S2 represents integrated management without AWD for site 2 respectively. Negative values denotes a removal of CO_2 or GHGs and vice versa.

4 Discussion and Conclusions

The study found that for the simulations to fit the data the model needed to consider higher C and N input values. Both, N and C, are inputs from aquatic biomass (e.g. aquatic weeds, BGA, azolla) and have a significant contribution to crop yield and SOC increase. Although our model results revealed that current management contributes to an increase in SOC over the study period in both cropping systems, our aim was to examine practices that improve soil quality and soil health, store additional SOC, and reduce GHG without compromising yield. Most of the selected alternative scenarios tend to increase SOC and maintain a stable yield when compared to the baseline, but the scenario giving the maximum yield was not the same as that giving maximum SOC increase. This study found that, rather than single management, integrated approaches with RT, more Rsd, reduced mineral N coupled with manure management could have the potential on SOC sequestration in both cropping systems. However, in considering GHG emissions from two rice cropping systems our findings demonstrated that the mitigation potential for monocropping rice systems would not be possible without AWD practices. This finding suggests that it is essential to consider all GHGs together. Although monocropping has contribution on increasing SOC but in aspect of determining net GHG balances, it is suggested to practice rice-wheat rotations in Bangladesh. This study emphasizes the importance of diversification in cropping systems to mitigate climate change impact in Bangladesh rice based agriculture. In particular, it shows how alternative management practices help improving soil quality by sequestering SOC and increasing GHG mitigation without affecting the yield. Further study is needed to explore crop diversification approaches in aspect of nutrient use efficiency e.g N, sulphur, zinc, and water use efficiency and assess other effective alternative management practices, which is not considered in this study.

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Factors constraining and facilitating crop diversification: results and lessons from a sample of Italian experiences

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1 Introduction

The problems caused by intensive agricultural practices (i.e. soil degradation, chemical pollution, groundwater depletion, biodiversity loss, GHG emissions) led to consider the need to adopt more sustainable and responsible alternatives (1, 2). The European Commission (3) stated that agriculture should shift towards a different growth path, fostering the sustainability of agricultural practices and securing soil functionality. Similarly, unfair distribution of added value along the food chain, oligopolies in strategic input supplies, consumers' quest for food identity and integrity as well as rural cohesion disaggregation represent some of the concerns around the food system that the European society demands be addressed (4).

Fostering crop diversification (i.e., through rotation, multiple cropping, inter-cropping) may represent a sound option towards a more sustainable agriculture, able to achieve multiple objectives such as guaranteeing or improving crop productivity, preserving and enhancing ecosystem services, increasing resource use efficiency and promoting overall sustainability of the agri-food value chains (2). Crop diversification, in particular multi-cropping and legume-rich rotations, may play an important role in organic agriculture as it seems able to greatly reduce the yield gap with convention farming (5). It has been reported that agronomic practices that promote crop diversity would result in requiring fewer agronomic inputs due to a reduced incidence of pests (6,7). Crop diversification may also reduce farmers vulnerability to external stressors, such as climate change (6).

Lock-ins and path dependence often represent important obstacles to the transition of technological systems (8, 9). Developing effective policies aiming at enhancing crop diversification, requires grasping a sound knowledge of the main obstacles and lock-ins that may constrain its adoption, and the levers that public authorities can deploy (9, 10), as well as of the plurality of values at stakes (10).

In this paper, we present the results of a survey, carried out in Italy during 2018 within the activities of the DiverIMPACTS (www.diverimpacts.net) H2020 project, on a sample of crop diversification experiences (CDEs).

The study aims at providing insights on how participants in CDEs (a) perceived the overall results of the experience and (b) assessed targeted outcomes. To our knowledge, this is the first survey of this kind run in Italy. Notwithstanding its limits, the study may represent a useful pilot work able to stimulate further investigations on the issue.

2 Materials and Methods

For this survey, 17 CDEs were chosen among farms that have been recently involved in CDEs (i.e., introduction of new crops in rotation, multiple cropping and intercropping), including 8 organic farming systems (OFS) - small and medium farms, 2-15 ha, all private farms - and 9 conventional farming systems (CFS) - medium to large farms, mainly private and the Veneto Region's pilot farms. Using a structured questionnaire, listing a number of questions concerning the overall results of the experience (i.e., failure vs. success), and assessed targeted outcomes (a number of aspects concerning the implementation of a CDE at farm level and its implications in value chains and in the policy domain), interviews included 20 actors, including farmers, researchers and technicians. Nine of these actors were involved in organic farming systems (OFS) (7 farmers and 2 field technicians) and 11 were involved in conventional farming systems (CFS), (two farm managers, six field technicians, one manager, one institutional supervisor, one researcher).

3 Results

Concerning the rate of success of these CDEs, 10% of the actors said they were slightly successful, 35% moderately successful, 45% successful and 10% very successful. It is notable that none reported no success or a failure, and that such distribution is closely maintained when data are disaggregated for OFS and CFS (Figure 1). No notable differences between different type of actors (i.e., farmers, technicians) were appreciable.

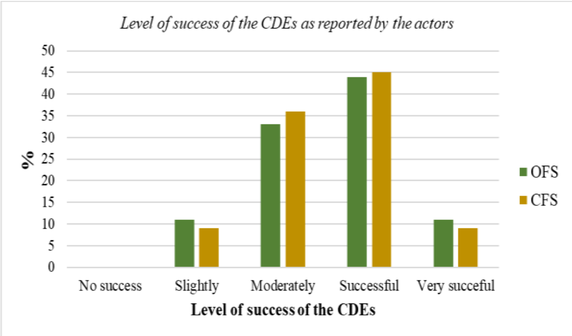

Figure 1. Level of success of the CDEs, as reported by the actors, in relation to the established goals

The more frequent and successful targeted outcomes resulted in higher economic income, lower input level, improved crop production stability, introduction of new food products and improved environmental preservation. Among the factors that contributed to the success, 90% of the interviewed reported the professional expertise of involved actors, 85% the commitment of the involved actors, 75% the communication activities. Technical solutions/tools applied, availability of inputs, amount of financial resources committed and available timeframe were mentioned in 60% of the cases.

According to the actors' perception, many factors contributed to facilitate (F) or hinder (H) the achievement of the objectives (a factor could be both F and H), the most notable were personal interactions (seen as F by 70% and as H by 20%), agronomic characteristics (F: 75%; H: 55%), funds availability (F 55%; H: 50%). Most of the initiatives included communication levers both within the initiative itself and towards other actors (i.e., technicians/experts, farmers, policy makers, consumers). The adopted communication initiatives were reported to be highly successful in 70-80% of the cases and successful in 20-30% of the cases.

4 Discussion and Conclusions

The importance of crop diversification in sustainable agriculture has long being recognised. Addressing obstacles and lock-ins to crop diversification, existing at various levels of the value chains, in order to support agricultural policies has been the concern of recent research (e.g., 9,11).

The present work attempted to address such issue for a sample of Italian CDEs. Although the work was intended as an explorative exercise, some noteworthy information arose.

Among the lessons emerged from the survey, the following are considered the most significant: the interviewed actors perceived their experiences as overall positive; a stronger collaboration between the actors was deemed very important to enable the objectives achievement; the integration of all the actors in the agri-food chain was considered an essential element for the success of the diversification initiative.

The actors interviewed were aware of the importance of diversification in fostering environmental sustainability and economic performances of agricultural activities. Technical support, financial resources availability and a strong collaboration between the actors were considered key elements for the CDE success.

Concerning the sample addressed by this survey, some indications for policy makers can be drawn, despite the limits of a generalisation. Policies aiming at promoting the adoption of sustainable agricultural practices, like crop diversification, should support farmers in: accessing funds (i.e. administrative simplification and easier access to credit), technical assistance (both at the field and food chain level), communication strategies among actors (i.e. training on project management) and with the public (i.e. marketing tools, training on dissemination tools and strategies). Notably, reported CDE experiences were initiated by the producers themselves, without the support of specific policies. This leaves room for hoping that, if sound policies could be implemented, crop diversification may gain further interest among farmers and in the food chain.

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Growing cover crops in maize production: the effects of triticale and winter pea

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1 Introduction

With the introduction of cover crops (CC) significant benefits can be achieved regarding diversification and crop rotation, with respect to the principles of a sustainable agriculture. However, extreme climate conditions and lack of precipitation in critical phases of growth and development raises a question about the efficiency and utilization of CC and their interactions with main crops. The use of CC in maize production is practice and there is no data on their interaction in our region. Therefore, the aim of this study was to determine the effect of CC and interactions on yield and morphological properties of maize in the semi arid conditions.

2 Materials and Methods

Research was carried out in the production years 2017 and 2018 at the Rimski Šančevi experimental station of the Institute of Field and Vegetable Crops in Novi Sad (45 ° 19' N 19 ° 50' E). The winter CC consisted of the combined intercrops: winter pea (*Pisum sativum* ssp. *Arvense* L.) + triticale (*Triticosecale*) (**PT**) and single-species CC winter pea (**P**). Cover crop plots were divided in 2 subplots: In the first subplot winter CC were cut and fodder was taken away- mowed (**m**), in the second subplot the plants were used as a green manure with plowing (**pl**).The experiment was conducted in 5 variants as follows (i) pea + triticale plowing (**PTpl**), (ii) **pea +triticale** mowed (**PTm**), (iii) pea plowing (**Ppl**), (iv) pea mowed (**Pm**) and (v) control without CC **(C),** all with nitrogen fertilization 50 kg ha^{-1} (**N_{50}**) and without the use of fertilizer (**N_0**). The sowing of winter CC was carried out in autumn in the first decade of November, and their mowing, cutting and plowing was done in the last week of May. After plowing and soil preparation, maize (*NS4051*) was sown in the first decade of Jun and harvested in October. The size of the main plot was 25 m^2. The investigated years differ noticeably in terms of precipitation arrangement and temperature sum for vegetation period.

3 Results

The statistical significance ($p<0.05$) was found between different variants (**PTpl**, **PTm**, **Ppl**, **Pm** and **C)** regarding the use of CC. The highest yield of maize in 2017 was obtained on the **PTplN$_0$** variant (4962.2 kg ha^{-1}), and the lowest in **PTmN$_0$** (1546.9 kg ha^{-1}). Compared to 2017, in 2018 the highest yield was determined on the variant **Ppl N$_{50}$** (7619.42 kg ha^{-1}). The lowest maize yield was achieved on the variant **CN$_{50}$** (3880.5 kg ha^{-1}), which is attributed to bad performance of seed bed preparation in unfavorable soil moisture content followed with poor plant density per unit area compared to the soil that was under CC until the moment of sowing of maize crops.

4 Discussion and Conclusions

Two-year research indicated that the maize yield is associated with climate conditions, primarily precipitation. Study showed that, on the basis of the obtained results CC can influence the achievement of higher yields in conditions with sufficient precipitation in spring and available soil moisture in accordance with the requirements of the maize in its critical stages of growth and development. Using CC as a green manure with favorable C:N ratio and conditions for mineralization, it is possible to provide plants with a certain amount of nutrients which would led to a reduction of inputs (mineral fertilizers), improve the physical properties of the soil, and achieve the corresponding yields in the "second harvest" with possible lower production costs. In the long term, such production system should provide an ecological effect and affect the preservation and increase of organic matter in the soil, with the continuous production of quality animal feed on the farm.

DiverIMPACTS European Conference on Crop Diversification September 18-21, 2019 Budapest, Hungary

Crop diversification in Pays de la Loire: collect and spread experiences of farmers and local actors to better support farmers

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1 Introduction

Over the last 50 years, there has been a trend towards specialisation and intensification to increase the efficiency of production. In Western France, farms are more and more specialised in livestock production and cropping systems are more and more simplified (only 4 crops occupy more than 80% of the useful arable surface of the Pays de la Loire area). Despite the availability of many crops and species for diversification, farmers have to face different barriers and locks in at technical, economical and organisational levels to develop these new crops.

Thus, the main challenge of this study is to explore different strategies for crop diversification, dedicated to feed at farm level or to sell at value chain level, in order to identify solutions to support farmers involved in diversification of rotations.

2 Materials and Methods

2.1 Choice of studied farms

During a week, students carried out interviews with 20 farmers, who have been chosen regarding to the presence of diversified crops in their rotation. This survey takes place only in the sector of cereal production and livestock production mixed with crops.

Farming system	Conventional farming	Organic farming
Cereal production	5	1
Livestock production with crops	8	6

Field studies were conducted within a sample of 20 farms, through all the Pays de la Loire area.

2.2 Analysis of diversification trajectories

Adopted approach in this study combines agronomics (technical changes) and sociology (determining factors). The interview guide is focused on the change process and expects to highlight diversification trajectory of farmers, their motivation, the mobilised resources and how the transition was made. The goal is to trace the farm history and to understand the factors of change.

3 Results

The interviews with farmers, engaged in crop diversification, allowed us to identify several drivers and different resources mobilised to diversify their crop rotation. First, we noticed 4 kinds of drivers, leading to diversification. (i) **The most often quoted is economic**: the will to increase their incomes, by a new crop with a remunerating outlet (sometimes unstable) or by creating added value with direct sales on their own farm; (ii) **organisational drivers can lead to diversification**. For instance, 25% of farmers try to reduce their animal fodder cost and want to increase their autonomy by inserting new crops or forages like soya or alfalfa. A change in the human organisation of the farm can also create needs of new crops; (iii) **the agronomic driver is essential**. Many farmers realise they need new crops in their rotation to reduce problems on crops like weeds, pest, diseases…or to improve their soil fertility; (iv) the last one is more **personal or ethical**. These new crops may not be very economically profitable but they can help wider benefits than farming level: local economy, less environmental impacts….

Regarding resources, the two main needs are **technical monitoring and decision support** about these "new" crops in their rotation. The last one is about **social reassurance**, which they can find within a group.

The individual decision for a personal change in crop rotation can be guided by 5 kinds of motivation. (i) **To reduce working time** by developing crops needing less technical intervention or being in charge of a cooperative and its technicians. This seems to be a lasting crop diversification, mostly due to contracts between farms and economic partners; (ii) **to fit to the needs of a new value chain because of economic interest**. This is mostly an economic and one-time shot motivation, where new crops can be stopped because of technical difficulties or lower market price; (iii**) to fit to the needs of a new value chain because of both economic and agronomic interest**. These farmers are much more autonomous in their decision-making and see positive impact of diversification in their rotation, which leads to a sustainable in time crop diversification; (iv) **to increase feed autonomy for livestock**, they grow new crops or forage in order to reduce external purchase (e.g. proteins). The surface of new crops is limited to the needs of the herd but stable. In our study, the crop diversification in this case, is closely linked to the arrival of a new partner in the farm and a strong farming system reorganisation; (v) **to aim for complete farm autonomy**. These farms are distinguished by their feed autonomy in forage and proteins, by their decision-making autonomy and by their diversified productions.

Considering these motivations, we can notice here the specificity of the agricultural region Pays de la Loire: the importance of mixed livestock farming and sales crops. The three first motivations are indeed very linked to sales crops value chain, under formal contract, although the last two are much more intended for livestock farming.

4 Discussion and Conclusions

The results of the study are displayed through different types. Each type has been described: the farm characteristics, the sociological profile of farmers, the diversification drivers, the mobilized resources and the farmers support. Choices have been done to create homogeneous farmers groups. So, even if this type construction can be discussed, the results are very interesting and a good working base to more precisely understand the diversification process in the Pays de la Loire area.

The farmers support has a significant influence on their trajectory. Indeed, all the farmers interviewed belong to an exchange group, but with more or less autonomy. To enhance sustainable crop diversification, it seems necessary to encourage farmers to take autonomous decision through peer exchanges. Furthermore, it also seems that in case of individual advices, they should take account of the farming system (or cropping system) to stimulate a lasting crop diversification.

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Getting out of the commodity trap: Enabling diversity through alternative food networks

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1 Introduction

Many UK arable farmers are stuck in a 'commodity trap'. Despite growing evidence of the role of temporal and spatial crop diversity in enhancing the resilience and performance of agroecosystems (Lin, 2011), they are limited by markets that demand large volumes of consistent products. The infrastructure built up around these commodity markets does not allow for small batches of more diverse crops – access to seed, production, harvest, storage, transport and processing present additional challenges. As such, although there is growing interest in crop diversification at a genetic, crop and rotation level, arable cropping in the UK is focused on a relatively small number of crops grown for the commodity market.

In parallel, there is a growing consumer interest in more resource efficient and plant-based diets, creating more demand for pulses and other novel grains. However much of this is currently met by imports and not supporting crop diversification and associated agroecological benefits in the UK. As such there is huge potential for initiatives which seek to support to connect these farmers and consumers to build diverse, agroecological food systems.

From asking the question 'Can Norwich feed itself?' a group of motivated local citizens sought to understand how local farming and diets would have to change and adapt. This raised awareness of the benefits of growing more pulses both for human nutrition and agroecological functions. In response to this Hodmedods Ltd was set up as a commercial company in 2012 to support the production, processing and marketing of pulses and other novel grains. Hodmedod's have created markets for minor crops, including some historically grown in the UK (such as Carlin peas, marrow peas and fava beans) and new crops (including quinoa, buckwheat and lentils). Many of the farmers in the network are also trialling new crops and innovating with crop diversification practices such as intercropping. Hodmedod's seek to ensure farmers receive a fair price and valorise the whole rotation. They support farmers in processing, packaging and marketing the crops and in some cases supplying seed and agronomy advice. Exploring practical experiences in this alternative food network may provide insight for future efforts to develop value chains which catalyse crop diversification.

2 Materials and Methods

The EU funded Horizon-2020 project DiverIMPACTS (Diversification through Rotation, Intercropping, Multiple Cropping promoted with Actors and value Chains towards Sustainability) builds on existing experiences of crop diversification through actor-orientated research in 25 case studies. Case Study 15 (Growing pulses and innovative crops for a less resource intensive diet) is working with actors in the Hodmedod's network to understand more about the functioning of this alternative food network, to explore the new relationships in the chain and identify best practice and lessons learned to support other similar initiatives to catalyse crop diversification elsewhere.

This paper will present the some of the initial insights through descriptive case studies, focusing on the Hodmedods model and practical experiences of farmers in their network (organic and conventional). Farmers motivations, crop diversification practices and enabling factors to diversification including the relationship with Hodmedods and other alternative food networks were explored in phone conversations, farmer meetings and discussions in the field. This was complimented with data collected in multi-stakeholder workshops, phone calls and face to face discussions with Hodmedod's staff.

3 Results

Farmers in the Hodmedod's network are seeking to enhance diversity at a number of levels including:-

- **Genetic** – variety mixtures, composite cross populations and older 'heritage' varieties of crops.
- **Crop rotation** – expanding the rotation, including 'minor' crops and pulses, livestock and leys
- **Intercropping and companion cropping**. In particular, cereals with pulses to provide scaffolding and suppress weeds.

Two farms are explored in more detail;

Farm A: An organic mixed farm growing several different types of peas for Hodmedods as part of a diverse rotation also including cross composite populations, heritage varieties, agroforestry and herbal leys. He grows carlin peas – a traditional black badger pea – which have a large amount of biomass and are prone to lodging. He has been trialling intercropping the peas with triticale at different seed rates to test the scaffolding ability. The mixture was part-separated on farm and final cleaning was done by Hodmedod's. His motivations for building diversity more than just the agroecological benefit;

> "*We valued peas in our rotation but felt they were not fairly valued by markets, especially given how difficult they are to grow. (working with Hodmedods) …has not only helped us to maintain a diverse rotation but has also helped us build meaningful connections with our customers*."

