Role of field experiments to support crop diversification

Antoine Messéan (Agronomy, Grignon) - Stéphane Cordeau (Agroecology Dijon)

Acknowledgements: Aurélie Cardona, Violaine Deythieux, Guénaëlle Hellou, Marie-Héléne Jeuffroy, Margot Leclère, Chloé Salembier, Loïc Viguier

Foulum, 7 June 2022

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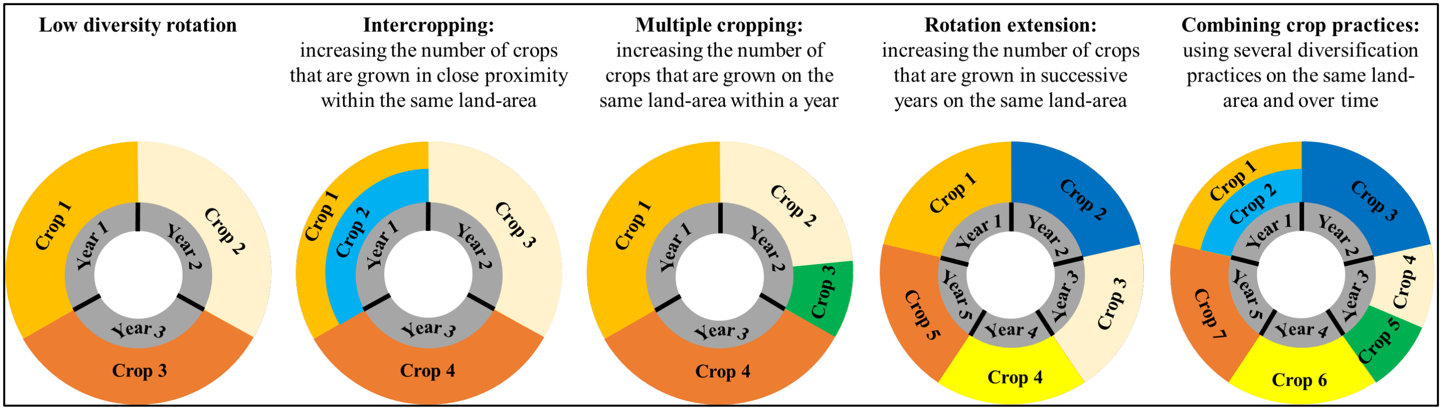
Crop diversification as a major pillar of agroecology



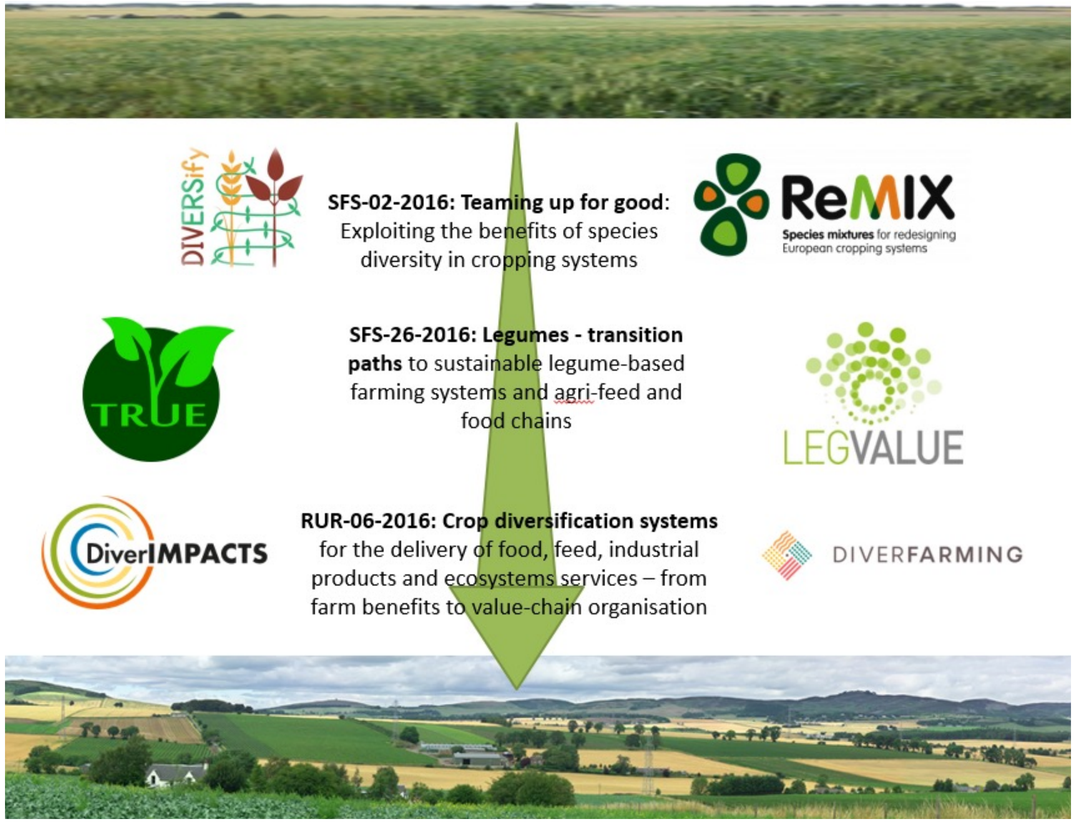
Low diversity rotation

Intercropping: increasing the number of crops that are grown in close proximity within the same land-area

Multiple cropping: increasing the number of crops that are grown on the same land-area within a year

Rotation extension: increasing the number of crops that are grown in successive years on the same land-area

Combining crop practices: using several diversification practices on the same land-area and over time



SFS-02-2016: Teaming up for good: Exploiting the benefits of species diversity in cropping systems

SFS-26-2016: Legumes - transition paths to sustainable legume-based farming systems and agri-feed and food chains

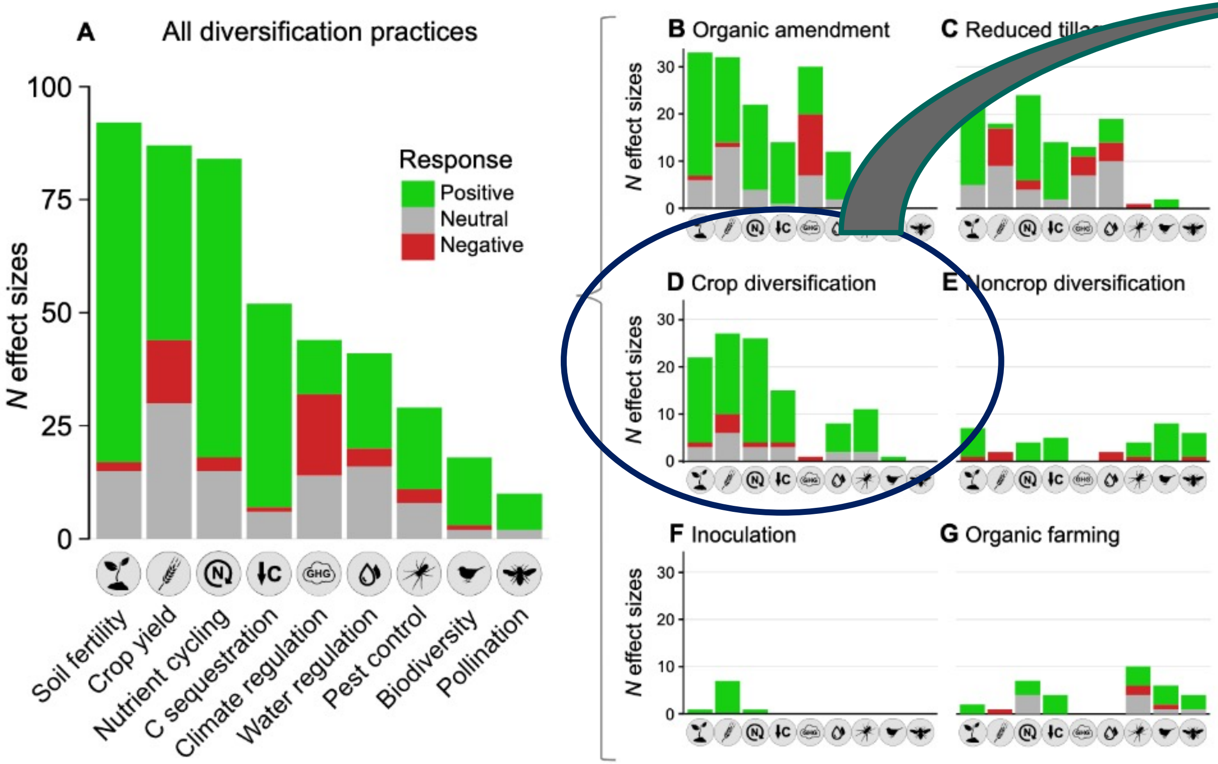
RUR-06-2016: Crop diversification systems for the delivery of food, feed, industrial products and ecosystems services – from farm benefits to value-chain organisation