Packaging of his peas includes information about his farm and he has direct communication with consumers on Twitter. Since working with Hodmedod's he has also developed relationships with an artisan baker, collaborating with millers to enable direct sales of population and heritage wheat.

Farm B: A conventional arable farm implementing a conservation agriculture approach. He is motivated to increase diversity to enhance environmental and economic sustainability. With the goal to reduce inputs by 50% in 5 years he has been experimenting with a wide range of 'plant teams' including beans-oats, spring oilseed rape-peas and linseed-lentils. In contrast to Farmer A, much of his produce goes into the bulk commodity market, made possible by building an on-farm separator. He is also seeking to widen the rotation and last year grew lentils for Hodmedods intercropped with linseed to provide scaffolding and weed suppression. Hodmedod's supplied seed and separated the mixed crop on his behalf. Other diversification practices include use of variety mixtures, cover cropping and integrating leys.

4 Discussion and Conclusions

Farmers in the Hodmedod's network are motivated to diversify their cropping systems and are innovating to over come the barriers. Their key motivations include the agronomic benefits of increased resilience to pest, disease and climate shocks. But they are also motivated by a number of other factors – namely the intellectual stimulation of learning and innovating; the economic benefits of niche markets and resilience to economic shocks; and the satisfaction of developing relationships with the value chain rather than selling to the commodity market. Moving from commodity traders to food producers.

The enabling factors include farmer enthusiasm; access to seed, agronomy advice and research support; and assistance with cleaning, storage and transport of small batches. In addition to the processing, packaging and marketing of the crops, Hodmedod's also take responsibility for legal food safety responsibilities (storage, testing and processing - including allergens and mycotoxins) taking this burden away from the farmers. Other opportunities identified and being explored by the farmers in the network include on farm hubs for equipment for management of small batches of novel crops – such as optical sorters, mills and decortication of crops such as buckwheat and millet. Exploration of these practical experiences, the role of new relationships and other enabling factors provides practical insight for future efforts to develop value chains which catalyse crop diversification.

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Chances and barriers of crop and value chain diversification from a perspective of an organic case study in Poland

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1 Introduction

Diversification is the process of introducing new crops and products to provide several independent sources of income for the farm. The current EU agricultural policy aims, among other things, at supporting management methods that ensure adaptation to climate change, market competition and follow consumer trends. Diversification of agricultural production fits in well with these objectives. Nevertheless, various agriculture diversification initiatives still face constraints.

2 Materials and Methods

A questionnaire survey was undertaken to assess the impact of different barriers to diversification. Ten farms whose activity meets the assumptions of the diversification process have been selected. The questionnaire form consisted of three parts: A) Description of the farm/activity, B) Self-assessment of the initiative, C) Dynamics of the development of the initiative. On the basis of the answers received, the key social, organisational and market factors which, influenced the development, success or failure of initiatives were analysed. The two best developed initiatives were interviewed in detail to gain an insight into the development of their value chains and their innovative solutions.

3 Results

The most frequently cited barriers to the development of diversification initiatives included: bureaucracy and frequent changes in regulations, lack of product recognition on the market and too low volume of production. Only two of ten examined farms fully controlled the up and down levels of the value chain, which contributed to their success in the organic market.

4 Discussion and Conclusions

A well-developed value chain is a key for the success of a farm, as well as the way to pass the barriers of diversification. Most farms handle only few links in the chain, so that the added value of the product was acquired outside the farm. Suppliers, processors and intermediaries benefited from this process, while the final price of the product became relatively high for consumers. A well-functioning farm should have control over at least several up and down levels of the value chain. Closing as many links of the value chain as possible on the farm guarantees a higher income, while control of added value should provide a lower final price of the product. Effective measures include: change of a farm model, introduction of processing and storage of the product, direct sale and shortening of the supply chain. The results of the analysis should allow a better understanding of the processes influencing the success of diversification initiatives and the development of support mechanisms for this process.

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Legume land races in short food supply chains – from small-scale farms to urban gastronomy – a Case Study of TRUE Project

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1 Introduction

The urgent imperative for climate adaptation and for enhancing resilience in food production, hand in hand with the increasing demand for healthy, residue-free food from sustainable and reliable/local resources, bring organically grown traditional varieties to the fore. From a slightly different angle, the growing interest for alternative protein resources in food and feed production and also the need to find transition pathways to a sustainable agriculture have put legumes in the focus.

Hungary is outstandingly rich in traditional, local legume-varieties: the Hungarian Centre for Plant Diversity (NÖDIK) stores more than 10.000 different legume varieties, including over 4300 common beans, 1000 lentils and 1100 chickpea variations mostly from the Carpathian basin. Germination potential of the different varieties is being checked regularly and the collection is being refreshed from the replantation on the fields of NÖDIK. Limited information is available, however, on the specific cultivation techniques, physiognomy/behaviour of these land races, and even less on the original/traditional and potential possibilities of use.

We are convinced that traditional legume varieties have great yet unexploited gastronomic and market potential thanks to their varied appearance, taste and nutritional content. However, both the registered growing area and the degree of consumption are rather low in the country – lower than the EU average. Based on a questionnaire survey conducted in 2018, legumes are widely regarded in Hungarian gastronomy as "cheap food". Traditional Hungarian cuisine uses limited legume varieties for a narrow assortment of seasonal (autumn-winter) foods that are rather difficult to digest. Contemporary customers are generally cautious with legumes due to their unwanted physiological effects, such as inflation, while modern cuisine turns towards lighter meals. Origin of legume raw materials used even in top urban gastronomy is not known.

2 Materials and Methods

Recent case study within the frame of TRUE project[1] aims to examine the possibility of (re)introducing and enhancing traditional/heritage legume varieties and land races into premium gastronomy and to reveal the conditions of this re-introduction from the producers' and the market's perspectives. During the 4-year long project, a number of selected traditional Hungarian pulse varieties are being tested in small-scale organic production, processed into different kinds of food products along traditional and new recipes, and tested by gastro-specialists and consumers at various scenes of urban gastronomy.

Cultivation experiments of traditional Hungarian legume land races are based on the genetic resource acquired from the Centre for Plant Diversity. During 2018 altogether 33 land races out of 7 legume species were selected based on stored sample size, information available on cultivation, physiognomy/behaviour of the plant, colour, and size of seed, as well as the site of collection. Five small-scale organic farmers were involved in the cultivation experiments from northern and central Hungary, planting a sub-selection of the 33 varieties. Centre for Plant Diversity acted as a reference site planting all 33 selected varieties. Based on results of 2018, cultivations experiments are being continued in 2019 with the involvement of 9 farmers and 24 varieties - a restricted selection based on last year's experience and with the involvement of new varieties.

[1] https://www.true-project.eu/

Technological descriptions for organic cultivation and on-farm protocols for the selected legume species were prepared by the Hungarian Research Institute or Organic Agriculture. On-farm protocols are being filled by the farmers themselves, with the assistance of the Institute.

Sensory examinations and kitchen tests will be carried out in cooperation with the National Food Chain Safety Authority (NÉBIH), as well as with the involvement of chefs and premium restaurants in 2019 and 2020.

3 Results

The experiment is ongoing, results has not yet been analysed. First results show significant differences between locations/farms and between varieties (especially among common beans).

Organized kitchen tests and sensory examinations will start in 2019. Preliminary directions for premium use may include attractive and edible flowers of the runner bean, chickpea and cowpea, the green stage chickpea and the fresh cowpea pods, respectively.

SESSION 16. VALUING CROP DIVERSIFICATION PRODUCTS

Chairs: Raúl Zornoza (Universidad Politécnica de Cartagena, Spain),
Barbara Pancino (University of Tuscia, Italy)

ORAL PRESENTATIONS

- Moving beyond competition in crop diversification niches
  Speaker: Barbara Koole, University of Amsterdam, The Netherlands
- The up-stream agro-food value chain actors relationship role in crop diversification adoption. A case from the Italian food valley
  Speaker: Eleonora Sofia Rossi, University of Tuscia, Italy
- The role of legume product development and consumption on transitioning towards a nutrition-friendly, sustainable diet
  Speaker: Marta Vasconcelos, Universidade Católica Portuguesa, Portugal
- How do bakery value chain downstream's actors pull farmers to diversify their cropping systems? The Mulino Bianco® Italian brand case study
  Speaker: Lorenzo Fosci, University of Tuscia, Italy

POSTERS

- How are legume crops valued in Europe? Insights from the analysis of several value chains case studies in the H2020 LegValue project
  Presenter: Tiana Smadja, Terres Univia, France
- Seed quality as a basis for successful soybean production in the South-eastern Europe
  Presenter: Svetlana Balesevic-Tubic, IFVCNS, Serbia
- Evidencing the utility of food- and feed-chain diversification: a life cycle assessment of pulse grain (pea, *Pisum sativum* L.) processing by distillation for neutral spirit and high-protein coproduct
  Presenter: Pete Iannetta, The James Hutton Institute, United Kingdom

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Moving beyond competition in crop diversification niches

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1 Introduction

To transform the dominant agro-food regime, which is locked in a specialisation logic, innovation niches supporting crop diversification can play a major role in experimenting, developing and learning. One example is the DiverIMPACTS (DI) project, comprising no less than 25 so-called case-studies in 11 European countries. Within this project, we seek to draw on the ideas and experiences of pioneering innovators to further analyse the agricultural, processing, retail, research and other practices implied in crop diversification, and to support their wider adoption. However, in a variety of case studies, pioneer actors are facing a dilemma between cooperating with other similar actors as part of a strategy to develop the innovation through network formation versus the risk that concurrent actors appropriate the innovation. Our objective is to better analyse the types of competition that could be at stake in such innovation dynamics and explore possibilities for overcoming that dilemma.

2 Materials and Methods

This work is based on interviews carried out with actors of the 25 DI case-studies and will illustrate our results with concrete elements coming from 3 contrasted case-studies we focused on: one in Sicily about hemp production, one in the United Kingdom about local pulses and minor crops; one in Sweden about organic legume crop production and consumption. The data from these case studies consists of a combination of interviews and participant observation. The analysis of a collective workshop organised on this issue in June 2019 with actors of other DI case-studies will also be integrated in the analysis. To analyse the data, we will use concepts from the coopetition literature which examines situations where competitors simultaneously cooperate and compete with each other (Keith & Custance, 2010). We will also integrate insights from transition studies, amongst others in regards to transition pathways (Schot & Geels, 2008), translation dynamics (Smith, 2007), and niche protection (Smith & Raven, 2012; Ulmanen et al., 2012; Ulmanen, 2013).

3 Results

Across the DI case-studies we distinguished different types of competition. In some cases, competitiveness exists around access and ownership of *material resources*, such as food processing facilities (e.g hemp mills in Sicily).

In other cases, competitiveness revolves around *information flows* and *transparency*, in sharing knowledge about growing or processing techniques. For example, actors from the British case faced suspicion when contacting farmers in Brittany (France) who had developed small-scale dehulling of buckwheat. These farmers feared that their knowledge would be appropriated by mainstream actors. From pioneer actors' perspective, sharing information with mainstream actors implies indeed various risks, from "dilution" of the innovation if it gets appropriated too early or too incompletely by mainstream actors to unfairness: while a niche has worked hard to develop an innovation, benefits are lost in favour of a mainstream player. Furthermore, local knowledge gained through developing the innovations could potentially get lost under such circumstances.

Competitiveness can also be of of an *economic* nature, for example when a small-scale local food business promoting new legume crops in Sweden fears losing its market position to a big food company. It can also be *reputational*, when a pioneer is afraid of losing his or her image of being the leader, or detaining the most advanced know-how for making a specific product.

In practice, different types of competition are often combined and can influence each other, for example guarding certain information out of fear for losing a market position. Concrete examples will be provided and analysed for each type of competition.

4 Discussion and Conclusions

A detailed analysis of competition factors and related risks in innovation dynamics is a first step to better support sustainability transitions. The competition-cooperation dilemma may be overcome by developing strategies that make limited adoption less likely or less attractive, in some way or another, and bring mutual benefits to all actors in a win-win logic. However, according to the type of competition at stake, possible solutions differ and will be discussed. This also implies different transition pathways, in which depend on the adoption of niche innovations by regime actors and the manner in which niches relate to wider structures and developments (see Smith & Raven, 2012). For each competition type, we will discuss the potential benefits, limits and suitable scale of transparency, sharing, (em)powering, defining clearly the "rules of the game" in negotiations and the role of reframing the problem to raise new perspectives. This furthers our understanding of translation dynamics between niches and regimes.

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The up-stream agro-food value chain actors relationship role in crop diversification adoption. A case from the Italian food valley.

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1 Introduction

In recent years we are witnessing a gradual but constant process of inversion of trend with the emergence of diversified cultivation systems, due both to the positive effects generated by diversification and to the fact that they naturally bring with them the theme of sustainability to which one is paying great attention by consumers and public policies. Within this context, the agricultural sector is particularly affected by increasing price volatility and supply insecurity due to competition from emerging markets and recent changes in the lifestyle of consumers, more careful to aspects such as food safety and an ethical production. The supply chains are demonstrating their fragility and must increase their resilience and efficiency by also redesigning the balance of power along the value chain.

One of the motivations lies in the large number of producers present upstream with an annexed pulverization of supply and against the high concentration of power in the hands of the last part of the chain, especially raw materials traders, wholesalers and retailers.

To understand how to intervene and how crop diversification can be a useful tool in this necessary process of redesigning, a thorough study of the supply chains and mechanisms of operation and of the relationships of force that have been consolidated over the years is necessary.

Therefore, the purpose of this research is to study the Italian durum wheat-dry pasta supply chains in order to understand the network of present relationships and evaluate the current status and the possible changes that can be implemented through a diversified cropping system based on rotation through wheat, tomato and other minor crops as legumes.

2 Materials and methods

To better evaluate the different phases and relationships between the different players in the Italian durum-wheat-dry pasta supply chain (SC), the study was divided into two steps, involving some of the SC main actors. In a first phase, a series of interviews were conducted with the main figures of some of the most important Italian food companies, involved in decision-making processes concerning R&D, production standards, procurement, processing and distribution. In a second stage, using the information and the results of the interviews, two different Focus Groups (FGs) were structured, one with the farmers and one with the elevators.

3 Results

As a first outcome of the interviews, the gradual but growing attention for consumers to the issue of sustainability emerged. Thus, agrifood companies are interested in considering this issue through different approaches, like certifications and quality standards. A common element that emerged both from the interviews and FGs is the vagueness of the term sustainable, which it is a relevant market problem. From the FGs it clearly emerges, especially from the farmers side, that revenues that do not compensate their effort of producing according to sustainable standards. Thus, a contract can indeed be the point of conjunction of a relationship of mutual trust between the producer and the elevators, guaranteeing benefits from both sides.

4 Discussion and Conclusions

To transform crop diversification, which is practiced due to the greening commitment, into favorable crop rotation a process of support and help for farmers it's required. The actors in the supply chain all agree with the positive effects that this brings to the production system but need recognition in terms of greater added value. The demand for more sustainable products moved by the market has been acknowledged by the agrifood companies which in turn through a cascade process have poured this demand on the farmers, who are increasingly faced with contracts where these practices are required. Producing different crops is at the same time an opportunity and a bet for the farmer who is, in some cases, in new markets with the support of consortia or producer associations. Certainly, as also appeared from the study, one of the solutions could be contracts generated by a horizontal integration of the supply chains, even if it emerged that this link could be too binding given a multi-year perspective. Another non-negligible aspect that could allow the spread of diversification is the support through the incentives deriving from the CAP, in this case a splitting of the sustainability-quality binomial could be functional where the efforts for the former are sustained through "political incentives" while the greater quality is directly paid by the consumers, with a process of revenues return up to the farmer.

The theme of sustainability has become the "engine" of every production process, starting from the cultivation phase, and how this is pursued through different methods including a request for crop rotation given the economic benefits in terms of improving the productivity of fields, as well as the environmental benefit of increasing biodiversity. If the agrifood companies are the first to push in this sense, they are also the first to exercise their power on the upstream actors as much as possible, as emerged from the FGs, indeed the elevators are those who interface with farmers using contracts that fix the standards required by the companies.

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The role of legume product development and consumption on transitioning towards a nutrition-friendly, sustainable diet

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1 Introduction

Current unhealthy and (un)sustainably produced foods pose a global risk, as food production methods are the largest pressure caused by humans on Earth. In current times, legumes are under the limelight due to their environmental and health benefits. Their important role in transforming the currently detrimental diet of western consumers towards a nutrition-friendly diet that is mindful of its environmental footprint has created a momentum for change. Legumes should be part of human diets throughout life, and in the course of food diversification, by the 8th or 9th month of life, may already be introduced into infant feeding. But for effective legume consumption at every life stage, legumes must be available, appealing, affordable and well-known. Also, in order to ripe full benefits of legume nutrition, diversification is key, since legume germplasm has substantial intra and inter-specific variability for numerous nutrients and processing characteristics.

2 Materials and Methods

In scope of work package 3 activities of the TRUE (Transition Paths Towards Sustainable Legume Based Systems in Europe) H2020 project, partners from the public and private sector have been working together towards understanding the European consumer barriers (and motivations) for taking up legumes, to educating consumers on legume palate and health benefits, on developing new legume based foods (that cater to different age segments and audiences), and finally assessing their health impacts via a legume based partial replacement diet. One example of results here demonstrated on the development of novel legume based foods is on the development of new pasta and legume based snacks. Extrusion has been a suitable technology used by IGV for the development of various legume based applications. Therefore, the following different types of extrusion have been applied in the processing of flours from legumes:1. twin screw extrusion (TSE) for the development of various, extremely light, expansive extrudates; 2. planetary roller extrusion (PWE) for the production of gelatinates, from which flakes have been produced by means of flaking and roasting; 3. single screw extrusion for the production of protein-rich pasta variants.

3 Results

Ninety-five collections of legume seeds (two growing seasons) from Solintagro SL were evaluated for their nutritional characteristics. Total protein content was measured, where lupin seeds showed about 10% more protein when compared to the other species; micro- and macronutrients profiles allowed to identify outstanding accessions with higher nutrient concentrations. Sensory analysis of legume based foods has been undertaken within a partial legume based replacement diet, and the sensorial acceptability of different legume based meals was collected, revealing positive health outcomes and optimum acceptance of legume dishes.The resulting extrudates were crispies, nuggets and balls, natural or enriched with flavour carriers. These can be used in protein-rich cereals or as additives for chocolate and bars. Selected ones were successfully tested as meat replacement ingredients for sports nutrition products and as the basis for vegan meatballs, burger patties, cooked meatballs or sauce bolognaise. The flakes (nature or enriched with flavours) can be used pure just like cornflakes, in muesli or with dairy products. The pasta products have been produced in different shapes.

4 Discussion and Conclusions

Here we showcase the developments made by TRUE in this topic, and emphasize the importance of: 1) increasing knowledge transfer on the benefits of legumes to consumers, including sharing health data; 2) support specific programs aiming at maintaining the current momentum of healthy consumption, but with a focus on legumes; 3) develop products that cater to a changing society that is more conscious of the environmental burden of food, but also has less time to devote to food preparation; Based on the resources, the extrudates developed are vegetarian as well as allergen and gluten free. On the one hand this will serve a growing clientele throughout Europe, on the other hand a new product family will be available to the markets.

How do bakery value chain downstream's actors pull farmers to diversify their cropping systems? The Mulino Bianco® Italian brand case study

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1 Introduction

The transition of the European agricultural sector towards sustainability seems to be an ongoing process.

At the same time, farmers are 'pushed' by a regulatory framework more focused on environment issues and 'pulled' by subsidies linked to the adoption of environmental practices supported by policies and supply chain initiatives (Matopoulos et al., 2007). In this context crop diversification is one of the most feasible practices to re-design cropping systems, inspired by agro-ecological principles (Altieri, 1995; Gliessman, 1998). Still, it has not enough diffusion into modern agricultural systems and practices.

From the side of food market demand, consumers pay more attention to sustainability credence attributes perceptible in processed products, especially in long value chains, where it is enhanced by retailers. Following this trend, several food companies had turned their attention to raw material suppliers, investing in branding and/or in certification schemes (Blasi et al., 2017; Lernoud et al., 2018).

Mulino Bianco® is one of the most important Italian bakery brand managed by the Barilla food company. Since 1975, Mulino Bianco® has characterized its communication strategy telling naturalness' icons and carefulness messages about environment and people. In 2017, it launched the "Buongrano" initiative, where the main goal is to increase the biodiversity in agricultural land, in order to obtain within 2020 all supply raw materials certified as "sustainable", following the general company sustainability strategy. To achieve these goals Mulino Bianco® requires to millers, cereal stackers and farmers to reach the compliance to ten rules, following production private standard called "Carta del Mulino" (CdM). Into this standard, two rules involve crop diversification practices adoption. These diversification practices adjust five years crop rotation with three different crop as minimum with two other condition: one of those crop must be a nitrogen fixers crop, and at least 3% of wheat utilized agricultural area, has to be dedicated to flower strips.

The business tool, identified to enhance CdM scheme adoption by the farmers, is a premium price payed for flour produced using wheat cultivated in compliance with crop-diversification rules (CdM).

The aim of the research is to estimate the cost (direct and indirect) of crop diversification practices implemented by farmers within CdM standard. At the same time the research will identify technical, structural and cultural gaps across different areas in Centre-North Italy, for the adoption of this standard by farmers.

2 Materials and Methods

The CdM crop-diversification practices costs were estimated following a methodological approach already used in payments definition for Common Agricultural Policy (CAP) agro-environmental- climate measures. EU guidelines suggest to define the amount of compensative payments as all or part of the additional costs and income foregone, resulting from the commitments made.

Considering the two above mentioned CdM rules, the analysis was applied to regions of Centre-North Italy where the soft wheat is commonly cultivated. This procedure identifies per hectare gross margin delta between the CdM crop diversification practice adoption and business as usual scenario at province level (NUTS3), following four methodological steps:

i) identification of ordinary crop rotation, using National Statistical Office (ISTAT) data for 2013-2017 period on arable land use;

ii) identification of suitable crop rotation in compliance with the rules of the CdM at province level following a ordinary arable land crop distributions.

iii) estimation of gross marketable production (GMP) and cultivation costs (CC) for ordinary and CdM cropping assessment, using respectively annual commodities prices available on National Agricultural Information System (SIAN) dataset and technical data carried out from Regional Agricultural Agencies; iv) identification of gross margin ranges variation per hectare (ΔCdM %) due to CdM Rules adoptions, for each province, following formula (1), in two different scenarios: whit and without soft wheat premium price

$$(1)\ \Delta \text{CdM}\ \% = \frac{(\text{GMP}_{\text{Cdm}} - \text{CC}_{\text{Cdm}}) - (\text{GMP}_{\text{Ord}} - \text{CC}_{\text{Ord}})}{(\text{GMP}_{\text{Ord}} - \text{CC}_{\text{Ord}})}$$

In first scenario we assume a hypothetical 10€/ton premium price, paid to wheat growers in compliance with CdM rules adoption.

To validate this method a direct survey with 26 farmers (adopters) involved in the initiative have been carried out. For the farms the gross margin range variation has been identified following the real arable land crop distribution.

3 Results

Data processing allowed to identify the cost and revenue for CdM crop diversification proposed for farms located in the Mulino Bianco® supply target Italian northern Regions. The results show evidences about territorial differences (Desk data analysis) and the related accounted "farm effort" (Adopters primary data analysis) request to apply the same crop diversification practices (Table 1).

Table 1 - Gross Margin variation per hectare "Δ CdM %"

	Desk data analysis				**Adopters primary data analysis**			
Regions	**no premium price**		**10 €/t premium price**		**no premium price**		**10 €/t premium price**	
	min	max	min	max	min	max	min	max
E. Romagna	-4,6	-1,3	0,4	2,5	-5,5	-0,1	0,6	8,5
Lombardia	-7,2	-0,7	-2,1	4,3	-2,5	-0,2	0,3	5,5
Piemonte	-22,6	-1,9	-21,8	0,3	-5,3	-0,6	1,5	12,9
Veneto	-8,2	-2,0	-3,5	0,3	-3,5	-1,7	2,9	7,2

Furthermore, in case of productive specialization based on high-income crops it has been found the lowest diversification costs only if the usual crop rotation scheme does not change in CdM adoption scenario. Those results seem to suggest that the introduction of not common crops in ordinary farm cropping systems affect the land profitability more than flower strips management.

4 Discussion and Conclusions

Looking at the preliminary results to support crop diversification adoption in CdM farms, a new business model should consider the possibility to define different premium price ranges as well as other not financial benefits like technical support appropriate to raw material provisioning areas features. Results show that to increase the numbers of adopters the Mulino Bianco® supply managers have to taking in to account the heterogeneity of pedoclimatic and farm productive structures across regions.

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How are legume crops valued in Europe? Insights from the analysis of several Value Chains case studies in the H2020 LegValue Project.

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1 Introduction

Currently, the EU agro industry is characterized by a self-sufficiency in cereals and a massive import of soybean, as a result of several self-reinforcement mechanisms that lock in this system (Meynard *et al.* 2013, Magrini *et al.*, 2015), which have relevant consequences in terms of costs and environmental impact. While scientific knowledge on legumes has been until now concentrated on a small number of species and crop management strategies, H2020 LegValue project aims to provide knowledge on a large range of legume species and cropping systems, together with their expected performances, thus offering great potential for locally-adapted crops for the very wide variety of agricultural conditions in Europe.

The introduction of a legume species in the crop sequence by farmers is highly dependent on the other actors of the chain (Meynard *et al.*, 2013; Magrini *et al.*, 2016), either upstream (such as breeders who offer adapted cultivars) or downstream (such as feed or food industry, which can valorise the harvested products). The organisational design of supply chains also determines the way added value is shared (Fares *et al.* 2012). The institutional framework (collective rules, norms and standards) has also a strong influence in the innovation capacity of legume sector actors to create new value sources (coming from process or product innovations).

Thus, to increase the cultivation of legumes, new outlets with higher added value based on these crops need to be identified. There is also a need to better share the added value in the legume supply chains and to promote institutional changes to optimise Europe's access to supplies of plant protein based on legumes and to foster innovations in legume value chains. For this, a prior diagnosis of existing legume-based value chains is essential. It helps not only to point out the main bottlenecks encountered by stakeholders dealing with legumes but also some levers to focus on for legume-based value chains development.

2 Materials and Methods

The value chain analysis is built on 27 case studies managed by LegValue partners. Each case study represents a legume-based value chain. The case studies cover the ten countries participating to the project (France, UK, Italy, Portugal, The Netherlands, Denmark, Switzerland, Lithuania, Latvia, Germany) and 8 legume species (pea, faba bean, soybean, chickpea, lentil, alfalfa, lupin, and mix of species).

To collect data on these case studies, a qualitative survey on stakeholders along the value chains has been conducted from January to September 2018. 127 interviews have been realized with 9 different stakeholders' types (farmers, collectors, processors, technical advisors, input suppliers, traders, end user processors, end user retailers, seed producers).

For the value chain analysis, the collected data were analysed through a multiple correspondence analysis (MCA) on 30 qualitative variables to get a typology of value chains. Indeed, it provides a general overview of our case studies sample as well as a comparative analysis of the associated value chains. Moreover, the data were cross analysed to characterize behaviours, strategies and perceptions of stakeholders in each type of value chain. This is to help to understand the main differences between the different value chain types.

3 Results

Our value chain analysis produces three main results.

- The MCA classifies 27 cases studies into 4 clusters (Figure 1), each cluster constituted by cases studies with similarities between them. Thus, each cluster corresponds to a value chain type with well-identified general characteristics.

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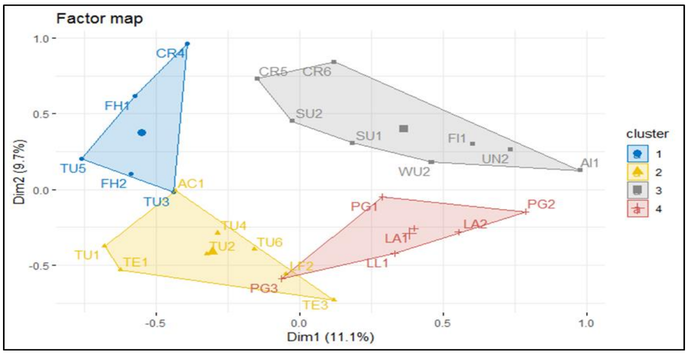
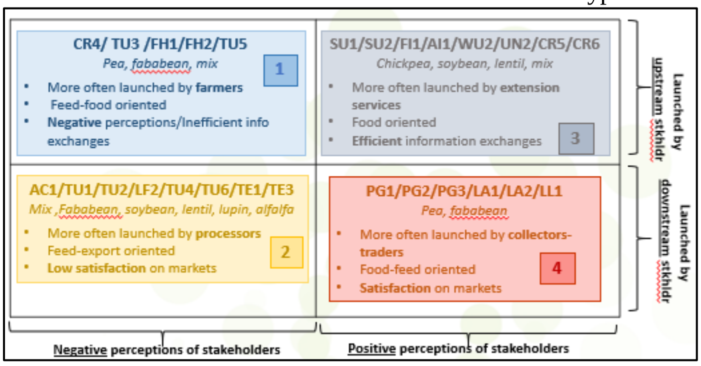


Figure 1. The four value chain clusters obtained from MCA

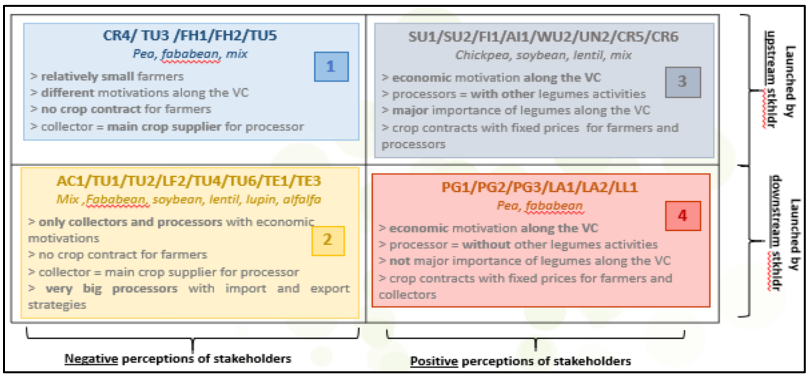
- Each value chain type is characterized by the stakeholder type who launched the value chain, the main outlet (feed or food) in the value chain and the general perceptions of the stakeholders on the general context of legumes business (Table 1). Thus, the first value chain type deals with pea and faba bean and it has been more often launched by farmers. Stakeholders are food or feed oriented, and they have negative perceptions on the legumes business context. The second value chain type has been more often launched by processors with no distinction of the treated legume species. Stakeholders have also negative perceptions on the legumes business context and are more often feed oriented. The third value chain type dealing with pulses and soybean has been more often launched by extension services. Stakeholders are exclusively food oriented and have positive perceptions on the legumes business context. The fourth and last value chain type dealing with pea and faba bean has been more often launched by collectors and traders. Stakeholders are food or feed oriented and have positive perceptions on legumes business context.

Table 1. The main characteristics of each value chain type



- The main differences between the four value chain types are based on specific practices, strategies or perceptions of their respective stakeholders mainly about their practices on contract, their motivations for dealing with legumes and theirs links with each other (Table 2).

Table 2. Some practices/strategies/perceptions of stakeholders



Thus, in the first value chain type farmers are relatively small. Motivations for dealing with legumes are different along the value chain: agronomic motivation for farmers, alimentary motivation for processors, economic motivation for collectors). And farmers are not involved in crop contracts with processors, as collectors are the main crop suppliers for these latter. In the second value chain type, stakeholders' motivations are also different: only processors and collectors have economic motivations for dealing with legumes, the farmers have agronomic ones. The processors are very export oriented and work mainly with collectors for their legumes provisioning. In the third value chain type, economic motivations are shared by all stakeholders. The processors are strongly involved in the value chain and work directly with farms for their provisioning through crop contracts. And in the last value chain type, all stakeholders have also economic motivations for dealing legumes and farmers work closely with collectors through crop contracts. Contrary to processors in the third value chain type, those in the last one are not very strongly involved in legumes activities.

4 Discussion and Conclusions

Four distinct ways to value legumes in Europe have been identified by our case studies analysis. Among these four ways, two are opposite. These are associated to the first value chain type and the fourth one, both dealing with pea and faba bean considered as the main legume species. Because in the first value chain type stakeholders have negative perceptions on legumes business and in the fourth one, stakeholders have positive perceptions on legumes business, it can be suggested that the fourth value chain type is a success model for pea or faba bean value chain. Another stimulating result is that the other value chain type whose stakeholders have positives perceptions is the third one which is food oriented, launched by extension services and on pulses and soybean. By illustrating the current interest on legumes for food, it can be considered as the second success model for legumes value chain, and particularly for pulses and soybean for food. Some key success for legume-based value chains have been highlighted: 1/an economic development project shared along the value chain, 2/ a strong involvement of farmers in the legumes valuation along the value chain (by contractualisation), 3/ the same importance given to downstream markets and upstream markets at the value chain level. Thus, better economic performances of the legume-based value chains would enhance the use of legumes in crop diversification.

Acknowledegments

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Seed quality as a basis for successful soybean production in the South-eastern Europe

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1 Introduction

One of the most challenging decisions in agricultural production is variety selection. This decision should be based on agro-ecological conditions in the production area and type of production, yield, protein content, etc. However, low-quality seed of the best variety can have low yield, whereas high-quality seed of the variety with less performance, at the end, can have higher yield. This confirms that the seed quality is significantly important, because it determines the success of the harvest. Seed of plant species is a complex biological system depends on various external factors, which cannot be predicted and planned in advance. Production technology applies various methods of seed quality improvement in order to enhance seed germination, and other seed properties. Seed quality improvement can reduce the effect of seed aging, as well as the effects of various stress factors. The IFVCNS therefore applies various methods for improving the quality of soybean seed.

2 Materials and Methods

Pulsating electromagnetic waves - The seed was exposed to pulsed electromagnetic field (PEMF) using the impulse generator and strip. Low frequency (16, 24, 30 and 72 Hz) PEMF in the duration of 0, 30, 60 and 90 minutes were used. Immediately after exposure of the seed to PEMF, sowing was carried out at optimum time. After sprouting, seedlings were counted to determine the percentage of germinated seeds.

Priming of seed - To determine the impact of seed priming on germination in the presence of NaCl, seeds were immersed into different solutions: potassium nitrate - KNO3 (1 %), ascorbic acid ASA - (100m g l-1) and potassium chloride - KCl (1 %). After 6 h (Miladinov et al., 2015) seeds were washed out with a jet of distilled water and dried at 25 °C up to moisture content of 10-11%. Salinity was imposed by addition of NaCl to the distilled water which was added during germination, in the following concentrations: 0 (control), 50, 100, 200 mMNaCl. Also, at optimum temperature -25° C and low temperature -10° C. Seed germination results were read daily and seed germination was defined by protrusion of the radical by at least 2 mm. Germination was recorded after 8 days.

Aging of seed and vigor - The seeds were placed in metal dishes, on metal sieve into water bath at 42 °C, and relative humidity of 100%. Testing was performed after three and five days, in four replications. Natural aging: Seed was stored in two ways. 1) seed was kept in cool chamber (controlled conditions) at 4 °C and relative humidity of 80 to 85%, 2) seed was kept under conventional storage conditions (uncontrolled conditions). Testing was performed after six and 12 months of storage.

The seed was kept in two ways:
1) in a cool chamber (controlled conditions) at 4°C and relative humidity 80-85%
2) under conventional storage conditions (uncontrolled conditions).

Testing was performed after storage for 6 and 12 months.

Hiltner test: 4 × 50 seeds were placed onto moistened sand, and a 3 cm layer of cracked brick (previously sterilized and moistened) was placed upon them. Incubation period under optimal condition lasted for 10 days.

Cold test: 4 × 50 seeds were placed onto moistened soil (up to 40% of field capacity) at 5-8°C for seven days, and afterwards placed in a germination chamber at 25°C for four days.

3 Results

Pulsating electromagnetic waves - The effect of pulsating electromagnetic waves on seed quality depends on the frequency and duration of exposure. Finding the proper combination is necessary to achieve a positive effect. In our research, the application of pulsating electromagnetic waves has increased seed germination in field conditions up to 8%. Such significant increase is a good basis for introducing this cultivation technique, primarily in organic production where the application of seed treatment is very restrictive according to Law of Organic Agriculture.

Priming of seed - Our research has shown that, as the level of salinity increases, the effect of seed priming as a pre-setting measure is increased. On average, when saturated with 50 mMNaCl, germination of primed seed increased by 6%, while saturated in 200 mMNaCl, the increase in germination of primed seed was 9%. Also, reduction of seed germination is a common occurrence at lower temperatures due to disruption of cell structure, reduction of enzymes activity, as well as reduction of respiration and transporting electrons processes. Results of our investigation pointed out that seed priming reduced the negative effect of low temperature on seed germination. At the temperature of 10°C, germination increased by 13% compared to the results obtained under optimum soybean germination temperature.

Aging of seed and vigor - Extreme conditions such as 40 °C and 100% of relative air humidity caused some biochemical changes in seed as well as reduction in seed germination. After three days of accelerated aging, obtained seed germination was on the level of six-month naturally aged seed germination, both under controlled and conventional storage condition. Seed germination after five days of accelerated aging was the same as the germination of seed stored for 12 months under conventional storage conditions. The highest difference in vigour of soybean aged seed and control was found after application of cold test. Tested soybean genotypes had initial seed germination 89.7%. The obtained results showed that soybean was significantly more sensitive to the duration of storage. The obtained results showed that soybean was significantly more sensitive to the duration of storage, as well as to storage conditions. Decrease in germination of soybean genotypes after six months of storage (soybean 81.0%), and under conventional conditions (soybean 76.8%).

4 Discussion and Conclusions

Pulsating electromagnetic waves - Besides physical and chemical methods, pulsating electromagnetic radiation is also applied in seed treatment. The effect of these methods is based on changing the course of some physiological and biochemical processes in the seed, which leads to an increase of vigor and improved growth and development in the stage of plant emergence.

Priming of seed - Seed priming is a common procedure in seed processing technology. It affects the metabolic activity of seed before the emergence of seedling root, and generally improves germination and seedling performances. Beneficial effects of this practice are primarily obtained under unfavourable environmental conditions, such as high salinity and low temperature. Increased salt concentration in soil solution can lead to a number of changes in plant metabolism as well as nutritional disorders. Although it affects all stages of plant growth, seed germination and initial growth are the most sensitive in most plant species.