Diversification through Rotation, **I**ntercropping, **M**ultiple cropping, **P**romoted with **Act**ors and value-**C**hains **T**owards **S**ustainability **(2017-2022)**
(33 partners, 11 countries)

Outline

- Crop diversification is a major pillar of agroecology but is hindered by technological, organisational and institutional barriers all along value chains and sociotechnical systems;
- Smart design of diversified systems can help achieve Farm2Fork objectives, reduce input uses, mitigate climate change without jeopardizing food security
- Assessing indirect and long-term effects is crucial to drive the nonlinear, dynamic and adaptive process of crop diversification
- Shifting to agroecology in a context of climate change calls for a change of paradigm in the way we produce actionable knowledge
- Farmer innovation « tracking », on-farm participatory field trials, on-station experiments and Long-Term Experiments should be articulated

Crop diversification is a major lever to reach F2F targets

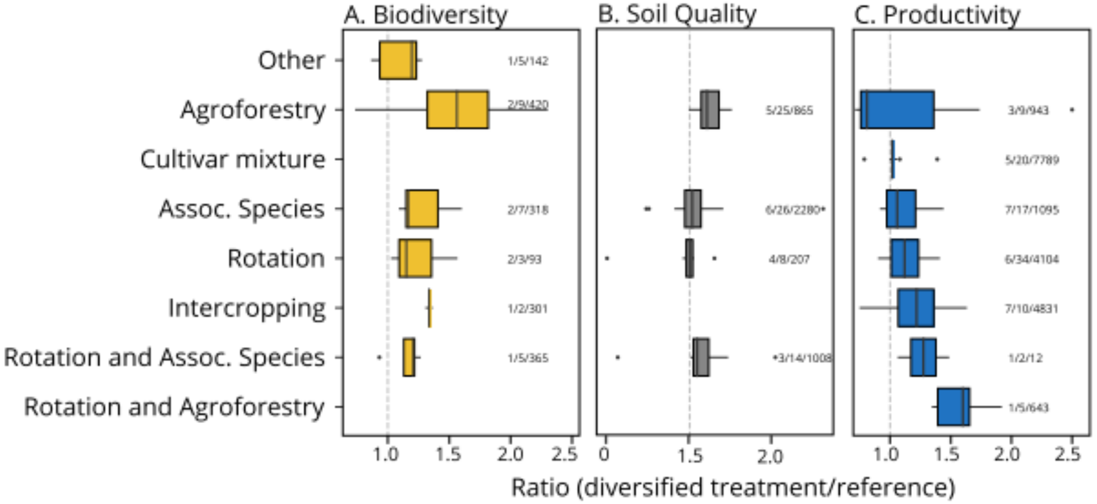


SCIENCE ADVANCES | **RESEARCH ARTICLE**

ECOLOGY

Agricultural diversification promotes multiple ecosystem services without compromising yield

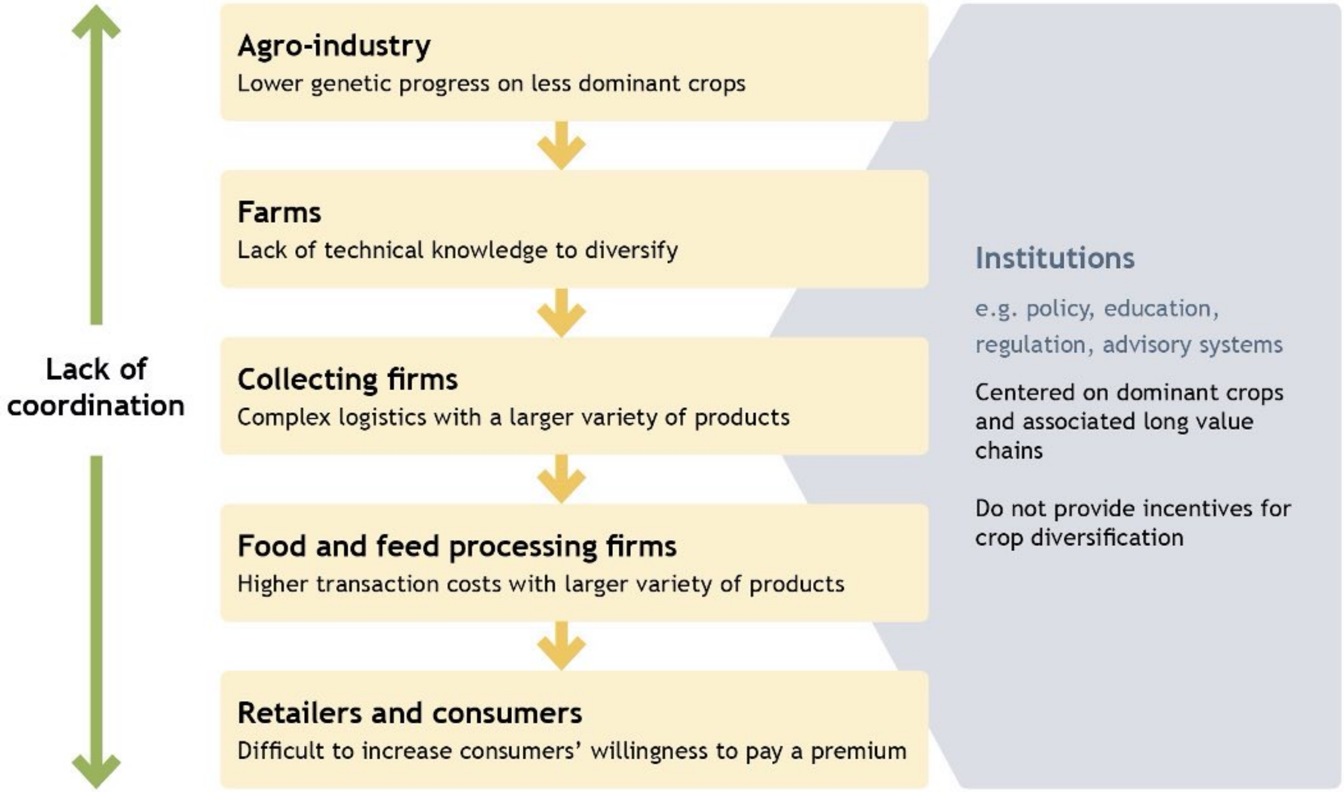
Giovanni Tamburini[1,2*], Riccardo Bommarco[1], Thomas Cherico Wanger[1,3†], Claire Kremen[4,5], Marcel G. A. van der Heijden[6,7], Matt Liebman[8], Sara Hallin[9]



Beillouin et al., 2019 Evidence map of crop diversification strategies at the global scale ;

Beillouin et al., 2020 Benefits of crop diversification for biodiversity and ecosystem services

Crop diversification is hindered by a series of barriers all along value chains



Agro-industry
Lower genetic progress on less dominant crops

Farms
Lack of technical knowledge to diversify

Collecting firms
Complex logistics with a larger variety of products

Food and feed processing firms
Higher transaction costs with larger variety of products

Retailers and consumers
Difficult to increase consumers' willingness to pay a premium

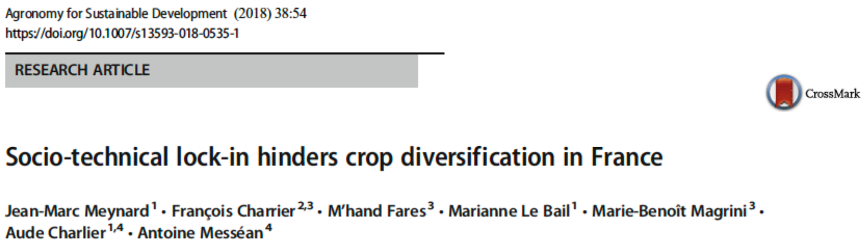
Lack of coordination

Institutions

e.g. policy, education, regulation, advisory systems

Centered on dominant crops and associated long value chains

Do not provide incentives for crop diversification



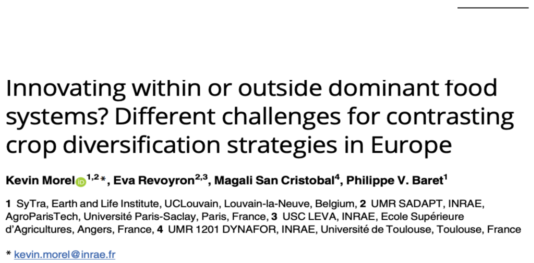
Agronomy for Sustainable Development (2018) 38:54
https://doi.org/10.1007/s13593-018-0535-1

RESEARCH ARTICLE

CrossMark

Socio-technical lock-in hinders crop diversification in France

Jean-Marc Meynard[1] · François Charrier[2,3] · M'hand Fares[3] · Marianne Le Bail[1] · Marie-Benoît Magrini[3] · Aude Charlier[1,4] · Antoine Messéan[4]



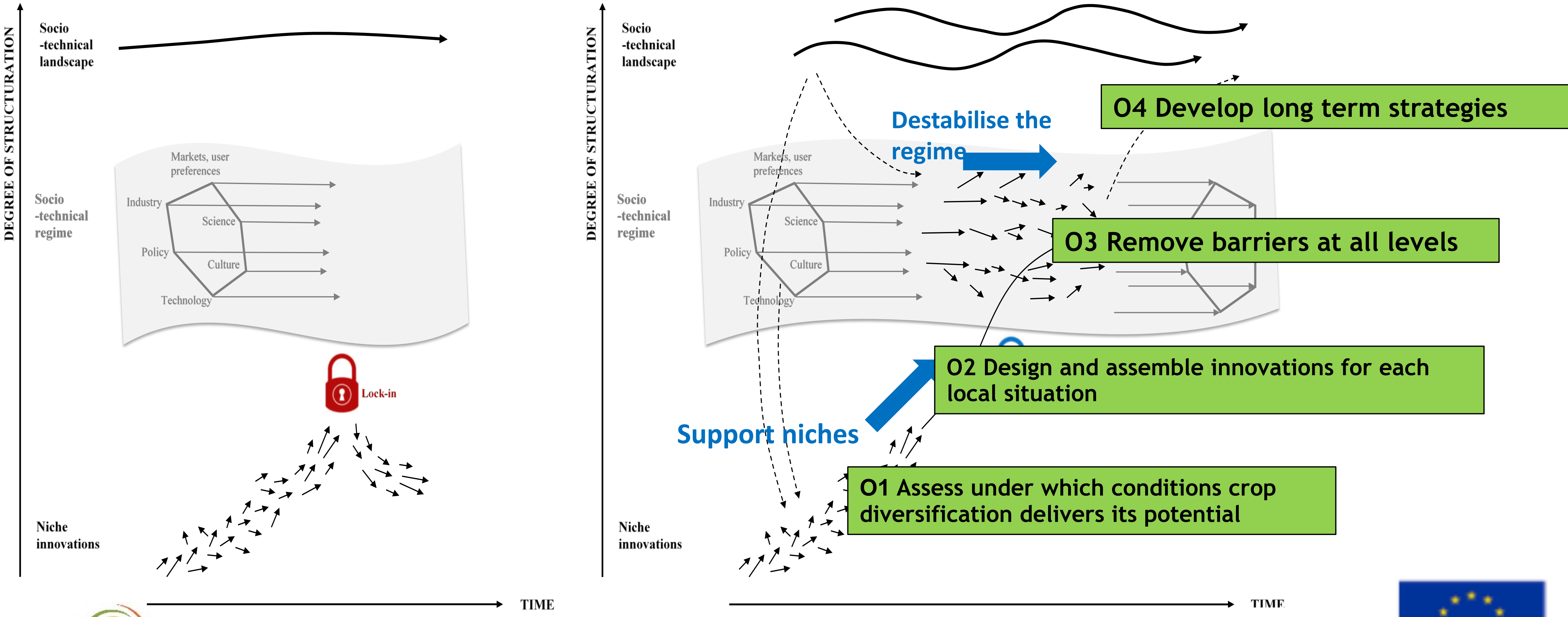
Innovating within or outside dominant food systems? Different challenges for contrasting crop diversification strategies in Europe

Kevin Morel[1,2]*, Eva Revoyron[2,3], Magali San Cristobal[4], Philippe V. Baret[1]

1 SyTra, Earth and Life Institute, UCLouvain, Louvain-la-Neuve, Belgium, **2** UMR SADAPT, INRAE, AgroParisTech, Université Paris-Saclay, Paris, France, **3** USC LEVA, INRAE, Ecole Supérieure d'Agricultures, Angers, France, **4** UMR 1201 DYNAFOR, INRAE, Université de Toulouse, Toulouse, France

* kevin.morel@inrae.fr

Unlocking the potential of crop diversification to support sustainability transitions requires systemic changes



Destabilise the regime

Support niches

O4 Develop long term strategies

O3 Remove barriers at all levels

O2 Design and assemble innovations for each local situation

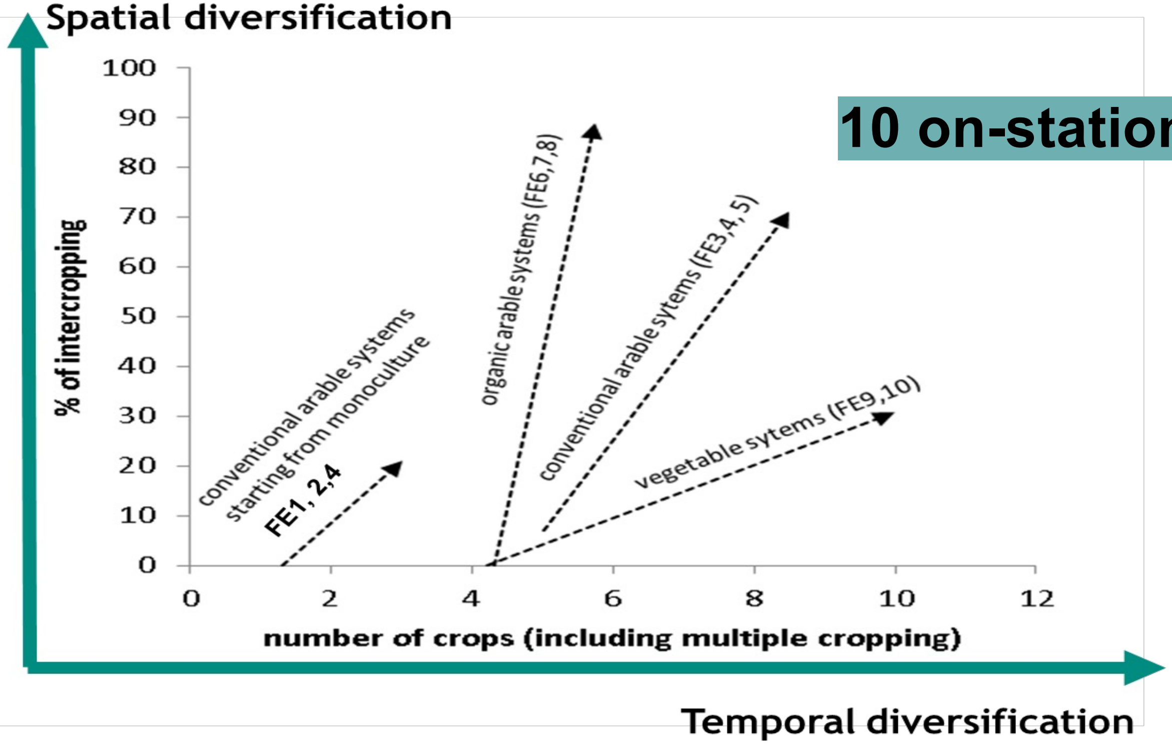
O1 Assess under which conditions crop diversification delivers its potential