Aging of seed and vigor - Better understanding of seed aging processes enables improvement of seed storage conditions, which is important not only for seed production, but also for the storage of high-value seed for breeding purpose and gene banks. Seed aging, both artificial and natural, stimulated various biochemical processes during seed storage. In our research, the aging of seeds, both artificially and naturally, caused the occurrence of various biochemical processes. The results showed that the degree of damage and the ability of the seed to resist the negative effects of aging depended on the length of the aging period, the way of seed keeping, and of the seeds characteristics of examined varieties. Cold test provides data on seed viability even in very adverse germination conditions, which gives better insight into seed behaviour during field emergence. Hiltner test imposes a physical stress on the seed, predicting seed emergence capacity under conditions of soil crust formation. Seed vigour declines first as seed deteriorates, followed by loss of germination and viability. The highest difference in vigour of soybean aged seed and control was found when cold test was applied. Cold test is the most reliable test for assessing aged seed viability and seed reaction under field emergence conditions.

Soybean seed is the subject of various experiments at the IFVCNS. This is because seed production is the base of successful plant production. The seed is the primary factor of high yield food production and supply, the basis for gene preservation for future breeding. Our main conclusion is: "The seed is starting point of everything – food and feed".

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Evidencing the utility of food- and feed-chain diversification: a life cycle assessment of pulse grain (pea, *Pisum sativum* L.) processing by distillation for neutral spirit and high-protein coproduct

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1 Introduction

Neutral spirit (alcohol) production using peas (*Pisum sativum* L., a pulse crop) provides a novel pilot study for the up-scaling of pulses in agri-food- and feed-systems. This is due to the large-scale production and potential profitability of the main product and high protein co-product called 'pot-ale', which is a liquid 'waste' containing carbohydrate, spent-yeast, protein and minerals.

2 Materials and Methods

We tested alcohol production from pulse starch for global mitigation potential in terms of climate-change offset and nutrient-loss reduction. This was done by undertaking an attributional and expanded boundary life cycle assessment (LCA) of gin production from wheat or peas (Figure 1).

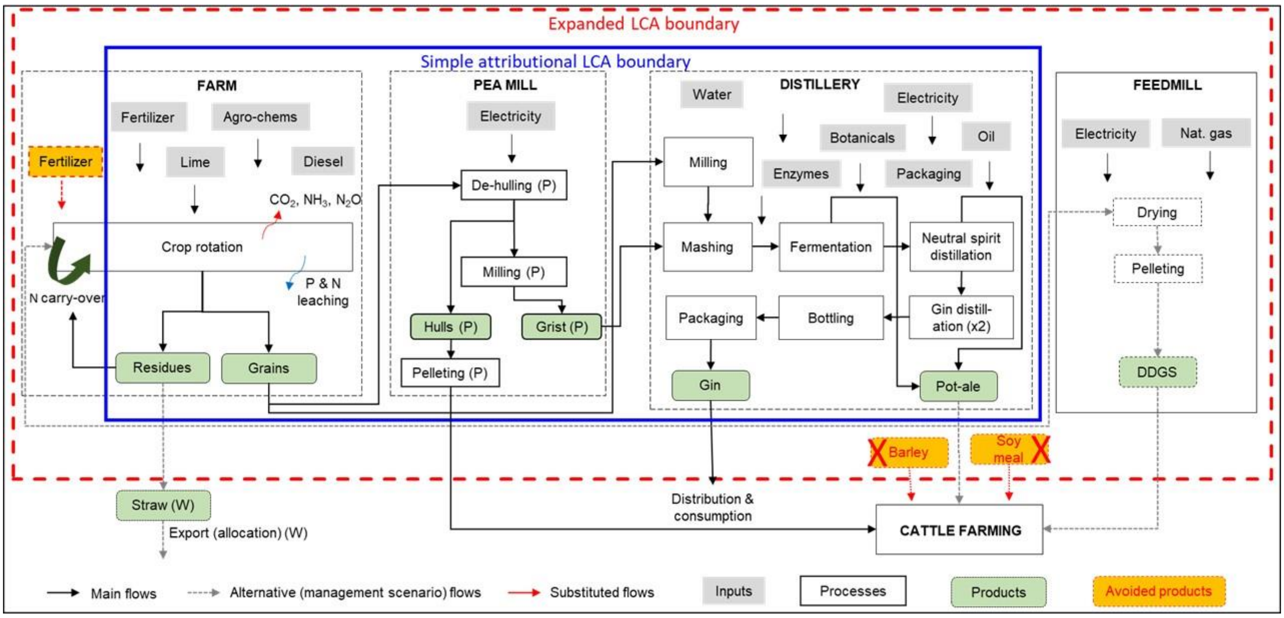

Figure 1. Illustrates the main processes and inputs accounted for the within simple attributional and expanded LCA boundaries. Flows show processes for wheat-(W) or pea-(P) gin, including substitution of soybean meal and barley for cattle-feed with pea hulls and dried distillers' grains with solubles (DDGS) isolated from pot-ale. Pot-ale may alternatively be treated as a "waste" in simple attributional LCA or considered to replace fertilisers following land spreading within expanded boundary LCA.

3 Results

Allocation of system burdens between gin and animal feed co-products indicated that gin produced from peas had a smaller environmental footprint than gin produced from wheat across 12 of 14 environmental impact categories (Figure 2). Global warming, acidification and terrestrial eutrophication burdens of pea were all less than that of wheat gin. However, land occupation was approximately two times greater for pea gin compared to wheat gin, due mainly to the comparatively low pea (starch) yields.

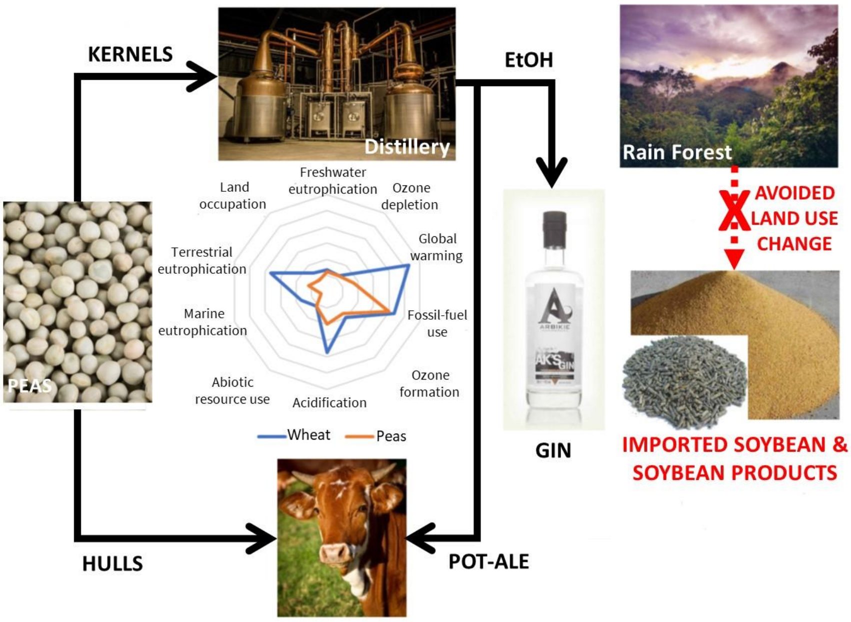

Figure 2. A graphical abstract which illustrates in simple terms the main findings of the analysis for wheat- compared to pea-gin, and the various impact categories assessed. It also shows uses of the main products and co-products of peas and for pea-derived gin. Pot-ale is defined here as, 'dried distillers grains with solubles' (or DDGS). For full details see Leinhardt *et al.* (2019) and Styles *et al.* (2019).

4 Discussion and Conclusions

Animal feed substitution using co-products increased the calculated environmental advantage of pea gin overall, owing to larger amounts of protein contained in co-products. Enhanced soybean meal substitution from use of peas in alcohol production could reduce Europe's protein deficit whilst potentially avoiding deforestation in Latin America, leading to net avoidance of CO_2 eq. for every L gin (or neutral spirit) produced.

Land areas potentially spared from soybean meal production partially offset the greater direct land requirement for pea gin. However, full consequential LCA should be applied to account for the detailed farm and landscape changes (*e.g.* cropping sequence, potential cultivation in Ecological Focus Areas) associated with increased cultivation of legumes within conventional (cereal dominated) rotations.

Acknowledgments

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SESSION 17. TOOLS TO DESIGN, MANAGE AND MONITOR DIVERSIFIED SYSTEMS FROM THE FIELD TO THE LANDSCAPE LEVELS

Chairs: Frédérique Angevin (INRA, France),
Christine Watson (Scotland's Rural College, United Kingdom)

ORAL PRESENTATIONS

- Modelling crop-weed canopies as a tool to investigate the role of crop diversification in agroecological cropping systems
  Speaker: Stéphane Cordeau, INRA, France
- The DiverIMPACTS set of indicators for the sustainability assessment of crop diversification
  Speaker: Stefano Canali, CREA, Italy
- SYSTERRE®, an online tool to describe diversified cropping systems, to calculate their performances, and assess their sustainability
  Speaker: Clotilde Toqué, ARVALIS, France
- Current dominant crop sequences across EU: a typology based on LUCAS dataset
  Speaker: Rémy Ballot, INRA, France
- Integrated assessment and modelling of the impacts of cropping system diversification from field to landscape and agro-chain levels: the MAELIA multi-agent platform
  Speaker: Rui Catarino, INRA, France
- Assessing area suitable for diversification crops: an example on soybean in Europe under climate change using machine learning
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DiverIMPACTS
European Conference on Crop Diversification
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Budapest, Hungary

Modelling crop-weed canopies as a tool to investigate the role of crop diversification in agroecological cropping systems

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1 Introduction

Crop diversification, both in time and in space, is considered to be a major component of agroecological pest management. Process-based weed dynamics models are valuable tools to (1) synthesize knowledge on crop diversification, (2) apply this knowledge to cropping-system design and (3) transfer research-based knowledge to stakeholders because (4) weeds are the most harmful pest in arable crops and must be managed at the rotation scale, and (5) crop-weed interactions are similar to crop-crop interactions in crop mixtures and crop rotations. The present paper illustrates these five items with the FLORSYS model.

2 Materials and Methods

The FLORSYS model is a virtual field for which the user enters a list of cultural operations lasting for several years (crop succession including cover crops and crop mixtures, all management techniques), together with daily weather data, soil characteristics and a regional weed species pool. These inputs influence the biophysical processes occurring in the field at a daily time step. FLORSYS focuses on processes leading to (1) plant emergence and establishment of crop and weed species with different ecological requirements (which allows for crops sown in different seasons and in mixtures where timing often determines the fate of a species), (2) the functioning of heterogeneous crop-weed canopies including diverse plant ages, morphologies and shade responses (as in crop mixtures), and (3) a carryover effect on future cropping seasons (which is essential for crop rotations). The detailed biophysical model outputs, which are essential to understand why a given technique or cropping system results into a certain performance, were aggregated into indicators of crop production and weed services and disservices to simplify the multicriteria comparison of cropping systems. To synthesize knowledge even further, FLORSYS was used as a huge virtual farm-field network, and the resulting simulation outputs were aggregated with random forests into an empirical model (called DECIFLORSYS), which can be used as a decision-support system. A series of case studies with data from different regions, cropping systems and stakeholders illustrate how these models can be used to evaluate and promote the benefits of crop diversification, by (1) identifying crop ideotypes for agroecological weed management, (2) tracking crop-diverse solutions in virtual farm-field networks, (3) *ex ante* evaluations of crop-diverse solutions proposed by experts and stakeholders, and (4) participatory workshops with farmers.

3 Results

The simulations showed that the crops with the lowest yield loss due to weeds over all tested regions and cropping systems were wide, shading and flexible: compared to high-loss crops, those with a low yield loss presented a larger plant width per unit biomass in unshaded conditions, reduced leaf thickness to increase leaf area, particularly from flowering onwards, and etiolated when shaded by neighbour plants, with taller plants per unit plant biomass and even thinner larger leaves [1].

A virtual farm field network based on farm surveys was simulated to determine which cropping systems allow reconciling low yield loss due to weeds with low herbicide use [2]. Three such cropping-system types were identified: maize monocultures and two systems based on crop diversification, both in time (different species in the rotation, both winter and summer crops, sometimes temporary grassland) and in space (with crop mixtures or cover crops during summer fallow), combined with well-reasoned tillage (stale seed bed, occasional ploughing).

Table 1. Weed impact on biodiversity and crop production in Integrated Weed Management (IWM) strategies simulated with FLORSYS and averaged over 30 years and 10 weather repetitions. In each column, cells were coloured from green (the best performance) to red (the worst performance) for crop diversity, weed services and crop production, and vice-versa for weed disservices. Numbers of a given column followed by the same letter were not significantly different at p=0.05 [3]

Cropping system§	Crop diversity over 12 years			Herbicide use (TFI$)	Yield (MJ/ha)		Weed impact			
	Number of species and cultivars	% winter crops	% years with cover crops				Yield loss		Bee food	
Reference	4	100%	8%	1.6	63563	C	50.9	D	2.30	B
IWM-simplified	18	77%	39%	1.7	51067	ED	58.4	C	2.42	B
IWM-intermediate	10	63%	8%	0.8	54443	D	55.3	DC	2.74	A
IWM-complete	8	55%	0%	0.7	67402	BC	40.9	FE	2.05	DC
IWM-no herbicides	12	63%	16%	0	69077	BC	50.5	D	2.10	C

§ Scenarios were simplified (no plough, little tillage, no mechanical weeding, herbicides), intermediate (plough, tillage, no mechanical weeding, herbicides), all (plough, tillage, mechanical weeding, herbicides), no herbicides (plough, tillage, mechanical weeding, no herbicides). $ Treatment frequency index, 1 means one product per year at full dosage over whole field area.

FLORSYS can also be used to evaluate cropping-system prototypes proposed by scientists or farmers in participatory workshops. The example of Table 1, for instance, shows that the system with the best performance in terms of yield, yield loss and herbicide use presented a high crop diversity in terms of species and cultivar numbers, sowing season and cover crops (IWM-no herbicides). A high species/cultivar number and cover-crop frequency was though not enough to ensure production if it were not accompanied by alternating sowing seasons and tillage (IWM-simplified). Moreover, crop diversity does not necessarily ensure weed services, as demonstrated by the low weed-based bee-food offer in the IWM-no herbicides system.

In participatory workshops, the decision-support tool DECIFLORSYS allowed an instantaneous evaluation of the cropping system designed by the farmers (data not shown), whereas as the slower FLORSYS was used outside workshops to determine the causes for the success or failure of the proposed management solutions. The workshops resulted in major take-home messages on crop diversification for both farmers (e.g., evaluate crops at the rotation scale, weather and inadequate crop management can cancel out diversification benefits, weed floras do not disappear but change) and scientists (e.g., farmers need biophysical explanations of cropping system performance).

4 Discussion and Conclusions

These studies demonstrated that the benefits of crop diversification for weed management depend on the production situations and cropping systems and thus the need for flexible rules on crop diversification and the usefulness of models such as FLORSYS to establish these rules.

Acknowledgements

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The DiverIMPACTS set of indicators for the sustainability assessment of crop diversification

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1 Introduction

Crop diversification is a key lever to increase and promote the sustainability of agro-food systems. In fact, crop diversification in field and along the rotation can satisfy simultaneously the need to produce different outputs, to enhance ecosystem services and to reverse in a long-term perspective the trend of specialization imposed by industrialized agriculture (Kremen et al., 2012). Nonetheless, there is still a lack of knowledge on the potential synergies and trade-offs resulting from the implementation of different crop diversification strategies. These effects have to be accurately evaluated to avoid introducing new problems in the system. Among the different proposed approaches for the sustainability evaluation, multi-criteria assessment (MCA) methods are increasingly gaining importance in agriculture. MCA should cover a wide range of criteria and elements suitable to capture the effects of crop diversification, including long-term ecosystem integrity, total resource flow, nutritional and health outcomes, livelihood resilience, and economic viability. Accordingly, the DiverIMPACTS project (https://www.diverimpacts.net/) settled a novel, updated set of indicators sensitive to crop diversification and embedded in a framework specifically developed to assess the overall sustainability of diversified agro-food systems at different scales including field, groups of fields, farm, territory, and value chain. The aim of this work is to describe how the DiverIMPACTS assessment framework was developed and to present the identified indicators that will be used for the evaluation of the economic, social and environmental sustainability performances of the diversified cropping strategies implemented in 25 Case Studies (CSs) selected by the project and located across Europe.

2 Materials and Methods

The new framework was designed integrating top-down and bottom-up approaches in order to integrate the point of view of both researchers and stakeholders.

The top-down approach was addressed referring to the hierarchical structure of FAO-SAFA framework (FAO, 2013) that was used to identify *a priori* a list of criteria and potential indicators considered relevant and sensitive to crop diversification by researchers. Criteria and indicators were selected by the project scientific community taking into account the evaluation of potential synergies and trade-offs, to avoid biased assessment results, and preventing redundancy that could increase the difficulty of result interpretation and data collection (Van Cauwenbergh et al., 2007). In order to integrate the perspective of stakeholders and local communities, actors of the CSs were involved through several workshops and surveys in the identification of aspects and measurements considered relevant for the sustainability assessment of diversified agro-food systems. These issues identified with the support of the actors were matched with the SAFA framework and a final agreed set of "essential" indicators covering the three sustainability pillars (economic, environment, and social dimensions) was established. The final indicators were designed and identified according to the feedbacks received by the CSs, in particular on data availability to avoid potential constraints, and considering the following further aspects: scientific relevance, feasibility, indicator type (causal or effect indicators; Bockstaller et al., 2015), spatial and temporal scale, adaptability in a wide range of regional conditions.

3 Results

The framework incorporates 19 criteria and 29 performance indicators (8 for the economic pillar, 19 for environmental sustainability, 2 for social dimension). The indicators were designed and adapted to encompass the whole rotation using the length of the rotation as temporal scale and, when possible, averaging the results on the number of the years of the rotation in order to capture the carry-over effects of the diversified cropping systems over several years.

Table 1. DiverIMPACTS assessment framework

Criteria	Indicators
Productivity	Energetic yield (EY); Land Equivalent Ratio (LER)
Stability of production	Yield Coefficient of Variation (YCV)
Profitability	Average gross margin at rotation level (RGM)
Dependency on external inputs	Total input/turnover (DEI)
Product quality	Product standard quality required by the sector/market (PSQ)
Local valorisation	Short food supply chain and local distribution (PSC); Supplier/customer contribution to profitability (SCCP)
Ecosystem/landscape Diversity	Crop Diversity Index (CDI); % Semi Natural Habitat (%SNH)
Crop diversification	Crop Diversity Index (CDI); % Legume in rotation (LEG)
Genetic diversification	Crop-cultivar diversity (CCD); Number of crop in the rotation with cultivar mixture (CCM)
Soil degradation	Proportion of crops harvested in wet conditions (NWHC); Bare soil during erosion risk or drainage periods (BSO)
Soil quality	C input during the rotation (ACI)
Water withdrawal	Relative available water remaining (RWAR)
Water quality (nutrient)	Surface nutrient balances (NBAl and PBAL); Bare soil during erosion risk or drainage periods (BSO)
Water quality (pesticide)	Amount of leachable active ingredient (LeachAI); Amount of active ingredients (QAI)
Air quality	Amount of volatile active ingredients (VolAI); Amount of active ingredients (QAI)
GHG balance	Mineral Nitrogen Use for GHG balance calculation (MNUGHG); Nitrogen Use (NU); Total fuel consumption at farm level for global warming potential; C input during the rotation (ACI); Global warming potential from total fuel consumption (FCFGHG)
Non-renewable resources	Total fuel consumption at farm level for fossil energy use calculation (FCFNRJ); Mineral Nitrogen Use for fossil energy use calculation (MNUNRJ); Mineral Phosphorus use (MPU)
Famer and public health	Treatment frequency index (TFI)
Farmers' quality of life	Work overload (WOL)

4 Discussion and Conclusions

This set of indicators has to be considered as preparatory elements needed to adapt existing multi-criteria assessment tools to better take into account benefits and drawbacks brought by crop diversification in terms of technical and economic performances as well as social and environmental services. To establish whether indicators satisfy these needs and to validate the results obtained by the new assessment framework, some CSs are currently being used as pilot to test them. After the validation, the new set will be applied for monitoring sustainability performances of all the 25 CSs located across Europe.

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SYSTERRE®, an online tool to describe diversified cropping systems, to calculate their performances, and assess their sustainability

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1 Introduction

Agriculture has to succeed in reconciling many different challenges, as food production, energy production and conservation of the environment. This requires a shift towards new production systems, based on ecological intensification, adapted to local conditions, and easily manageable by farmers. Crop diversification (CD) in annual crops is expected to provide clear benefits at farm, value chain and territory levels (Kremen *et al.*, 2012). CD is studied as a major solution in the European Project DiverIMPACTS (https://www.diverimpacts.net/). The promotion of crop diversification at farm scale involves to describe innovative diversified cropping systems but also to assess their technical performances as well as their sustainability toward economic, social and environmental pillars. To this aim, Systerre® software has been chosen to characterize and evaluate the systems implemented in the 25 case studies (CS) and 10 long term experiments (FE) of the project. In this paper, we focus on the description of the tool and its capacity to reconcile the different needs of the project.

2 Materials and Methods

Most of tools assessing performances in agriculture are designed to evaluate practices on a yearly basis and focus only on few criteria, which could not provide an overall view of the sustainability of the cropping systems that include these practices. In addition, they are not designed to store describing data (practices, equipment, prices…). To address this issue, the Systerre® software was designed in 2008 by Arvalis[1]. It helps in describing cropping systems and farm characteristics and allows calculating simultaneously a wide range of technical, economic and environmental indicators (Jouy *et al.*, 2018). The results from Systerre are used in two main cases: i/ to build advice for farmers, to exchange with them on their practices and propose alternatives (Jouy *et al.*, 2011); ii/ for the monitoring of long-term experiments (Toqué *et al.*, 2011). Its scope covers arable crops, mixed crop and livestock systems as well as arboriculture and agroforestry. Systerre® is widely used in France by advisors, economic organisations and several technical institutes (which are involved in its development since 2017).

Within DiverIMPACTS project, Systerre® has been chosen to collect all the data related to the field (FE) and farm (CS) experiments in a common perennial database allowing to demonstrate the benefits of CD at these scales. Before this choice, we have checked the possibility 1/ to describe all the cropping systems studied in the project – (arable and vegetable crops), 2/ to describe the three types of diversification, *i. e.* rotation, intercropping and multiple cropping, 3/ to use it in production contexts over Europe (e.g. while adapting reference databases for pesticides, commodity prices, equipment) 4/ to calculate the minimal set of sustainability indicators proposed by the project (See Canali et al., in these proceedings).

Systerre® is accessible on a Webserver with secure access. It uses of a PostgreSQL DBMS to allow networking and interoperability with other databases and tools. Several forms are available to describe the farm (farm equipment, plots and their surfaces, workforce), to record by crop and per year practices and to inform economic data, and technical results (yield, quality). Systerre® calculates a set of 20 standardized indicators (Guillaumin *et al,*. 2007) that can be detailed into 50 secondary indicators. Indicators are calculated

[1] French technical institute on arable crops

from the recorded information and internal databases and made available in the form of dashboards (i.e. without aggregation or ponderation) by plot, by crop and by cropping system(s).

3 Results

Systerre® was initially designed to be adaptable to many situations. Most of the indicators used in the minimal set to evaluate CD in the arable systems are already accessible through Systerre® (Table 1). The missing one will be introduced in the software to facilitate the monitoring over the project.

To represent multiple cropping and intercropping, users are now required to create sub-plots within the parcels and then to allocate each practices to each crop to allow indicators calculation and the output representation. DiverIMPACTS results will allow to simplify the data entry by providing adapted indicators.

We have also to consider the specific case of protected vegetables as diversified systems. To this aim, rules defined thanks to the DEPHY experimental network (Hossard et *al.*, 2017) will be integrated within the software. Definition of a "campaign" has been precised and shared with the partners. Units for some system descriptors have been changed to be more relevant for vegetable systems. Existing indicators calculations have now to be tested and adapted consequently.

In order to extend use to all European contexts, introduction of external reference databases (e.g. characteristics of pesticide products) will be simplified. Furthermore, in 2020, Systerre® will become a webservice available in several languages.

Table 1. Cross-analyse between criteria chosen to assess expected impacts of CD in DiverIMPACTS and indicators calculated by Systerre®. Number of indicator available/total indicator by dimension.

Pillar	Indicators available within Systerre	Derivable from Systerre	Not available yet within Systerre
Economic	(5/8)	-	(3/8)Land equivalent ratio, product standard quality, short food supply chain and local distribution, supplier/customer contribution to profitability
Environmental	(8/19)	(10/19)	(1/19) % semi natural habitat
Social	(1/2)	(1/2)	-

4 Discussion and Conclusions

For arable crops, most of the indicators required to assess the sustainability of diversified systems agriculture are accessible thanks to the data recorded in the software. After some adaptations, Systerre® will meet the current requirements of the DiverIMPACTS partners concerning indictor calculation. The final aim is to integrate the new/adapted indicators resulting from the project in order to help the design of diversified systems adapted to contexts and to support farmer advice.

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Current dominant crop sequences across EU: a typology based on LUCAS dataset

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1 Introduction

Assessing benefits expected from crop diversification requires an accurate description of current cropping systems (i.e. crop sequence and crop management) as a baseline. However, such a description is still lacking for Europe, for at least two reasons: (i) existing datasets at the European scale (e.g. LUCAS dataset, see below) provide information about land-use categories but no information about crop sequence and crop management, (ii) national and sub-national datasets that describe crop sequence and/or management practices are available in the EU-state members, but a lack of harmonization (e.g. spatial and temporal resolution, included descriptors) between these datasets makes them difficult to use in a cross-analysis. To overcome this problem, we developed an original method that combines European-level and national-level datasets to create a map of current dominant crop sequences at the European level.

2 Materials and Methods

The method is based on two public datasets: (i) the French national "Pratiques culturales" survey (PK), and (ii) the European Land Use Cover Area frame statistical Survey (LUCAS). The PK dataset contains information about 5-year crop sequences for a sample of fields across France (c.a. 20 000 fields surveyed for arable crops in 2014, Agreste, 2016). The LUCAS dataset contains information about land use for a grid of points in all EU-state members (c.a. 45 000 points with observations in 2008, 2012 and 2015 for agricultural uses, EUROSTAT, 2019). Both datasets are independent. We proceeded in three steps. First, we classified fields from the PK dataset, according to eight variables characterizing crop sequences (i.e. frequencies of cereals, oilseed rape, sunflower, dry pulses, corn, sugar beet plus potato, alfalfa plus clover and temporary grassland). Based on this set of eight variables, a principle components analysis combined with hierarchical clustering distinguished seven groups. Second, based on this first typology, we derived decision rules to assign each point of the LUCAS dataset to one of these groups. To validate these rules, we compared distributions of crop sequence types for France, resulting respectively from PK fields classification, and from LUCAS points assignment. As both distributions were very close, we finally applied assignment rules to LUCAS data for all EU countries.

3 Results

For France, the first type is characterized by crop sequences based on oilseed rape and cereals (Table 1). The second one gathered corn-based crop sequences, which could be monocropping or corn-cereals sequences. Third came sunflower-cereals sequences. The fourth type gathered crop sequences with annual crops and temporary grassland. Crop sequences based on industrial crops, such as sugar beet or potatoes represented the fifth type. Then came crop sequences with dry pulses (e.g. pea, faba bean, soybean) rotating with cereals. The seventh type gathered crop sequences including multiannual forage legumes (e.g. alfalfa or clover).

The consistency of both approaches validates the assignment of LUCAS observations as a good proxy of crop sequences distribution. Assignment rules applied to other EU countries resulted in a ranking of crop sequences, close to the French one (Figure 1). At the EU scale, oilseed rape-cereals sequences represented 41%, corn-based sequences 21%, sequences with temporary grassland 9%, beet or potato-based sequences 9%, sunflower-based sequences 6%, sequences with dry pulses 6%, and sequences with alfalfa or clover 5%. Most of LUCAS observations across EU fitted into crop sequence types defined for France; only 3% went in none of these groups.

Table 1. Percentage of agricultural area under different types of crop sequence in France according to the PK dataset and as estimated from the LUCAS dataset.

Crop sequence type	PK	LUCAS-based estimate
Crop sequence including oilseed rape	36%	32%
Crop sequence including corn	28%	29%
Crop sequence including sunflower	12%	9%
Crop sequence including temporary grassland	6%	9%
Crop sequence including industrial crops	9%	8%
Crop sequence including dry pulses	7%	5%
Crop sequence including alfalfa / clover	2%	5%
Other types of crop sequence	-	3%

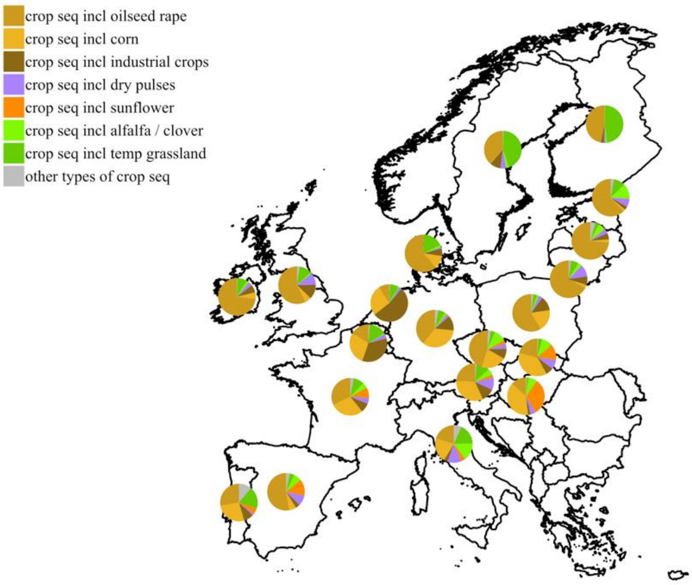

Figure 2. Distribution of crop sequence types by country in Europe, as estimated from the LUCAS dataset.

4 Discussion and Conclusions

In the next months, this description of dominant crop sequences, already validated by partners from each country, will be completed with information about crop management, to describe current cropping systems. This typology could be used to assess all types of diversification, for example increasing protein crops, as proposed by the European protein plan.

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Integrated assessment and modelling of the impacts of cropping system diversification from field to landscape and agro-chain levels: the MAELIA multi-agent platform

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1. Introduction

During the last decades food production has increased thanks to intensive use of non-renewable and agrochemical inputs and simplification of landscapes (Therond et al., 2017). Yet, the present inefficient use of pesticides and fertilizers and the increasing prevalence of intensive and simplified cropping systems are leading to negative impacts on biodiversity and its associated ecosystems services (Rusch et al., 2016). Actually, these are the same systems that may push agriculture over a sustainability tipping point (Ray et al., 2012). Thus, it is a priority to develop innovative forms of agriculture that stabilizes both yields and farmers' profitability while developing ecosystem services (Therond et al., 2017). Cropping diversification is regarded as a key path for a strong sustainable development of multifunctional agroecosystems (Ponisio and Kremen, 2016). However, little is still known on the potential synergic and trade-off effects brought by the implementation of different crop diversification strategies at different spatial and temporal scales. Integrated Assessment and Modelling (IAM), a multicriteria and multilevel assessment based on modelling platforms and involvement of stakeholders may help to deal with this challenge. As part of the EU H2020 DiverIMPACTS project, this work uses MAELIA, an IAM platform of agricultural landscape (Therond et al., 2014), to perform on three contrasted European case studies (CSs), an assessment of the benefits and drawbacks brought by diversification from field and farm to landscape and agro-chain levels.

2. Materials and Methods

MAELIA is a high-resolution multi-agent platform, that allows to simulate at fine spatial resolution the daily dynamic and interactions between human activities (e.g. farming practices), ecological processes (e.g. crop growth), and governance systems (e.g. agricultural regulations). It is applied in three very different CSs used as pilot test for the implementation of different diversified agricultural strategies.

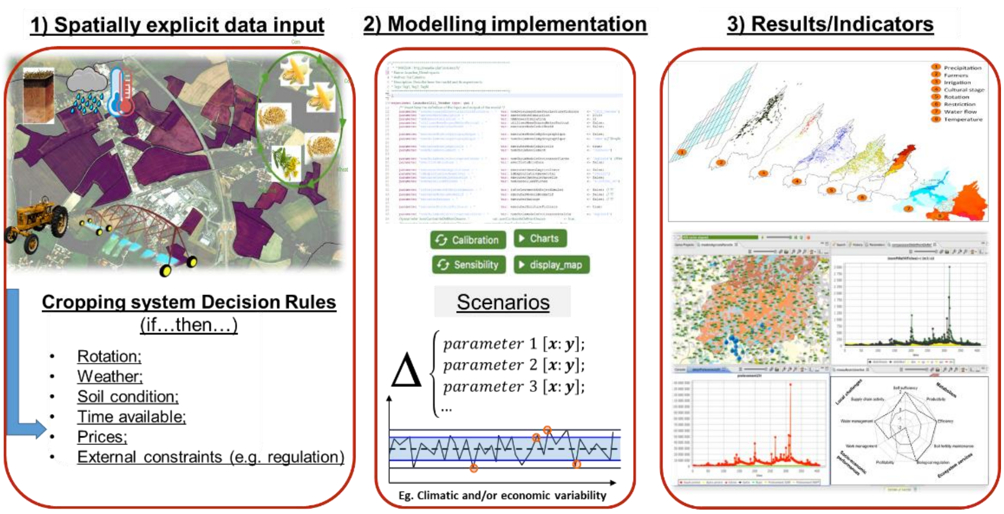

Figure 1. MAELIA implementation scheme : 1) integration of spatial data describing each farms present in each case study; (2) application, calibration and sensitivity analysis are performed before the simulation of different scenarios regarding cropping practices, climate and economic changes; (3) environmental and socio-economic indicators are retrieved, analysed and displayed.

A first CS is located in Germany, is composed by 25 farmers with a common goal of improving water quality in catchment basin trough new valuable and sustainable farming strategies based on diversified rotations, as well as to increase the cooperation and trade between local farmers. A second CS in Romany is composed by four very large farms (800 to 14000 ha each) in which the objective is to assess in an *ex-ante* way the effects of including in the rotation legumes and other winter crops on soil quality, yield stability and economic returns. The third CS, in France, corresponds to ten farmers where the challenge is to develop exchanges between cereal and livestock farmers, in order to offer diversification opportunities (e.g. forage production), while dealing with water quality and availability. The IAM process was structured in three main participatory steps. Firstly, data and knowledge were collected and integrated to develop in MAELIA a concrete model of the current functioning of each CS. Second, a participatory design process led by stakeholders was conducted to specify changes in the cropping systems. Thirdly, the integrated assessment of these scenarios was carried out with MAELIA, and results were analysed and discussed with stakeholders.

3. Results

A large set of pre-defined indicators (8 for the economic pillar, 19 for environmental sustainability, 2 for social dimension; see Canali et al. 2019) and stakeholder-oriented indicators (e.g. biological regulations issues) will be calculated to assess the direct and indirect effects of diversification over time (intra and inter year variabilities, rotation and long term) and space (field, cropping system, farm and territory). Based on outputs of scenarios simulations, this conference will provide opportunity to present and discuss the first key results of the IAM procedure.

4. Discussion and Conclusions

To support policy makers, it is necessary to define policies and strategies at the relevant levels at which impacts (e.g. biodiversity and economic return) are managed, such as farm or landscape. These impacts are also intrinsically linked with local biophysical processes, defined at very fine scales, such as soil-plant level. Here, we propose an IAM approach that allows simulating and assessing the main aspects of cropping systems, including social, environmental and economical, steering a transition to more sustainable food. Namely, the discussion is focused on the effects of cropping system diversification on a large range of generic and stakeholders oriented indicators. We will focus above all on the viability of agricultural holdings and the robustness/resilience to technical, climate and socioeconomic changes; stability of production and economic returns; soil (e.g. quality, erosion); GHG balance and non-renewable resources; water quality and availability; agricultural environmental impacts (e.g. nitrogen leaching); and, farmers' quality of life (e.g. workload).

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Assessing area suitable for diversification crops: an example on soybean in Europe under climate change using machine learning

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1 Introduction

Crop diversification is often considered as a pillar of agroecology, based on an increasing amount of evidence showing that crop diversification can improve the productive and environmental performances of farming systems, as well as their resilience, in different ways (Beillouin et al. 2019). A key question to assessing the potential adoption of diversified cropping systems is to identify areas suitable for the cultivation of so-called diversification crops. This task is challenging because (i) diversification crops are usually minor crops with limited harvested area, making identification of their climatic niche difficult, and (ii) on-going climate change might shift suitable areas in the future. Legume crops are often regarded as interesting diversification crops because they provide many benefits, such as reduced nitrogen fertilization due to their ability to fix atmospheric N_2, and increased yield of the following crop in the rotation. Among grain legumes, soybean is the species experiencing the fastest expansion rate in Europe, with an increase of its harvested area by more than three-fold from 2004 (1.2 Mha) to 2014 (4.5 Mha) according to the FAO.

2 Materials and Methods

Here we present an estimation of areas suitable for soybean in Europe under current and future climate scenarios. Using machine learning techniques (Random Forests, Neural Network, Generalized Additive Models, Multiple linear regression), we develop and evaluate a series of niche models relating soybean yield to relevant agro-climatic indices, and then use the most accurate model (Random Forest, Root Mean Square Error of Prediction = 0.14 t ha^{-1}) to assess current and future soybean potential distribution in Europe according to different climate change scenarios (from height Global Circulation Models, and four RCPs). We use two recently published global datasets including historical soybean yields and crop-relevant weather variables, which cover the totality of the world's agricultural land on a 1.125° grid from 1981 to 2010 (Iizumi et al. 2014a,b). Models are trained at the global scale, and then applied in Europe to assess soybean potential distribution under historical climate (1961-2010, and in the 2050s and 2090s, considering contrasted climate change scenarios.

3 Results

Our results indicate that European soybean suitable area extends further out of its actual distribution (Figure 1A), and is likely to shift in the near future (in the next 30 years) under moderate warming (RCP 4.5), with gains in the north and losses in the south (Figure 1B). Projected soybean yields suggest that dramatic shifts are likely to occur by the end of the century under RCP 8.5 (Figure 1C), increasing the presence of soybean in the north while decreasing it in the south compared to 2050.