The Multi-Level Perspective

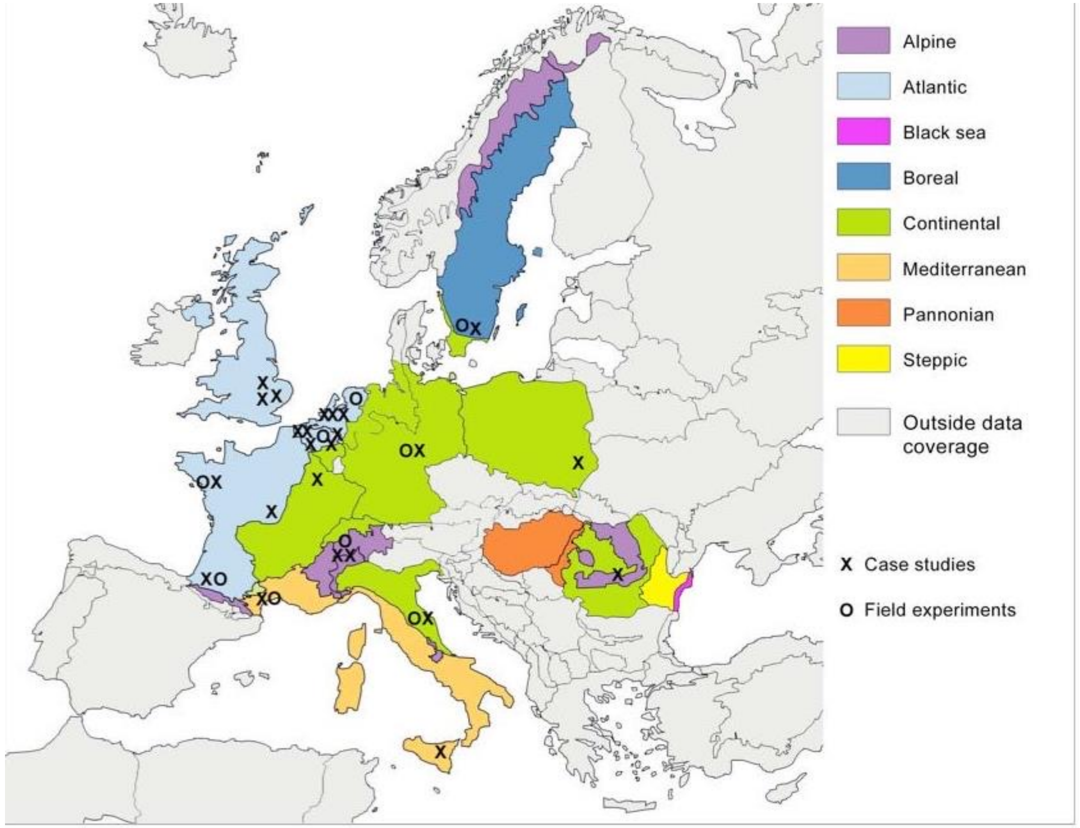
(adapted from Olivier et al., 2018
who adapted it from Geels et al;, 2002)

Start from existing situations, explore crop diversification potential and drive the crop diversification process towards sustainable goals

DiverIMPACTS



10 on-station field experiments and 25 multiactor case studies



Various motivations

- Improve protein autonomy
- Create new outlets
- Reduce input uses
- Solve technical impasses

Diversification strategies of Field Experiments (FE)

- **Rotation**:
  - Legumes for their expected ecosystem services
  - New markets (hemp, lentil, soybean, bionergy from silage)

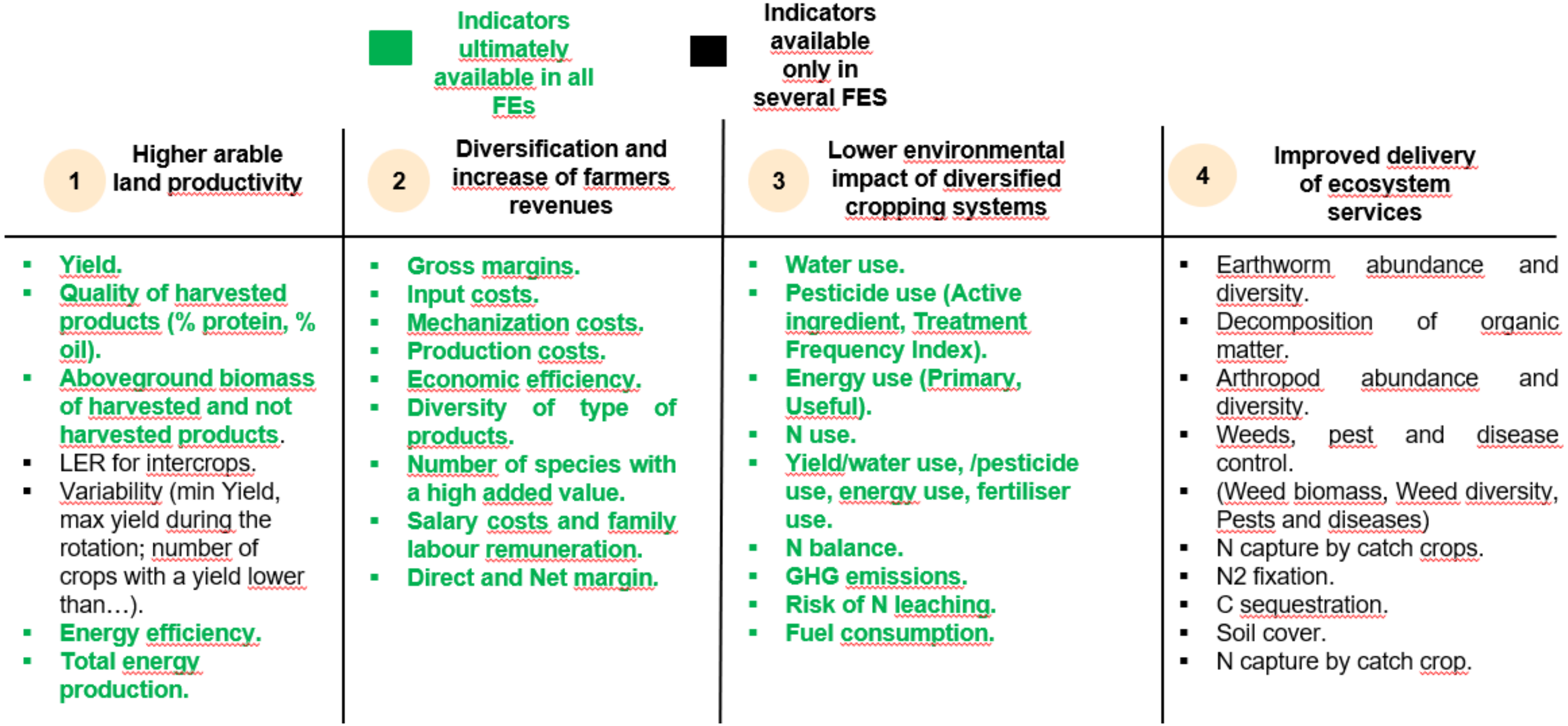
- **Intercropping**:
  - Cereal-grain legumes (pea-wheat, pea-barley, lupin-wheat)
  - Relay cropping (maize-ryegrass)
  - Oilseed rape/frost-sensitive legumes
  - Strip cropping for vegetables

- **Multiple cropping:**
  - Cover crops
  - Forage production (feed and energy production)

CC = Cash Crop
MSCC = Multi-Services Cover Crops

System	Rotation duration (years)	Number of species		% of legumes in rotation		% intercrops		% soil cover by MSCC
		CC	CC + MSCC	**CC**	**CC + MSCC**	CC	CC + MSCC	
REF	3.6	3.5	3.8	**7**	**8**	3	3	4
DIV	4.3	4.9	7.1	**15**	**22**	37	40	20

Indicators used to assess performances in Field Experiments



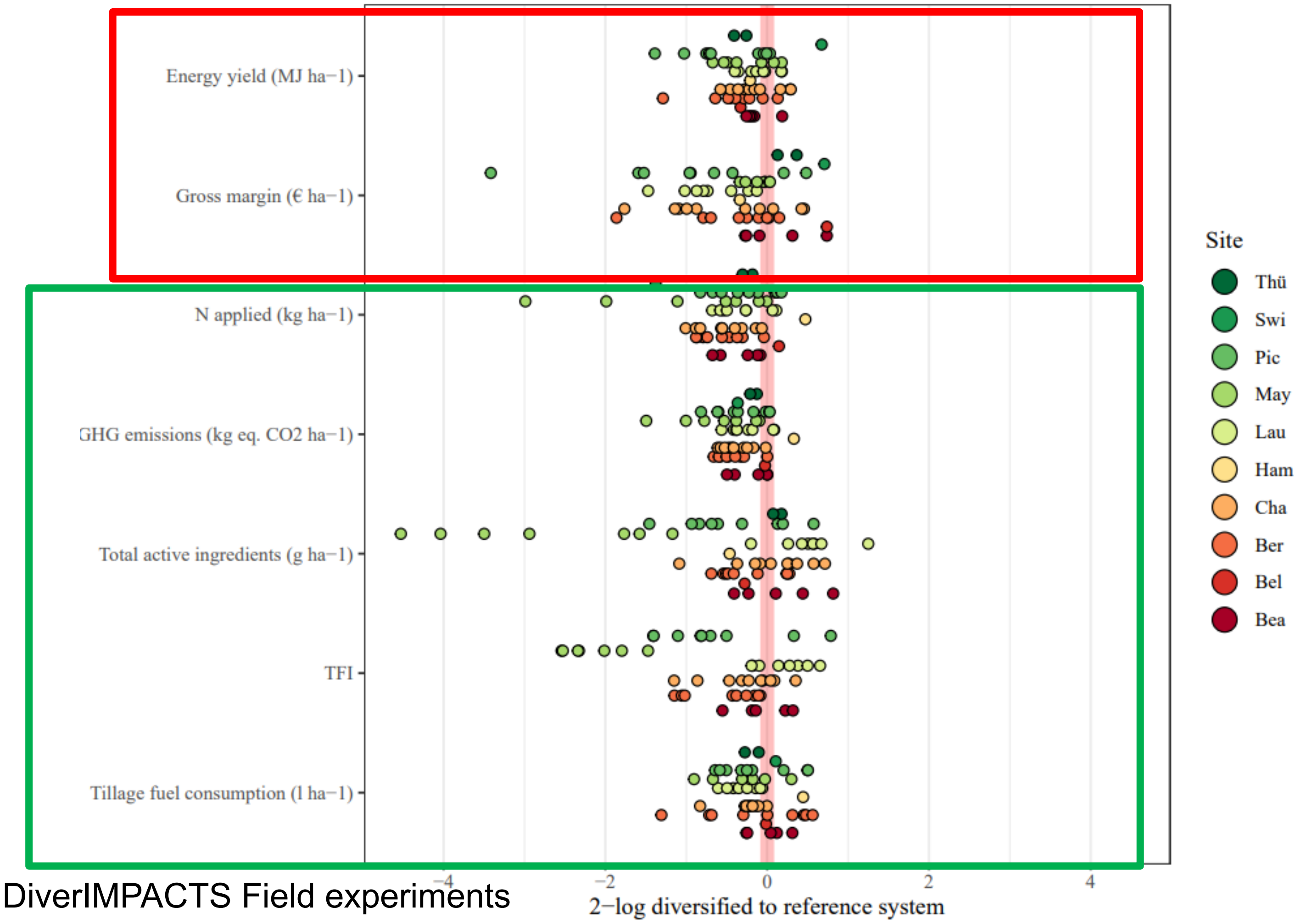
🟩 Indicators ultimately available in all FEs

⬛ Indicators available only in several FES

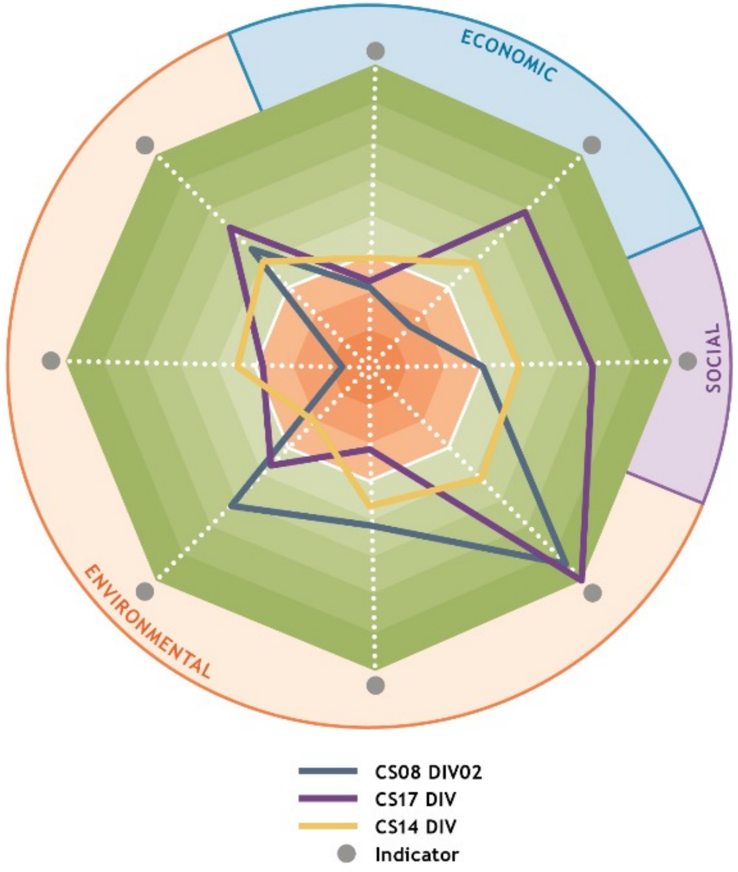
1 Higher arable land productivity	2 Diversification and increase of farmers revenues	3 Lower environmental impact of diversified cropping systems	4 Improved delivery of ecosystem services
🟩 Yield. 🟩 Quality of harvested products (% protein, % oil). 🟩 Aboveground biomass of harvested and not harvested products. ⬛ LER for intercrops. ⬛ Variability (min Yield, max yield during the rotation; number of crops with a yield lower than…). 🟩 Energy efficiency. 🟩 Total energy production.	🟩 Gross margins. 🟩 Input costs. 🟩 Mechanization costs. 🟩 Production costs. 🟩 Economic efficiency. 🟩 Diversity of type of products. 🟩 Number of species with a high added value. 🟩 Salary costs and family labour remuneration. 🟩 Direct and Net margin.	🟩 Water use. 🟩 Pesticide use (Active ingredient, Treatment Frequency Index). 🟩 Energy use (Primary, Useful). 🟩 N use. 🟩 Yield/water use, /pesticide use, energy use, fertiliser use. 🟩 N balance. 🟩 GHG emissions. 🟩 Risk of N leaching. 🟩 Fuel consumption.	⬛ Earthworm abundance and diversity. ⬛ Decomposition of organic matter. ⬛ Arthropod abundance and diversity. ⬛ Weeds, pest and disease control. ⬛ (Weed biomass, Weed diversity, Pests and diseases) ⬛ N capture by catch crops. ⬛ N2 fixation. ⬛ C sequestration. ⬛ Soil cover. ⬛ N capture by catch crop.

- Not all indicators are available in all FEs
- The rotation scale requires gathering several growing seasons both in its spatial and temporal dimensions

Trade-offs exist across sites and within sites



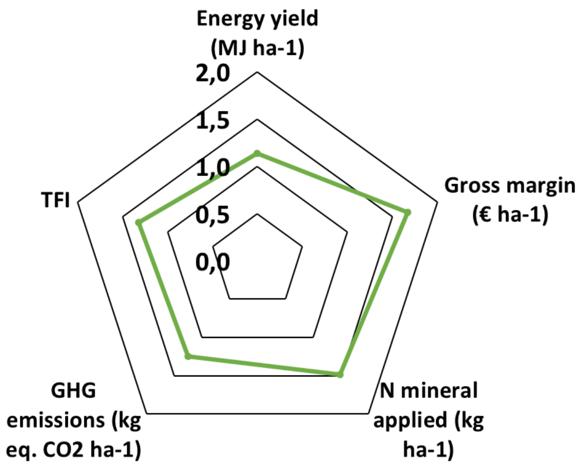
DiverIMPACTS Field experiments



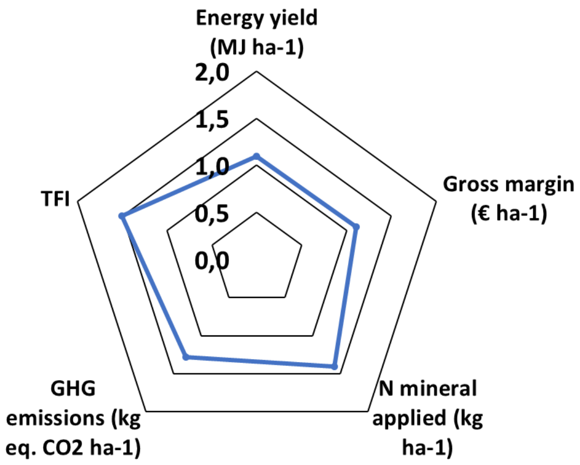
Performances of diversified systems / reference systems