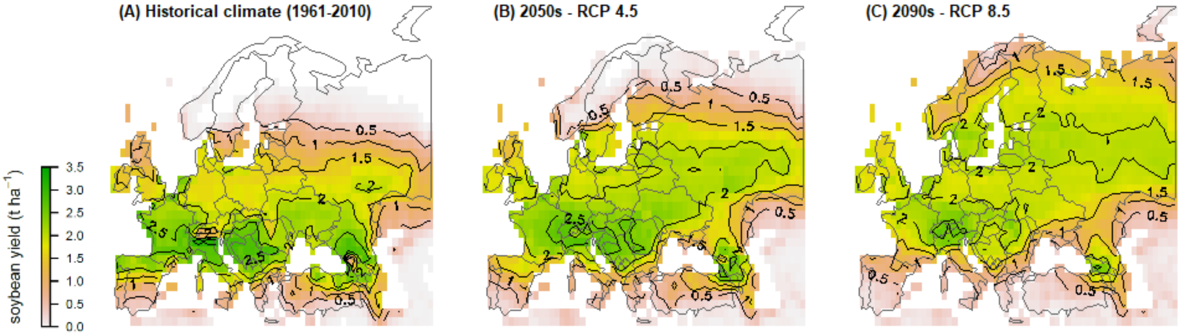

Figure 1. Projections of soybean yield in Europe under historical climate (A), by mid-century (2050-2059) under RCP 4.5 (B) and by the end of the century (2090-2099) under RCP 8.5 (C). Maps show median projected yield using the Random Forest model with the GRASP dataset (Iizumi et al. 2014b) for historical climate (1961-2010), and over the eight Global Circulation Models used in this study for future climate scenarios.

4 Discussion and Conclusions

These results show a strong potential for soybean expansion in Europe during the coming decades. Our study reveals that soybean could become a major lever for diversifying cereal-based cropping systems, especially in Northern Europe. The method developed in this paper could also be used to assess suitable areas for other diversification crops.

Acknowledgements

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New interactive front-end tools for visualizing and analysing data from quantitative and qualitative surveys: application to Crop Diversification Experiences across Europe

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1 Introduction

Temporal and spatial diversification of crops through rotation, multiple and intercropping schemes can improve farming systems efficiency, productivity and resilience, and thus sustainability. During recent years, farmers, scientists, advisors, private companies experienced crop diversification all across Europe. These initiatives, how they are carried out and their outcomes, implies a wide diversity of parameters that are not easily taken into account by classical experimental approaches. We developed a series of computer sciences tools for analyzing and visualizing data of various nature (qualitative, quantitative) collected to characterize european crop diversification experiences. During this conference, we propose a practical demonstration of how to use these tools and how they can be adapted for further needs.

2 Materials and Methods

A two-fold survey was carried out in order to document crop diversification experiences across Europe. The first part of the survey is based on a structured on-line questionnaire (LimeSurvey). One hundred-twenty-eight complete questionnaires were collected by partners of DiverIMPACTS project in 15 European countries. The collected data were mainly categorical (factors) and Likert-type scales. Results of this quantitative survey are reported in a parallel article (Drexler et al., this issue). Twenty-four crop diversification experiences were then selected for the second part of the survey based on a qualitative approaches. Partners used an interview grid constituted by a limited number of open-ended questions for surveying various players/stakeholders of the selected crop diversification experiences value chains.

Three tools were developed and used for analysing the data and visualizing the results of this two-fold survey. They rely on functions written in the R programming language at back-end in order to process the data, proceed with analyses and build graphs. The 'Shiny' R-package was used for building ShinyApps, as a front-end tool that interact with R back-end functions and data.

3 Results

Three tools will be presented during the conference and can be tested by attendees. These three tools are fully functional, but have a 'development' status, as new features are added based on users' needs. They are open-source and hosted on collaborative platforms (see section links to source code).

The first one is the R-package 'surveyvisualizr' which aims to visualize results of quantitative surveys (numerical, categorical, Liker-type data) through a ShinyApp running in a web-browser. The application will be used by the presenter or attendees in order to explore the results of the quantitative part of the survey on crop diversification experiences across Europe (task 1.1), and more precisely to highlight main characteristics of initiatives, their main success and failure factors, and the major enablers and drawbacks they encountered.

The second one is the R-package 'qcoder' which aims to conduct qualitative coding of documents. This tool was initiated in May 2018 by international developers and was taken as a starting point for developing a relevant tool for applying the Cognitive Mapping Approach for analysing Systems of Practices (CMASOP, Vanwindekens et al. 2013) to transcribed qualitative interviews. Documents – such as transcribed interviews – are loaded, classed and qualitatively coded through a ShinyApp in a web browser. Practically, the researcher attribute directed relationships between two concepts of various natures to part of documents, typically sentence(s) or paragraph(s). This tool is used to process qualitative interviews of players from a variety of European crop diversification experiences.

The third tool is the R-package 'cogmapr' which aims to treat the outputs of 'qcoder' in order to draw cognitive maps. Cognitive maps are digraphs of variables that can be used as a semi-qualitative model of interviewees' worldviews. The 'cogmapr' tool contains major functions from CMASOP: drawing Individual Cognitive Maps, computing Social Cognitive Maps and indicators from the graph theory. It works with a front-end ShinyApp shared as 'cogmapvisualizr' R-package. The 'cogmapvisualizr' application will be shown for exploring the results of the analyses of the qualitative interviews conducted among European crop diversification experiences.

4 Discussion and Conclusions

Recent developments done in the R community, particularly around R-studio and Shiny, allow scientists to build user-friendly and interactive front-end applications in order to treat, analyse and visualize data, by interacting with back-end R functions. During this conference, we present our experience with the development of three ShinyApps and their usage in DiverIMPACTS for documenting a sample of crop diversification experiences in Europe. These tools and their concrete results could interest not only the scientific community, but also practitioners of crop diversification.

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Links to source code

- 'surveyvisualizr' gitlab.com/FrdVnW/surveyvisualizr
- 'qcoder' github.com/ropenscilabs/qcoder
- 'cogmapr' frdvnw.gitlab.io/cogmapr/

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Life Cycle Assessment of farming practices that improve citrus orchards sustainability in semiarid areas

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1 Introduction

For decades, agricultural practices have been focused on increasing yield, maximizing human labour efficiency and reducing costs. Such an agriculture intensification has led to soil, water and environment deterioration and the system could become unsustainable. Therefore, moving towards more environmental-friendly farming systems is strongly necessary. In this sense, the H2020 Diverfarming project (ID: 728003) is developing and testing different diversified cropping systems under low-input practices with the aim of increasing land productivity and crops quality, and reducing machinery, fertilisers, pesticides, energy and water demands.

The objective of this work was to identify the best strategy in mandarin production in order to reduce the environmental impact of farming practices compatible with the sustainability of the agricultural production.

2 Materials and Methods

2.1 Life cycle assessment

The environmental impacts of citrus crops have been assessed using the Life Cycle Assessment (LCA) methodology and following the ISO 14040-44 standards. In the present study, the "cradle-to-gate" approach was used. All the production processes involved from raw materials extraction (i.e. the cradle) to the point where the final product is made available at the gate of the field were considered. One hectare of land was used as a functional unit.

The impact assessment was estimated according to CML-IA methodology (Guinée et al., 2002), using SimaPro 8.5 software. The following six midpoint impact categories were considered in the present study: abiotic depletion potential (ADP), acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), ozone layer depletion (OLD), photochemical oxidant potential (POP). In addition, cumulative energy demand (CED) and water use (WU), which are especially relevant in the LCA of food products, were assessed.

2.2 Study case

The present study evaluates the sustainability of irrigated citrus in Spain. The following four management practices scenarios:

- Current cropping system:
  - MCh-CTL, mandarin crop with conventional farming practices. Weed control in tree rows with herbicide and intense tillage.
- Proposed low-inputs management practises:
  - MCg-CTL: pesticides reduction scenario. Replacement of herbicides by geotextile.
  - MCh-RDI: same as MCh-CTL but with 30% of water supply reduction.
  - MCg-RDI: same as MCg-CTL but with 30% of water supply reduction.

3 Results

Overall, the three low-inputs management practises carried out in the MC treatments (MCg-CTL, MCh-RDI, MCg-RDI) reduced all the impacts categories as compared with the control (MCh-CTL) (Table 1). MCg-CTL provoked a reduction in all impact categories that ranged from 5% in the case of ADP to 17% in the case of POP. MCh-RDI was quite moderate and ranged from 0 in the case of AP to 7% for ADP and CED; and finally, MCg-RDI showed the main reductions of environmental footprint (8% in the case of EP and 18% for POP).

It is worthwhile noting that the reduction of 30% water supply in RDI treatments (MCh-RDI and MCg-RDI) improved the water use efficiency without significant differences in yield.

Table 1. Environmental impacts of mandarin crop at treatment control (MCh-CTL) and comparative environmental impacts of low-inputs management practices vs control.

Impact category	Unit	Control MCh-CTL (unit/ha)	Low-inputs management practises MCg-CTL (%)	MCh-RDI (%)	MCg-RDI (%)
ADP	kg Sb_{eq}	6.57E-02	-5	-7	-12
AP	kg $SO_{2\ eq}$	3.18E+01	-12	0	-12
EP	kg $PO_{4\ eq}$	2.21E+01	-6	-2	-8
GWP	kg $CO_{2\ eq}$	7.22E+03	-9	-1	-10
OLD	kg CFC-11 $_{eq}$	7.06E-04	-16	-1	-17
POP	kg $C_2H_{4\ eq}$	1.66E+00	-17	-1	-18
CED	MJ	1.21E+05	-10	-7	-17
WU	m^3	4.29E+03	0	-30	-30

MC: mandarin crop, h: herbicides, CTL: farm irrigation, g: geotextile, RDI: regulated deficit irrigation.

4 Discussion and Conclusions

Results of the present study are consistent with those of other studies on citrus performed in other countries. Regarding GWP, De Luca et al. (2014) in Italy and afterwards Aguilera et al. (2015) in Spain reported similar values in conventional orange production (6800 and 6520 kg $CO_{2\ eq}$/ha, respectively). However, the recent value reported by Ribal et al. (2019) is 36% higher than ours (9830 kg $CO_{2\ eq}$/ha). This difference could be attributed to their intensive use of pesticides and manure. Concerning other impact categories, Pergola et al., (2013) reported lower values of POP and AP in conventional orange production (0.92 kg $C_2H_{4\ eq}$/ha and 21.42 kg $SO_{2\ eq}$/ha). These lower values could be explained by the reference period used (50 years) that included four unproductive years. Nevertheless, Ribal et al. (2017) reported higher values for AP and EP and lower for GWP in conventional orange production (67.7 kg $SO_{2\ eq}$/ha, 38.1 kg $PO_{4\ eq}$/ha and 5570 kg $CO_{2\ eq}$/ha, respectively). The higher values for AP and EP could be associated to the intensive use of pesticides (32 L of active matter/ha-year compared to 9 L in our study), whereas the lower value of GHG was probably due to lower diesel consumption compared with our study (63 L/ha compared to 161 L/ha in our study).

In conclusion, the study suggests that the large-scale implementation of the proposed low-input practices would surely increase the sustainability of mandarin production in semiarid areas such as the south-eastern of Spain.

Acknowledgements

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Towards the prediction of levels of infestation of *Acyrthosyphon pisum* in pea-wheat mixtures

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1 Introduction

Crops are affected by a wide range of diseases, weeds and animal pests causing significant economic losses (Yuan et al., 2014). On average, they cause between 20% and 40% of yield losses of global agricultural productivity, and regularly threaten global food security (Oerke 2006; Flood 2010). For example, *Acyrthosyphon pisum* commonly known as pea aphid, reaches densities in some places high enough to become a significant economic problem in pea crops (Van Emden and Harrington, 2017; Trotta et al 2018).

Species mixtures, also called « intercrops », can enhance and improve the control of animal pests, diseases and weeds (Altieri, 1999). In addition, species mixtures can increase crop productivity and resilience to abiotic stresses, including those triggered by climate change. Intercrops involve the growth of two or more crops in the same field at the same time, or relayed, which could compete for growth resources during the common growth periods (Willey, 1979). Some studies reported significant reduction of aphid infestations in pea/wheat intercrops in comparison with sole pea crops (Ndzana et al., 2014). Farmers are thus counting on such innovations to reduce their reliance on agrochemicals to help protect yield (Shtienberg, 2013). However, these innovations require adaptation of cropping systems. In this respect, modeling tools can help improve agroecosystem management. Considering the growing interest in species mixtures, and especially for their role in pest control, we propose to design a tool to predict pest injuries in wheat-pea mixtures. In order to do so, we will use the qualitative modelling framework Injury Profile SIMulator (IPSIM; Robin et al., 2018). This modelling framework permits to design qualitative models to represent the impact of cropping practices, soil, weather and field environment on injury profiles caused by multiple pests (plant pathogens, weeds and animal pests; Aubertot & Robin, 2013). So far, IPSIM had been used in sole crops. In order to implement intercrops and benefit from their advantages, we aim to design an IPSIM model predicting *Acyrthosyphon pisum* final infestation in pea/wheat mixtures. The remainder of this paper is organized as follows: Section 2 presents the qualitative modelling platform Injury Profile SIMulator; Section 3 IPSIM-Aphids-severity model; and Section 4 presents discussions and conclusions.

2 Materials and Methods

IPSIM-Pea/Wheat-*Acyrthosyphon pisum* was developed using the DEXi software (Bohanec, 2009), adapting the DEX method (Bohanec et al, 2013). It is based on qualitative hierarchical multi-attribute decision modeling. In other words, DEX breakdowns a complex decision problem into smaller and less complex subproblems, characterised by attributes that are organised hierarchically into a decision tree. The development of IPSIM-Pea/Wheat-*Acyrthosyphon pisum* followed 3 steps:

1. Identification and organisation of attributes in hierarchical structure.
2. Definition of ordinal or nominal scales for basic and aggregated attributes.
3. Creation of aggregating tables for each aggregated attribute. A set of ''if-then'' rules define the value of the considered attribute as a function of the values of its immediate descendants.

3 Results

For the first step, attributes were identified through literature review and expert knowledge. We identified 17 attributes, 11 input attributes, and 6 aggregated, including the final attribute (*Acyrthosyphon pisum* level of infestation). Subsequently, we proposed the hierarchical structure presented in ***Figure***.

Attribute	Global	Scale
Aphids severity on pea/wheat intercrop		Very low; Low; Intermediate; High; Very high
├**Weather**	23	Favourable to aphids; Moderately favourable to aphids; Unfavourable to aphids
│ ├**Spring**	53	Unfavourable to aphids; Moderately favourable to aphids; Favourable to aphids
│ │ ├Temperature	38	Favourable to aphids; Unfavourable to aphids
│ │ ├Rainfall	43	Low; Medium; High
│ │ └Wind Speed	19	Favourable to aphids; Unfavourable to aphids
│ └Winter temperature	47	Favourable to aphids; Unfavourable to aphids
├Treatment	44	High efficacy; Moderate efficacy; No treatment
├**Landscape composition**	21	Favourable to aphids; Unfavourable to aphids
│ ├Proportion of semi-natural areas	15	High; Medium; Low
│ ├Proportion of leguminous crops	54	Low; Medium; High
│ └Proportion of organic fields	31	Low; Medium; High
└**Impact of intercropping**	12	Favourable; Moderetely favourable; Unfavourable
├**Intercrop sowing doses**	50	Favourable to aphids; Moderatelty favourable to aphids; Unfavourable to aphids
│ ├Wheat density	75	Lower than recommended sowing dose; Less than recommended sowing dose; Recommended sowing dose
│ └Pea density	25	Less than the recommended sowing dose; Equal to the recommended sowing dose; Lower than the recommended sowing dose
└Type of intercrop	50	Strip; Mixed

Figure 1. Hierarchical structure and attribute scales of IPSIM-Pea/Wheat-*Acyrthosyphon pisum* (DEXi screenshot). The "Global" column corresponds to the global attribute weights**.**

For the second step, we defined qualitative scales for the basic and aggregated attributes (***Figure***). The value scale corresponds to discrete values (e.g., low, normal or high) rather than numbers. For example, basic attribute "Temperature" is described using two-value scale (favourable or unfavourable to aphids). Red value scale corresponds to effects favourable to aphid development, green values correspond to effects unfavourable to aphids, and black values indicate neutral behaviour to aphids.

The third and last step consists in defining aggregative tables. For each aggregated attribute in the model, a set of ''if-then'' rules defines the value of the considered aggregated attribute as a function of the values of its immediate descendants' attributes in the model. For example (***Figure***), if "Temperature" and "Wind Speed" are favorable to aphids and "Rainfall" is low, the spring weather is globally favorable to aphids.

Once the aggregative tables are finalized, DEXi calculates automatically weights associated to each attribute through local and global normalized functions (Bohanec, 2009). For instance, attributes "Wheat density" and "Pea density" sum up 75% and 25% respectively for the "Intercrop sowing doses", as shown in ***Figure***.

4 Discussion

Before using the model for advises, one further step is necessary: the evaluation of its predictive quality. This evaluation consists in comparing observed and simulated classes of disease severity using an independent dataset covering a wide range of production situations. In addition, in order to run the qualitative model, it is necessary to design a converter that will transform nominal input variables (such as the name of a cultivar), or quantitative input variables (such as a sowing rate) into ordinal variables such as required by the IPSIM approach. Currently, we are building a dataset from French experimental crops (provided by research centers) in order to evaluate IPSIM-Pea/Wheat-*Acyrthosyphon pisum*.

This model will help design cropping systems with lower risks of aphids on wheat /pea mixtures and less reliant on pesticides, for a wide range of production situations. Ultimately, this model will be integrated in a future IPSIM-Pea/Wheat model that will predict injury profiles on Pea/Wheat mixtures (Yellow rust, brown rust, and Fusarium Head Blight on wheat and *Ascochyta* and *Acyrthosyphon pisum* on pea). Such integrative models are critical for the implementation of agroecological crop protection strategies, but also for transfer, communication and training.

Acknowledgements

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DiverIMPACTS
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An inventory of existing tools to promote crop diversification: fifty tools and methods already available for farmers and advisors

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1 Introduction

Nowadays, farmers and advisors can access numerous tools and methods linked to crop diversification. Some of them express their difficulties to find the most adapted within this jungle. In DiverIMPACTS project, an inventory of existing tools and methods for crop diversification across Europe was carried out in 2018, aiming to identify and characterize them according to their purpose, type, users and technical characteristics. This is the first step to build a decision tree to support farmers, advisors and other actors along the value chain, to identify the most suitable tool for their situation and needs.

2 Materials and Methods

The inventory of tools and methods was based on an online survey and interviews to collect needed information. The questionnaire contained 32 questions and was divided in 5 parts. After a short introduction to present the objectives and give some useful definitions, the main points addressed are (i) the aims of the tool / method and strategies of diversification promoted; (ii) the spatial scale and validity spectrum to precise the context of use of the tool / method; (iii) technical information on the tool / method (language, parameters, time to fill it in, information about the creator…). The questionnaire ended with descriptive information about the respondent.

The questionnaire included both close-ended and open-ended questions**.** An online survey was developed and published online with Framaforms and was available between the 9th of March and the 5th of July 2018. It was disseminated in European networks but also available on the DiverIMPACS project website. Interviews have also been realized to go further and get more detailed information.

3 Results

58 responses have been collected from 38 different people from 11 countries. The database contains 42 tools and eight methods from eight different countries. A tool/method often allows users to make several kinds of decisions (e.g., management, design, mobilization of references, diagnosis, assessment) and can mobilize different diversification mechanisms (e.g., rotation, multiple cropping, intercropping) or a combination of different levers.