There exist some diversified systems that mitigate trade-offs

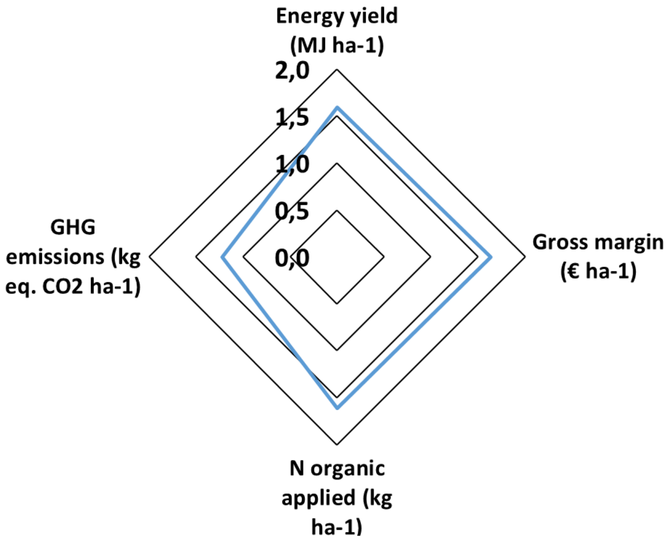
Very low diversity reference (conventional)



Low diversity reference (conventional)



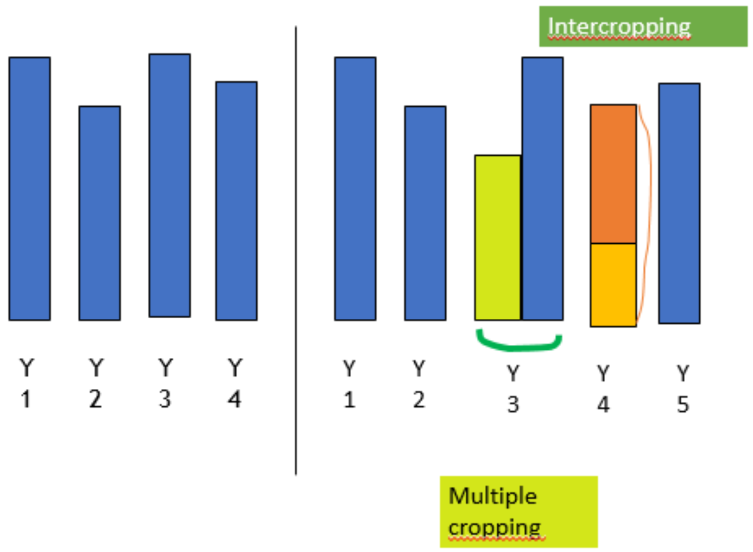
Relatively high diversity reference (organic)



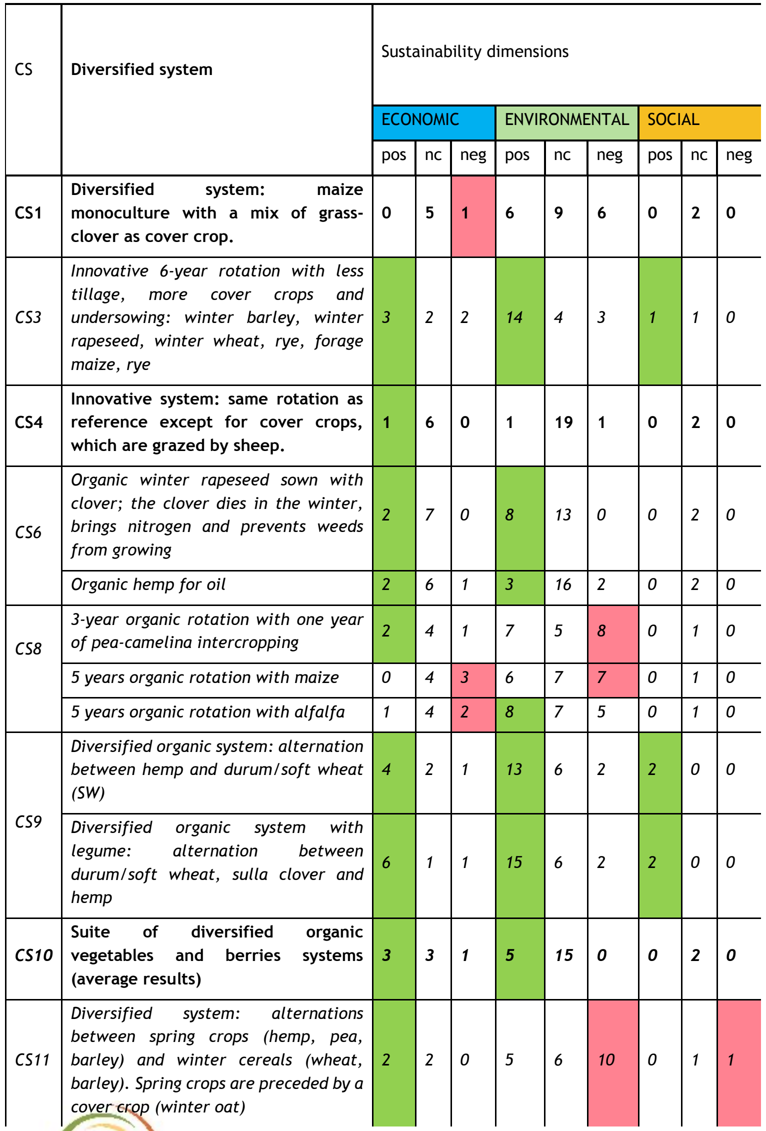
Performances of 4-year long diversified crop sequences relative to their respective reference in the network of 10 field experiments in DiverIMPACTS).

The ingredients for a successful crop diversification have been identified

1. Maintain a significant proportion of dominant species in the diversified system
2. Add minor crops to increase global ecosystem service provision
3. Use « compensatory strategies » to increase and secure yields while increasing global ecosystem service provision
4. Combine levers - system approach
5. Use an adaptive management to face uncertainities and to adapt to evolving pedo-climatic and socio-economic factors



Similar findings observed in case studies



CS	Diversified system	Sustainability dimensions								
		ECONOMIC			ENVIRONMENTAL			SOCIAL		
		pos	nc	neg	pos	nc	neg	pos	nc	neg
CS1	**Diversified system: maize monoculture with a mix of grass-clover as cover crop.**	0	5	1	6	9	6	0	2	0
CS3	*Innovative 6-year rotation with less tillage, more cover crops and undersowing: winter barley, winter rapeseed, winter wheat, rye, forage maize, rye*	*3*	*2*	*2*	*14*	*4*	*3*	*1*	*1*	*0*
CS4	**Innovative system: same rotation as reference except for cover crops, which are grazed by sheep.**	1	6	0	1	19	1	0	2	0
CS6	*Organic winter rapeseed sown with clover; the clover dies in the winter, brings nitrogen and prevents weeds from growing*	*2*	*7*	*0*	*8*	*13*	*0*	*0*	*2*	*0*
	Organic hemp for oil	*2*	*6*	*1*	*3*	*16*	*2*	*0*	*2*	*0*
CS8	*3-year organic rotation with one year of pea-camelina intercropping*	*2*	*4*	*1*	*7*	*5*	*8*	*0*	*1*	*0*
	5 years organic rotation with maize	*0*	*4*	*3*	*6*	*7*	*7*	*0*	*1*	*0*
	5 years organic rotation with alfalfa	*1*	*4*	*2*	*8*	*7*	*5*	*0*	*1*	*0*
CS9	*Diversified organic system: alternation between hemp and durum/soft wheat (SW)*	*4*	*2*	*1*	*13*	*6*	*2*	*2*	*0*	*0*
	Diversified organic system with legume: alternation between durum/soft wheat, sulla clover and hemp	*6*	*1*	*1*	*15*	*6*	*2*	*2*	*0*	*0*
CS10	**Suite of diversified organic vegetables and berries systems (average results)**	***3***	***3***	***1***	***5***	***15***	***0***	***0***	***2***	***0***
CS11	*Diversified system: alternations between spring crops (hemp, pea, barley) and winter cereals (wheat, barley). Spring crops are preceded by a cover crop (winter oat)*	*2*	*2*	*0*	*5*	*6*	*10*	*0*	*1*	*1*

- Effects of diversification depend on:
  - Local pedoclimatic conditions
  - Level of performances of the REF
  - Management of cropping practices in relation to objectives