Table 1. Number of tools according to the kind of decision and the diversification startegy (one tool can address one or several diversification strategies or one or several kinds of decision)

	Rotation	Multiple Cropping	Intercropping	Local market	Other
Management	23	14	13	3	4
Design	18	14	17	2	1
Assessment	28	15	15	2	3
Diagnosis	23	12	11	3	7
Mobilisation of references	7	4	4	2	3
Dissemination	1	1	1	1	1

Different kinds of information about how to mobilize these tools/methods have also been registered such as format, language, when to use the tool, training requirements, cost of the tool and contact person or organization.

4 Discussion and Conclusions

This inventory aims to give an overview of the existing tools and methods to promote crop diversification, including all its components (e.g., rotation, multiple cropping, inter-cropping) at the value chain and territory levels. The large scope of this inventory led to identify tools and/or methods created to support crop diversification (with one or more identified strategies), as well as those using crop diversification as a way to achieve an expected impact.

Most of tools are dedicated to farmers and the scale is the field, the cropping system or the farm (46/50). Only few tools (8) cover the territory or value chain scales and are dedicated to value chains actors and policy makers.

Table 1 shows that several tools can mobilize the same strategy of diversification, with the same kind of decision. However, a deeper analysis of the tools created to design intercropping identifies a diversity of approaches in the tools. Table 2 shows the selection of tools with these characteristics (only those without assessment feasibility). Two of them are specifically dedicated to grassland, two to cover crop mixing design and two to intercropping for harvest. The last two tools have similarities (suitability of the most promising grain legume/cereal mixture in their context, adapted to organic farming with technical information…). Both of them are based on field trial results and expertise. But important gaps are also identified: the geographical validity area is different (North-West of France and Switzerland), tested species in trials are also different. Another technical specificity is the language: French for one and German or Hungarian for the other one.

Table 2. Description of 6 tools crossing intercropping issues and design decisions

	Choose grassland species	Calculator for mixing grassland species	Catch crop in maize	OSCAR	Guidance for mixing cereals and grain legumes	Successful cultivation of grain legumes mixed with cereals
Tool or method	Tool	Tool	Method	Tool	Tool	Tool
type of intercroping	grassland	grassland	cover crops	cover crops	intercropping for harvesting grains	intercropping for harvesting grains
species	grassland	grassland	mainly clovers	many species	pea/fababean/lupine with cereals	pea/beans/lupins/soy/lentils/vetches…
specific context of use	Conventional farming	Conventional farming	Organic farming	Conventional farming	Organic farming	Organic farming
geaographical validity area	Pays de la Loire (one region of France)	Probably France	unknown	European context	some area of France: Bretagne, Normandie, Nord, Pays de la Loire	Written for Swiss conditions
Language	French	French	English, German	English	French	German

So the question of the overlap between tools needs to be precisely analysed before providing a decision tree to help farmers and advisors identify the most suitable one.

The database describing all of the tools is available and will be incremented during the project with new tools. Eight tools under development (mainly from other H2020 projects) were also identified during the inventory process. They will be added to the database when they become available to end-users.

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Most frequent sequences in arable crop rotations in Wallonia (Belgium)

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1 Introduction

Among other environmental, social and economic benefits, crop diversification is assumed to play a role in improving yields, lessening pest pressure or decreasing fertilizer needs of subsequent crops. Facing increasing fuel and fertilizer price, crop diversification is therefore promoted to sustain or stabilize crop production and farmers' income.

The aim of this study is to (i) identify the most frequent crop sequences encountered in Wallonia (Southern Belgium), and (ii) evaluate their degree of diversification.

This study identified reference crop sequences for the region, to be compared with the more diversified cropping systems studied in the DiverIMPACTS project. Depending on data availability, a similar work could be carried out in partner countries in order to identify more reference systems.

2 Materials and Methods

Using Land Parcel Identification System (LPIS) data from 2008 to 2017, the most common crop sequences in Wallonia were identified. In order to observe if crop sequences are more diversified now than they were ten years ago, results were compared to the observations performed from 1997 to 2003 by Leteinturier *et al.*, 2006 and Leteinturier *et al.*, 2007.

3 Results

Results from LPIS data treatment showed that crop sequences are not more diverse than they were a decade ago. Silage maize areas are expending.

Table 1.Number of different crops observed (in % of the considered area) from 2008 to 2017, according to the agricultural area and for the whole Walloon region, in comparison with 1997-2003 results (Leteinturier et al., 2007)

Agricultural area	Considered area (ha)		Number of different crops in a 7-year crop succession (% of the considered area)													
			1		2		3		4		5		6		7	
	2008-2017	*1997-2003*	2008-2017	*1997-2003*	2008-2017	*1997-2003*	2008-2017	*1997-2003*	2008-2017	*1997-2003*	2008-2017	*1997-2003*	2008-2017	*1997-2003*	2008-2017	*1997-2003*
Ardenne	13 891	1 670	5%	23%	24%	19%	32%	22%	24%	19%	10%	13%	4%	3%	1%	1%
Campine Hennuyère	170	185	7%	6%	13%	6%	20%	24%	40%	33%	18%	23%	2%	5%	0%	1%
Condroz	45 652	55 222	3%	1%	8%	5%	24%	27%	41%	44%	20%	21%	3%	3%	0%	0%
Famenne	13 354	10 200	6%	5%	17%	13%	26%	29%	29%	32%	16%	17%	5%	4%	1%	0%
Région herbagÞre	5 056	3 567	30%	31%	26%	18%	21%	29%	15%	16%	5%	6%	2%	1%	0%	0%
Rég. herbagère (Fagne)	3 151	2 501	9%	11%	17%	15%	24%	25%	28%	31%	17%	14%	4%	3%	1%	0%
Région Jurassique	5 978	3 884	8%	11%	20%	16%	28%	27%	26%	26%	15%	16%	3%	4%	1%	0%
Limoneuse	126 756	142 466	1%	1%	5%	4%	27%	28%	42%	45%	21%	20%	4%	3%	0%	0%
Sablo-limoneuse	70 944	23 161	1%	2%	3%	8%	9%	34%	82%	38%	5%	15%	1%	3%	0%	0%
Wallonia	**285 907**	**242 879**	**3%**	**2%**	**7%**	**6%**	**22%**	**28%**	**49%**	**42%**	**16%**	**19%**	**3%**	**3%**	**0%**	**0%**

As visible from Table 1, the number of different crops in a 7-year crop succession has not increased during the last decade.

Figure 1 shows the cumulative frequency of the preceding crops for the five main crops in Wallonia. These results are also very similar to those observed by Leteinturier *et al*., 2006, with one notable difference: silage maize is more frequently the preceding crop of winter wheat, switching places with sugar beet. Similarly, the frequency of silage maize as the preceding crop of itself has increased, highlighting the trend towards more silage maize monoculture.

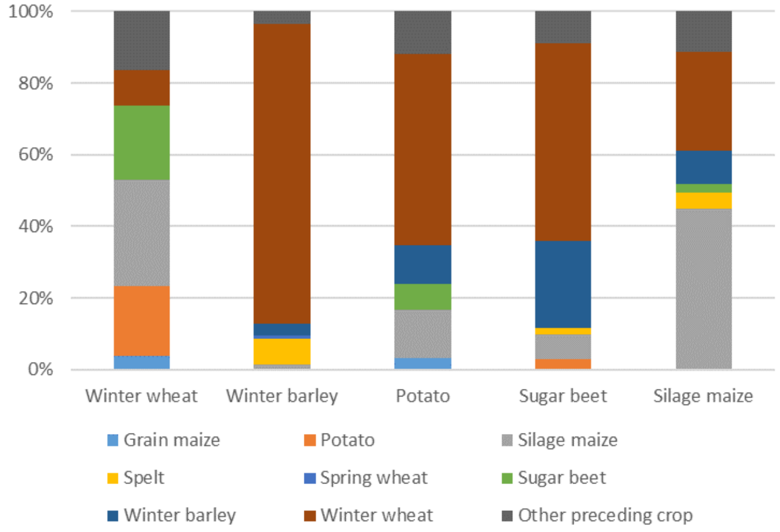

Figure 3. Cumulative frequencies (%) of preceding crops of the five major crops in Wallonia (2008-2017)

4 Discussion and Conclusions

The observed expansion of silage maize areas is related to increasing feed production and decreasing food production in Wallonia, according to trends already pointed out by Delcour *et al*. (2010).

The analysis of the LPIS data do not show a trend towards more diverse crop rotations in Wallonia. On the contrary, they highlight the increasing occurrence of silage maize, in short rotations (2 to 4 years) or in monoculture.

The next step will connect LPIS data with the Walloon Farm Accountancy Data Network (FADN) database to link, on the one hand, crop sequences and, on the other hand, yields and amounts of inputs (fertilizers, pesticides) used. This will enable to use real field data to support the assumed beneficial effects of crop diversification.

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DiverIMPACTS
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Assessing the influence of diversified cropping systems on land productivity and the soil-plant system at different scales. A case study from Southern Italy

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1 Introduction

Crop diversification in intensive agricultural systems contribute to the environmental sustainability of farming systems, and might represent an important strategy for climate change adaptation. The H2020 Diverfarming project (Grant Agreement 798003) aims to promote low-input innovative practices of crop diversification putting together a consortium of researchers, farmers and agro-industries.

The methods used to evaluate the effect of diversification are usually based on multicriteria assessment, considering economic, social and environmental aspects. Such evaluations are valid at small scales, i.e. field or farms. However, the assessment of crop diversification at landscape scale is necessary to better guide landscape agricultural planning and can assist in setting priorities for more detailed monitoring of economic and environmental aspects. To improve the contribution of agriculture to sustainable regional development, assessments must take into account the locations and diversity of cropping systems.

Our specific goal in the framework of the project is to assess how diversified cropping systems influence soil-water-atmosphere systems in different pedoclimatic regions of Europe adopting an integrated cross-scaling approach based on geographical procedures at three levels of study: point, farm and landscape. To this end data from different sources like measures, model outputs, and existing archives of soil maps, land use/land cover maps, will be utilized.

2 Materials and Methods

In a case study located in Foggia Province (Southern Italy), crop management scenarios with and without diversification options were investigated.

Measured point data, or modelled ones, need to be generalized to the field to which they belong, to have a comprehensive view of the effect of crop diversification on farm yields, soil, and environment. Because of high cost and limited resources, data collection is usually conducted only in a limited number of selected point locations, needing to be interpolated in space (Marchetti et al., 2010). Most environmental data is of a spatial nature: the quality of spatial information depends on the availability of spatial data, collected and linked to their position (geo-referenced), and then processed to derive the information. Thus, a procedure for upscaling modelled and measured data from point to farm level up to landscape scale is being defined, adopting a geostatistical approach for spatialization based also on available relevant information about each study area (Hengl, 2009). Incorporation of auxiliary data often allows to reduce the estimation error when performing an interpolation of measured/modelled data over a broader territory (Ping and Dobermann, 2006), thereby improving our understanding of interactions among landscape features. A spatial framework made up of units with relatively homogenous conditions (soil, climate and management) was developed, identifying as reference grid the grid system used in INSPIRE (1x1 km), a pan-European Infrastructure for Spatial Information in the European Community for environmental policies.

First, the sample data were examined through a descriptive statistical analysis, and the presence of spatial autocorrelation was verified through a variographic analysis. Total Organic Carbon (TOC) content represents an important soil property that can be effective in assessing the diversified cropping systems, but it is not the only one: the application of the proposed procedure is foreseen also for other properties like pH, nutrients and heavy metals. Finally, the relationships and the degree of correlation between target variable and auxiliary information collected for the area were verified and quantified, extending the estimation to the landscape scale.

3 Results

Some preliminary results are showed. In Figure 1 the interpolated map of TOC in g kg^{-1} in some plots at the beginning of the Diverfarming experiment is reported as an example. Since a good theoretical model of spatial autocorrelation for these data was difficult to find, a deterministic interpolator (Inverse Distance Weighting, IDW) was selected as the most suitable interpolation method to estimate data at field scale.

In Figure 2 the spatial distribution of TOC for the Foggia province at "time zero" is reported, obtained by applying a geostatistical interpolator (Empirical Bayesian Kriging, EBK) to the auxiliary data available (as in Farina et al., 2017).

Figure 1. TOC in 4 plots of Foggia case study, interpolated by IDW.

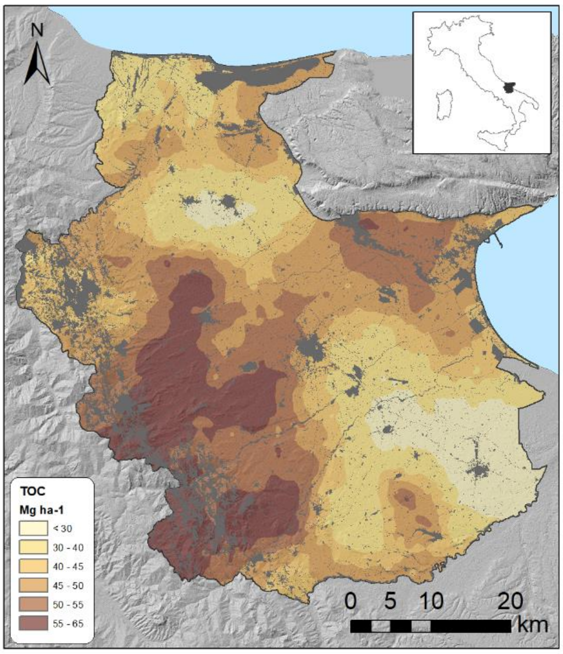

Figure 2. TOC in Foggia province, interpolated by EBK.

4 Discussion and Conclusions

Even if the differences among sampling points in plots are very small, at the considered scale a gradient from SW to NE can be identified. The effects of diversification will be evaluated by spatialising the analytical results at the end of the experiment.

What we expect to obtain is a set of territorial maps with integrated assessment of several scenarios with and without diversification, including maps of productivity per land unit, SOC sequestration potential, N_2O and CO_2 emissions, and other eventual indicators of sustainability.

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WORKSHOPS

WORKSHOP 1: BREEDING FOR CROP MIXTURES: OPPORTUNITIES AND CHALLENGES

Convenors: Lars Kiær (University of Copenhagen, Denmark) and Alison Karley (The James Hutton Institute, United Kingdom)

Background

When carefully combined, crop mixtures such as intercrops and variety mixtures are found to enhance agronomic performance and ecosystem services such as improved resource use efficiency, pest and pathogen management and yield stability. However, ideotypes for sole cropping may not perform well in crop mixtures, and the need for developing specific genotypes of crops for intercropping has long been recognized.

Workshop format and objectives

The cross-disciplinary workshop featured flash talks from representatives of breeding, ecology and agronomy. Facilitated discussions addressed key challenges for the practical implementation of modern breeding programs for crop mixtures:

- Identifying relevant breeding targets;
- Identifying operational breeding methods;
- Managing genotype-environment interactions;
- Market opportunities and challenges.

Read more

"Breeding for crop mixtures: Opportunities and challenges" (link to abstract)

WORKSHOP 2. TECHNOLOGY INSPIRED BY ECOLOGY FOR THE ADOPTION IN PRACTICE OF SPATIAL CROP DIVERSITY

Convenors: Wijnand Sukkel (Wageningen University and Research, The Netherlands) and Cristina Castognotto (Industrias David, Spain) (tbc)

Background

Technology has shaped 20th century agriculture neglecting or even excluding ecology. Compared to monocultures, cropping systems with a high spatial diversity have proven to (potentially) perform better on resilience, resource efficiency, productivity and biodiversity. To make use of the potential benefits of diverse cropping systems a different approach is needed in the relations between agronomy, ecology and technology. How should technology inspired by ecology look like? What are the current developments in technology which could support the adoption of diverse cropping systems? And what kind of cooperation, support and inspiration is needed for the transition to a new paradigm in farm technology?

Workshop format and objectives

The workshop was introduced with a short talk:

- "When Technology meets ecology" (link to abstract)
  Speaker: Wijnand Sukkel (Wageningen University and Research, The Netherlands)

Facilitated discussions addressed the following objectives:

- Identifying technology needs in primary production and the food chain to enhance adoption of spatial crop diversity;
- Identifying relevant technology developments which can help to overcome the technology lock ins for adoption of spatial crop diversity;
- Drawing a discussion brief for actions needed to support technology development to support the adoption of spatial crop diversity.

WORKSHOP 3. TOWARDS A CROP DIVERSIFICATION NETWORK

Convenors: Antoine Messéan (INRA, France) and Walter Rossing (Wageningen University and Research, The Netherlands)

Facilitators: Margarida Ambar (EIP-AGRI, Belgium), Dóra Drexler (ÖMKi, Hungary), John Grin (University of Amsterdam, The Netherlands), Pete Iannetta (The James Hutton Institute, United Kingdom), Liisa Kübarsepp (EIP-AGRI, Belgium), Anja Vieweger (ORC, United Kingdom)

Background

The H2020 Crop Diversification cluster (https://www.cropdiversification.eu/) brings together research projects which operate in countries across Europe to increase the impact of crop diversification research. The cluster encourages sustained uptake of diversification measures by European farmers and through innovations across the agri-value chain. Also, the EIP-AGRI brings together innovation actors (farmers, advisers, researchers, businesses, NGOs and others) at EU level and recently organised a worskhop **"Cropping for the future: networking for crop rotation and crop diversification"**. Against this context, there is a need to align those initiatives and to discuss how networking could be used as a means to support the transition to diversified and systainable agrifood systems.

Workshop format and objectives

The workshop was introduced with short talks on (i) what is already being done within the cluster; and (ii) the outcomes of the EIP-AGRI workshop on crop diversification which was held in Almere, The Netherlands, in June 2019. Facilitated discussions addressed the following objectives:

- Identify expectations and needs as well as experiences in terms of networking on crop diversification;
- Suggest ideas, processes, instruments and tools, and make recommendations to support networking on crop diversification.

WORKSHOP 4. SUPPORTING COLLABORATION RATHER THAN COMPETITION BETWEEN DIVERSIFICATION VALUE CHAINS IN EUROPE

Convenors: Barbara Koole (University of Amsterdam, The Netherlands) and Kevin Morel (INRA, France)

Background

This workshop explored how competition between stakeholders plays out in collaborative innovation processes for crop diversification. It specifically zoomed in on the interactions between scientists and other actors within collaborative research settings. It hoped to facilitate a dialogue based on experiences and theoretical insights from niche management and coopetition literature.

Workshop format and objectives

The workshop was introduced with a short talk on the outcomes of a preliminary workshop which was held during the DiverIMPACTS annual meeting in Alnarp, Sweden, in July 2019. The workshop also included flash talks from scientists who faced tensions due to competition in working with value chain actors. Facilitated discussions addressed the following objectives:

- Discussing possibilities and strategies to foster collaboration and sharing rather than competition between actors of diversification value chains in Europe (especially between small and big players);
- Exploring the position of scientists when facing issues of competition in collaborative research settings;
- Exploring concrete possibilities to develop a European network for exchanging information for diversification value chain development (especially post-harvest management, processing, marketing, business models and setting prices).

WORKSHOP 5. POLICY RECOMMENDATIONS TO MAKE THE SOCIOTECHNICAL SYSTEMS MORE DISPOSED TO CROP DIVERSIFICATION

Convenors: Barbara Pancino (University of Tuscia, Italy), Bálint Balázs (ESSRG, Hungary)

Background

Agricultural policies have contributed to shaping cropping systems over the last decades and play a major role, together with other drivers, in the sociotechnical lock-in that prevents crop diversification despite its benefits. Several measures have been introduced or are being proposed to enhance crop diversity in European agriculture. Overall, current policies may not provide sufficient incentives to promote crop diversification and it is paramount to take stock of the actual implementation of existing policy instruments and discuss which measures could foster crop diversification while accounting for the high diversity of agroecosystems and socio-economic situations.

Workshop format and objectives

The workshop was introduced with two talks:

- "How to promote crop diversification across Europe" (link to abstract)
  Speaker: Barbara Pancino (University of Tuscia, Italy);
- "New governance solutions for legume-based food systems" (link to abstract)
  Speaker: Bálint Balázs (ESSRG, Hungary).

Facilitated discussions were based on the experience of the H2020 Crop Diversification cluster projects (https://www.cropdiversification.eu/) and addressed:

- Policy incentives and barriers to crop diversification, and in particular to legume-based food systems
- Processes to identify measures and indicators that could be implemented by policy makers.

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Breeding for crop mixtures: Opportunities and challenges

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1 Introduction

When carefully combined, crop mixtures such as intercrops and variety mixtures are found to enhance agronomic performance and ecosystem services such as improved resource use efficiency, pest and pathogen management and yield stability. These benefits rely on a range of physiological, morphological and phenological characteristics of the component partners in interaction with the growing environment and management. For some of these traits, similarity among mixing components is desirable (mainly traits conferring good performance under agronomic management, such as early establishment, simultaneous ripening and high yield), whereas complementarity in other traits may confer advantages such as enhanced resource uptake and improved weed suppression. In addition, some component-specific traits enable mixing partners to facilitate the growth and performance of others, including structural support against lodging, switching of nutrient sources, and weed suppression. While most traits in the former category were already selected in traditional sole crop breeding, traits in the other two categories are exclusive to crop mixtures. Hence, ideotypes for sole cropping may not perform well in crop mixtures, and the need for developing specific genotypes of crops for intercropping has long been recognized (e.g. Finlay, 1976).

2 Workshop format

The cross-disciplinary workshop will feature flash talks from representatives of breeding, ecology and agronomy. Facilitated discussions will address key challenges for the practical implementation of modern breeding programs for crop mixtures.

3 Discussion topics

3.1 Identifying relevant breeding targets

Some plant traits that optimise agronomic performance and environmental benefits of crop mixtures have been identified and more are under investigation. Generally, useful traits for components of a crop mixture are those that optimize complementarity and facilitation (Costanzo & Barberi, 2014). *To be discussed: Is the performance of all components equally important –should crop improvement focus more on specific components? Is it useful to identify mixture-ideotypes for specific crop mixtures?*

3.2 Identifying operational breeding methods

A number of methods for crop mixtures breeding have been applied. Each method having a number of pending questions and uncertainties.

(i) Statistical evaluation of genotypic performance in (a range of) mixtures (e.g. Federer, 2012). This includes several attempts to estimate the general (and specific) mixing ability of genotypes, for example using diallel and nested mixing designs. *To be discussed: Are these designs sufficiently efficient in the search for general mixing ability? Is it realistic to generalize mixing ability beyond the set of tested combinations? Can genetic markers associated with general mixing ability be identified?*

(ii) Evolutionary plant breeding (Döring et al., 2011) and within-mixture breeding. Selection for 'mixable' genotypes may be more efficient in mixtures than in sole crops (Harper, 1967; Finlay, 1975; Zimmermann et al., 1984; Zuppinger-Dingley et al., 2014). *To be discussed: What could feasible and efficient programmes for within-mixture breeding look like? E.g. is it feasible to carry out selection within mixtures with representatives (testers) of a wider companion gene pool (cf. Davis & Woolley, 1993)? At which stages of* *selection - early (e.g. Barot et al., 2017)?, How important is the effect of neighbour phenotype relative to the effect of not growing with conspecifics? How to avoid selecting merely for competitive ability?*

(iii) A trait-based approach, selecting for specific plant functional traits that improve performance in species mixtures (Brooker et al., 2015). Recent research has focused on the potential for devising mixture ideotypes, assembly rules and mixture breeding design (e. g. Gaba et al., 2015; Litrico and Violle, 2015). Being inspired partly by the findings of the widely successful large-scale biodiversity experiments (e. g. Scherber et al., 2010), these trait-based approaches aim to embrace plant community complexity at levels beyond the assignment of general genotypic traits for mixing ability and competitiveness. *To be discussed: Can we identify clearly what traits are more important? Should traits and outcomes not typically measured in sole crop breeding programmes be included?*

3.3 Managing genotype-environment interactions

Correlation of performance under mixed and sole crop conditions is often low (Francis, 1986), suggesting that trait information from sole crop trials is not always useful. The phenotypic plasticity that enables plants to adapt to a range of growing conditions also shapes their ecological niche in the community (Berg and Ellers, 2010) and ultimately governs the yield stability of agricultural crops (Lazzaro et al., 2017). Significant levels of crop trait plasticity are reported on a regular basis, also in response to mixing (Zuh et al., 2016). (G × G) × E × M interactions in crop mixtures therefore poses an additional level of complexity. *To be discussed: Assuming that plasticity levels differ among traits, species, 'neighbours' and environments, which traits categories are more plastic in modern temperate crop varieties and hence more variable? Does trait plasticity tend to reinforce or reduce niche overlap in crop mixtures – and to what extent does this influence crop mixture synergy and the prediction of optimal combinations?*

3.4 Market opportunities and challenges

Carefully combined crop mixtures and 'mixture-ready' cultivars with specific trait combinations could present a novel market opportunity for breeders and seed sellers. *To be discussed: Is this attractive for actors along the value chain? Is convergence possible, or is there inherent conflict between rapid short-term gains from sole crop breeding and breeding for crop mixtures, which may need more long-term efforts?*

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When technology meets ecology

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There is an increasing body of evidence that cropping systems making use of spatial crop diversity, potentially perform better in several aspects than monocultures. Pest and disease incidence (Brenda B. Lin, 2011) is lower, biodiversity of (beneficial) insects is higher (van Apeldoorn, unpublished) and use efficiency of water and nutrients is potentially higher. But also the productivity of more diverse cropping systems is higher than monocultures. A meta-analysis on intercropping has shown that it result on average in a land equivalent ratio of 1.25 (Yu et al., 2015). The advantages are dependant of the intensity and diversity of the mix of the different crops.

There are different reasons why, in spite of its potential advantages, crop diversity in space is hardly practiced in modern agriculture. The current production system is optimised to produce food in monocultures, providing an abundance of food, with a minimum of labour input and for a low price. Mechanisation, technology, genetics, farm management, processing, trade, legislation etc. is completely tuned to the use of monocultures. Together they keep modern agriculture 'locked in' in their current way of working. To escape from this mode, several components of this system therefore have to change simultaneously.

Let's focus on one of these lock ins, namely mechanisation and technology, including cultivars, pesticides and fertilizers. During the 20th century these technologies have shaped modern agriculture to what it is now. Monocultures, ever increasing in homogeneity and size are grown because of the available mechanisation, to easily spread pesticides and fertilizers and to simplify crop management. Technology has shaped 20th century agriculture neglecting or even excluding ecology (figure 1a). The downsides of this approach, like decrease of soil quality (for example soil compaction caused by heavy machinery), emissions and environmental damage caused by the use of synthetic fertilizers and pesticides and decreasing biodiversity, are becoming increasingly evident.

To make use of the potential benefits of diverse cropping systems a different approach is needed in the relations between agronomy, ecology and technology. The paradigm should change to an agriculture that is connected with ecology, facilitated by technology which is inspired by ecology (fig 1b).

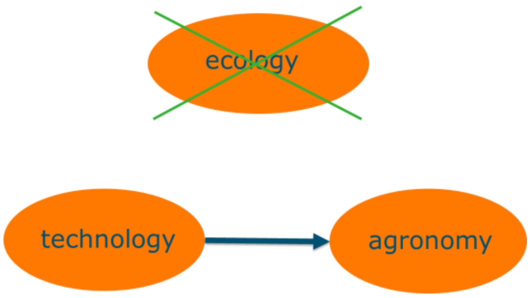

Figure 1a. Technology determines agronomy

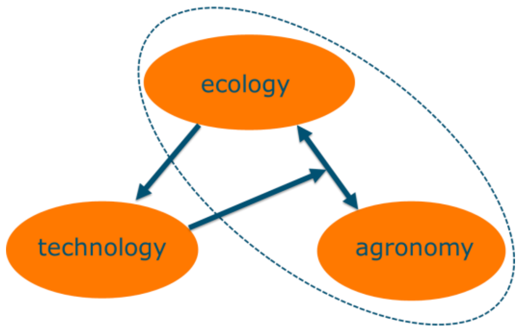

Figure 1b. Technology based on ecology and supports agro-ecology

The type of technology needed to make spatial crop diversity practicable is dependant of the spatial configuration and the number of species of the crop mixture. This configuration can be alternating strips of different crops with a strip width of 3 meters or more (strip cropping) or more intensive mixtures alternating one or a limited number of crop rows with a strip width of a maximum of approximately 1,5 meters, or complete mixes of two or more crop species. The latter configuration is often used in intercropping of legumes and cereals or in multiple species mixes, sometimes also referred to as pixel cropping.

Strip cropping is a cultivation system that can be already quite easily implemented by farmers, as its mechanical demands are mostly within current standard technological capabilities. Therefore it is already being adopted by the first innovative farmers in the Netherlands. Two years' experience on an organic farm in the Netherlands shows that this system is manageable with a limited additional labour need compared to monocultures. Strip cropping on conventional farms however still needs adapted spraying machinery for chemical pest, disease and weed control. New, full automatic and high precision small spraying machines, which are already available on the market, could help to overcome this obstacle.

For more intensive mixtures, the technology needed, depends on whether crop cultivation and harvest needs to be specific for every single crop. For the more classical mixtures of legumes and cereals, there is no specific management per crop. Sowing, crop cultivation and harvesting is done with standard mechanisation. Getting the mixed yield separated after harvest might need additional sorting further in the chain, this technology is however available.

Cultivating crops simultaneously in an intensive mix, where for every crop specific management is needed, poses much more challenges on the technology. Getting the harvest of the land in a limited timeframe and with a low labour input and managing and harvesting every crop row or even every plant individually, are important bottlenecks. New agronomic technology and machinery is needed, most likely in different combinations of new techniques like sensors, ict, electronic traction and gps. Either be it as small scale, light and autonomous machines or combined with gantry systems, pivot systems or otherwise. The good news is that the technical developments go fast and also the big companies for agricultural machinery are investing in these innovations. If agronomists, ecologists and technicians work closely together, the technological lock ins for the broad adoption of divers cropping systems can be overcome.

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How to promote crop diversification across Europe

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1 Introduction

In recent years, European crop systems have changed dramatically, increasingly converging towards intensive monoculture agriculture with a high use of external inputs. This has developed processes of soil degradation, biodiversity reduction and an increase in economic risk by farmers. Diversified agricultural systems can be the answer and the solution to these problems. Diversification, specifically intended as crop diversification, therefore practices of rotation/intercropping of crops combined with a set of low input practices (such as minimum tillage, mulching, integrated pest management) brings significant benefits to the farm system. There is a lower risk of crop failure (and therefore a reduction in economic risk by the farmer), an increase in environmental benefits (such as improving the quality and soil structure that generate positive impacts on productivity), and in some cases also a reduction in production costs. The synergistic effect triggered by diversified and sustainable agricultural systems is important and attention needs to be paid to why it is not yet so widespread in Europe.

In this panorama, public intervention and therefore agricultural policies play a decisive and fundamental role for the introduction and diffusion of diversified production systems. It is necessary to investigate the current agricultural policies to understand how the theme of diversification is dealt with and what are the tools that policy makers have devised to encourage the adoption of crop diversification practices (CDPs). In order to have a broad understanding of the situation, it is therefore necessary to understand the barriers that hinder adoption and to take action initially also through the help of public intervention to eliminate them.

2 Materials and methods

In order to have a more detailed picture of strengths and weaknesses of the European agricultural policies, a survey was carried out within the European H2020 Diverfarming project. The project counts 16 case studies within 6 countries, which gives a wide territorial coverage to understand the political framework and the incentives and constraints present for each country and case study (CS).

The questionnaire was compiled by both the case study manager and the farmer of each CS, in order to have both a scientific and a technical point of view.

The survey included the insertion of general data on the farm and the territory of origin and specific questions on the agricultural policies to which each CS refers. More specifically, whether the CDPs are supported by any European, national or sub-national agricultural policy and through which instruments. Furthermore, a brief description of the diversification agricultural practices undertaken as well as the reason for implementing them was investigated. As for the practice of diversification, it was also necessary to indicate who inspired them in the choice of diversification practice, how widespread it is in their region, which drivers can contribute to the adoption of this practice and which are the limits that are encountered in the diffusion of the same.

3 Results

The survey outcomes show that choice of implementing a CDP is made to solve the main problems related to biodiversity, soil erosion, soil organic matter and water pollution risk. The main drivers and constraints seems to be the same, that is economic and market aspects; which leads to the concept that there are not good or bad CDPs, but indeed their sustainability depends on the context. As it regards policy issues, half of respondents, with not great discrepancy about the information level about local policies between farmers and CS managers, stated that there are policies promoting the kind of diversification practice implemented in the CS. Thus, even when policy instruments are given they are not well known among stakeholders (farmers, technicians and researchers).

4 Discussion and Conclusions

This difficulty to understand which are the measures to be used in case of crop diversification is due to the absence of a clear definition of it and related guide-line to classify the heterogeneity of crop diversification solutions. Furthermore, the survey highlights that farmers often need to ask for support to third parties to identify the exact measure to which reference and from which incentives could come. This demonstrates a first major obstacle for the diffusion of diversified production systems which is accompanied by the problem of the sale of alternative crops on the market. Indeed, not all the crops have the same demand and therefore the same economic potential. The public intervention should therefore act mainly on these two fronts, first of all trying to facilitate the process of identifying and understanding the type of support that farmers can receive, then acting on the mechanisms of the market trying to encourage the sale of minor crops.

For instance, a tool that can favor a specific CDP such as the rotation is the implementation of horizontal supply chain agreements between the different actors involved.

In a general context where the attention and demand from consumers for more sustainable lifestyles and products is increasing and the new CAP tends to be increasingly green goes, crop diversification can play an important role. It is therefore of fundamental importance that in this framework policy makers give clear disposal regarding the definition of CDPs and easily accessible tools to enable the dissemination of sustainable practices throughout Europe.

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New governance solutions for legume-based food systems

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1 Introduction

Legumes are at the centre of policy debates concerning global food security, sustainable food production systems and our transformation towards more sustainable food systems. Where they exist, policies to realise legume-based food production have failed to increase legume-based diets and even production over the long term. The marginal role of legumes in agri-food systems illustrates 'pars pro toto' our unbalanced agri-food systems which are 'locked-in' to unsustainable states of operation that systematically obliviate the true economic, social and environmental costs of current production and consumption patterns (Westhoek et al., 2011). Such legume paradox presses for more effective policy innovations to avoid further incoherencies among policies across sectors. However, this needs to be realised in a highly fragmented, unknowable, 'no-one-stop-shop' policy environment. Public funding for legume production and consumption would provide clear opportunities for synergies, as 'sustainable diets' might be a policy goal that is most widely acknowledged. This paper will provide critical analysis of existing policies and governance solutions for legume-supported systems, which help identify limiting and enabling factors as well as leverage points for further policy interventions to support legume-based systems. We combine systematic reviews and key stakeholders' interviews, to perform interpretive policy analysis of actors, networks and processes which are key to create effective policy solutions. By 'policy' framework, we mean not only legal regulations (Laws, Decrees, Strategies etc.) but also public and private initiatives which aim to change or implement the framework conditions. The main question we address is what the practical policy challenges to increase legume production, and consumption in Europe are?

2 Materials and Methods

As a first phase literature review and document analysis have been used to understand how current EU-level policies influence the production and consumption of legumes in Europe. We searched for peer-reviewed articles focusing on the policy and governance aspects of legumes, which have then been critically reviewed. As a second phase, we rely on interpretive policy analysis of official legal/strategic documents and key informant interviews to reveal underlying values, arguments, as well as the interplay of actors. We analyse eight in-depth policy case studies focused on different parts of the value chain to point out the role of different types of stakeholders. Altogether the analysed cases cover various actors all along the value chain, and in many instances provide insights on how these actors interact with each other to achieve policy transformation.

3 Results

Consumption policies mobilise regulating bodies, consumer groups, professional organisations and processors, while farmers and actors at the lower end of the value chain show less influence. Production actors (e.g. seed suppliers, crop breeders, agronomists) have a strong influence on how the increased demand for raw materials or commodities can be met. Production (and processing) policies mobilise processors and agronomists such as farmers and state regulators, while crop breeders, seed suppliers or civil society are seen to play less important roles.

Trade policy has a considerable influence on legume production and consumption. A small number of large companies (often conglomerates) push the agri-food system towards large-scale operations to decrease import dependence and meet the protein demand of the animal feed sector. Emerging partnerships and networks between various actors of the value chain, as well as bottom-up initiatives of societal actors, create space for innovation both in legume production and processing and can push regulatory changes as well, especially if backed by social actors and the media. Change agents in sustainability transformation are niche market innovators, formal and informal networks between seed suppliers, farmers and processors, as well as NGOs and civil associations.

Currently, four dominant narratives support a transition to more sustainable legume-based systems in Europe. The first discourse is on increasing European self-sufficiency of plant protein sources and aims for the status quo of more demand for animal feed, large-scale agriculture and soybean production. The second discourse on improving health and nutrition as well as sustainable food consumption collects diverse stakeholders but strangely legumes are not in the centre of this narrative, and their exact role is still debated. The third discourse on countering biodiversity loss and climate catastrophe seems dominant in international science-policy forums and stands behind the EU greening measures too. Finally, the fourth discourse on improving opportunity for knowledge sharing converge multiactor projects in several scales and open doors for private initiatives and innovations.

4 Discussion and Conclusions

Our insights from the European Union (EU)-funded H2020 project Transition paths to sustainable legume-based systems in Europe (TRUE) point out how to enable co-innovative practices to bring into effect policies that may more successfully support current, and future, food and nutritional security challenges via the use of legumes.

The critical policy challenges in national and EU level (knowledge gaps, lack of awareness of the benefits of legumes; technological lock-ins and financial limitations regarding legume production; different measures in policy, disintegration along the value chain) created limited pathways for sustainable legume-based systems. However, networking and collaboration are critical for innovative value chain development. Governance solutions shaping legume production and consumption in Europe are inherently multi-level. There is a strong interplay between the EU and the member states for agricultural policies (CAP greening + voluntary coupled support), and an increasing collaboration for production and trade within the EU (including a stronger coordination to represent the European market in international dialogues, as pinpointed by the Donau Soya initiative and recent dialogue with e.g. Chinese actors). On the other hand, food and nutrition-oriented policies are less centralised. This policy field is characterised by diverse solutions at the national or regional level and an increased openness for knowledge exchange on best practices. In addition to the multi-level nature of relevant policies, a multi-actor governance approach seems to emerge, characterised by private and societal actors playing a role in policy formulation and development of bottom-up governance solutions.

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