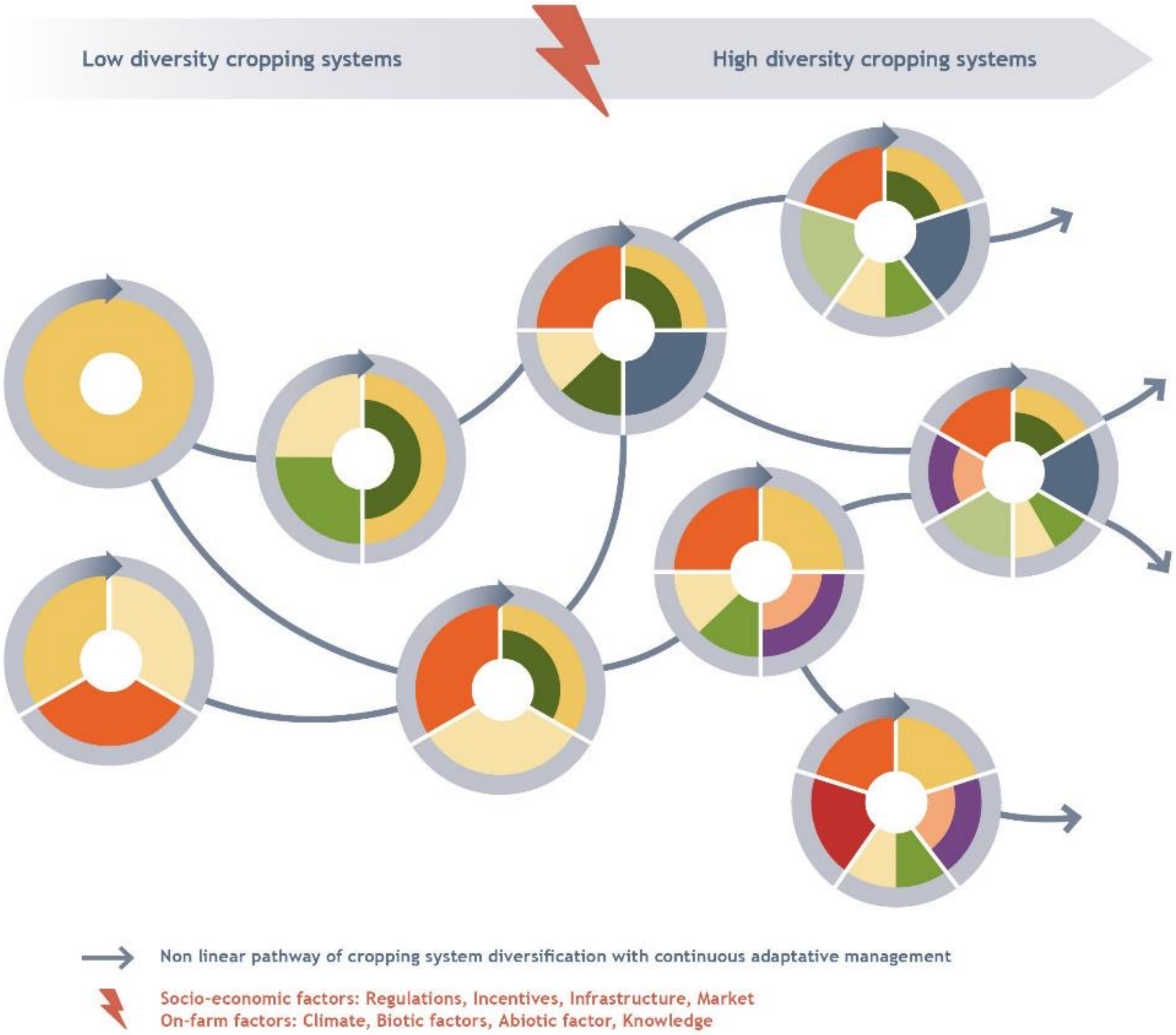
- Diversified cropping systems do not always outperform their reference in all indicators → trade-offs

- How to mitigate trade-offs:
  - Learnings, sharing knowledge
  - Use of *ad hoc* tools for driving DIV
  - Cooperation between actors of the value chain
  - Support from institutions

Crop diversification is a dynamic and nonlinear process

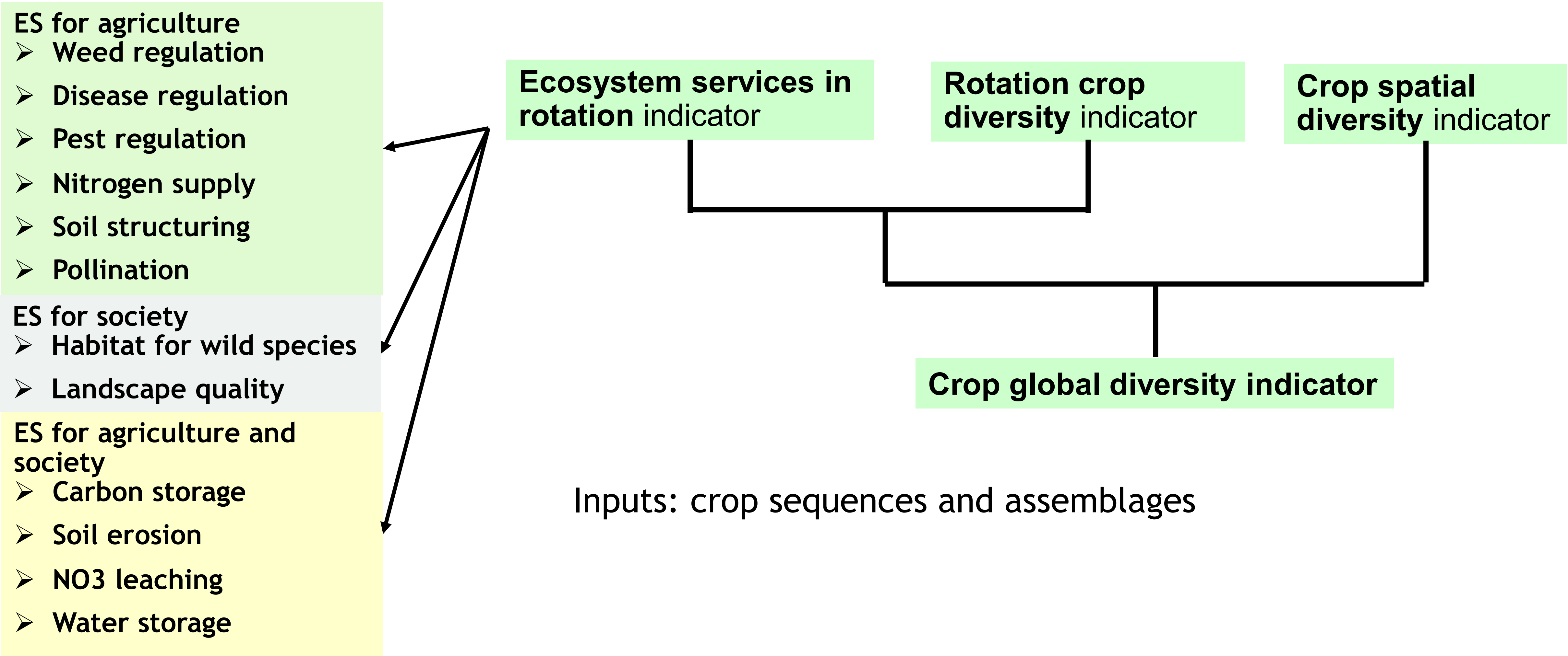
No “one size fits all” solution

- Solutions should be tailor-made to local contexts and needs;
- Climate change and long-term transition require continuous adaptation of cropping systems



→ Approaches and tools to support actors drive their pathway towards sustainable agrifood systems

Assessment tools to drive crop diversification at policy level



ES for agriculture
- Weed regulation
- Disease regulation
- Pest regulation
- Nitrogen supply
- Soil structuring
- Pollination

ES for society
- Habitat for wild species
- Landscape quality

ES for agriculture and society
- Carbon storage
- Soil erosion
- NO3 leaching
- Water storage

Ecosystem services in rotation indicator

Rotation crop diversity indicator

Crop spatial diversity indicator

Crop global diversity indicator

Inputs: crop sequences and assemblages

Keichinger et al ., (2021) Un indicateur évaluant la diversité globale des rotations : de la diversité des cultures aux services écosystémiques. *Agronomie, Environnement & Sociétés,*

Such an indicator helps assess the potential impacts of diversified on ecosystem services

Site	Modality	I-ES	Weed regulation	Disease regulation	Pest regulation	Nitrogen supply	Soil structuring	Pollination	NO3 leaching	Soil erosion	Carbon storage	Landscape quality	Habitat for wild species	Water storage
Bea	REF	0,22	0,13	0,38	0,50	0,00	0,12	0,08	0,50	0,24	0,50	0,11	0,28	0,29
Bea	DIV01	0,48	0,57	0,29	0,78	0,58	0,63	0,04	0,83	0,73	0,85	0,62	0,65	0,15
Bea	DIV02	0,44	0,70	0,19	0,82	0,22	0,60	0,02	0,68	0,79	0,85	0,69	0,88	0,21
Bel	REF	0,31	0,37	0,31	0,90	0,00	0,19	0,03	0,38	0,48	0,57	0,40	0,56	0,49
Bel	DIV	0,43	0,31	0,24	0,90	0,27	0,42	0,23	0,70	0,56	0,67	0,47	0,64	0,48
Ber	REF	0,45	0,43	0,42	0,97	0,05	0,55	0,27	0,54	0,62	0,63	0,59	0,61	0,62
Ber	DIV01	0,52	0,38	0,80	0,92	0,39	0,61	0,32	0,74	0,53	0,66	0,49	0,54	0,44
Ber	DIV02	0,52	0,38	0,70	0,93	0,33	0,68	0,32	0,68	0,53	0,63	0,50	0,58	0,48
Swi	REF	0,49	0,54	0,38	1,00	0,43	0,57	0,33	0,29	0,52	0,57	0,54	0,55	0,65
Swi	DIV	0,50	0,48	0,07	0,90	0,53	0,65	0,40	0,46	0,60	0,72	0,60	0,61	0,64

🟥 Low ES

🟩 High ES

Implications for actionable knowledge

- Challenges
  - Agroecology transition means no “one-size-fits-all” solution anymore
  - Climate change increases the level of uncertainty
  - A new vision of systems efficiency is required
    - Different spatial and temporal scales
    - New criteria/indicators
    - Actors’ preferences to be considered
- Change of paradigm for research & development
  - Drive pathways for transition rather than proposing “ready-to-use” systems
  - Participatory approaches and on-farm experiments to complement field experiments
  - Diversity of ways to produce actionable knowledge

Participatory design with actors:
Development of camelina for a biorefinery

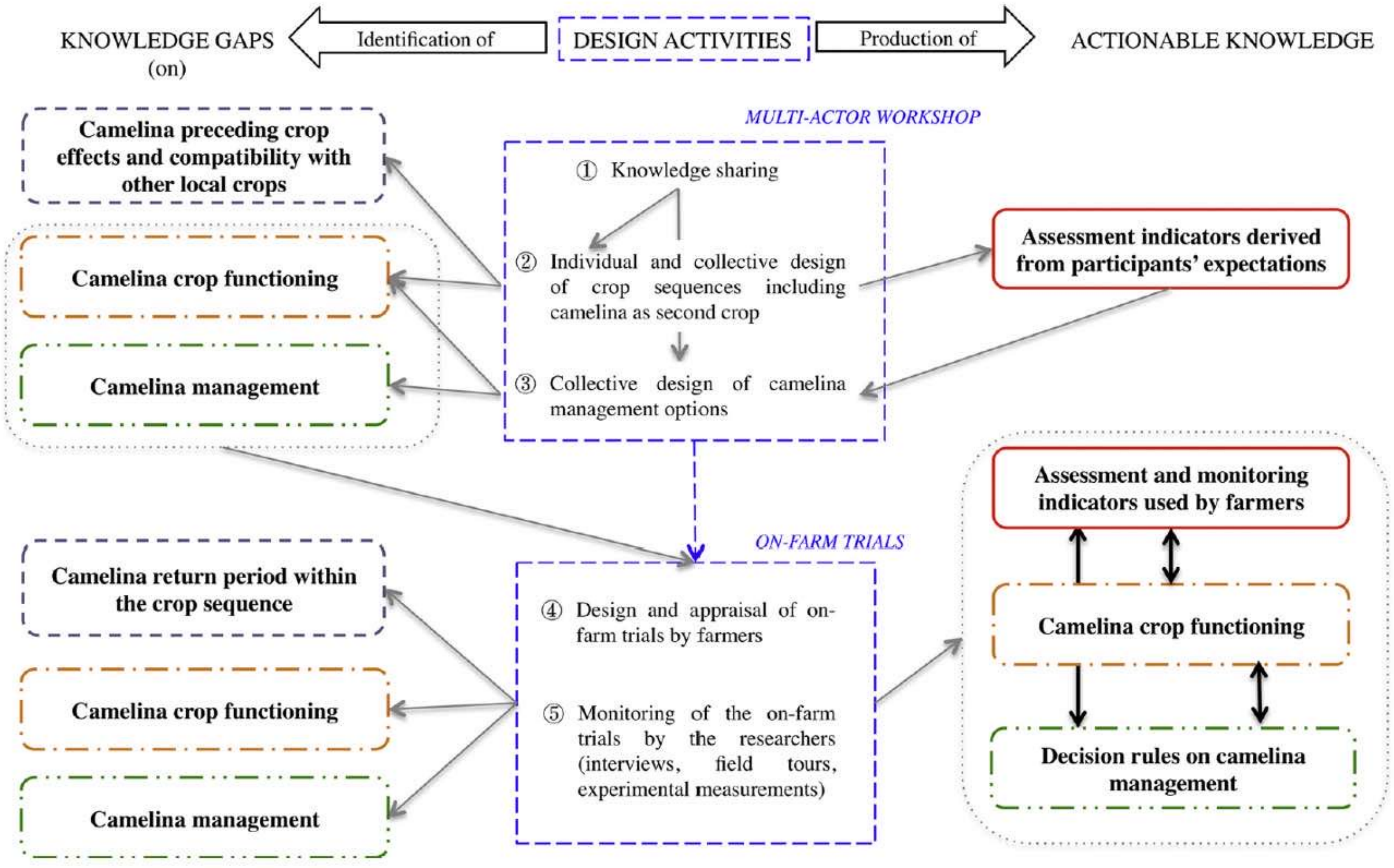


Fig. 1. A participatory design approach to produce actionable knowledge and identify knowledge gaps.

Contents lists available at ScienceDirect

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Growing camelina as a second crop in France: A participatory design approach to produce actionable knowledge

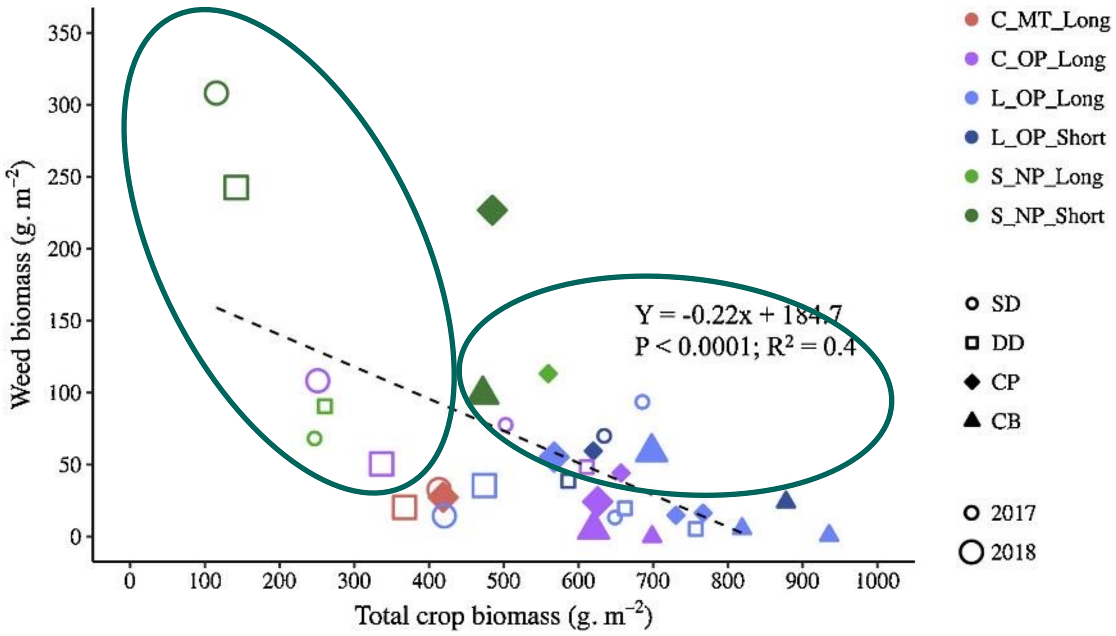
Margot Leclère*, Chantal Loyce, Marie-Hélène Jeuffroy

UMR Agronomie, INRA, AgroParisTech, Université Paris-Saclay, F-78850 Thiverval-Grignon, France

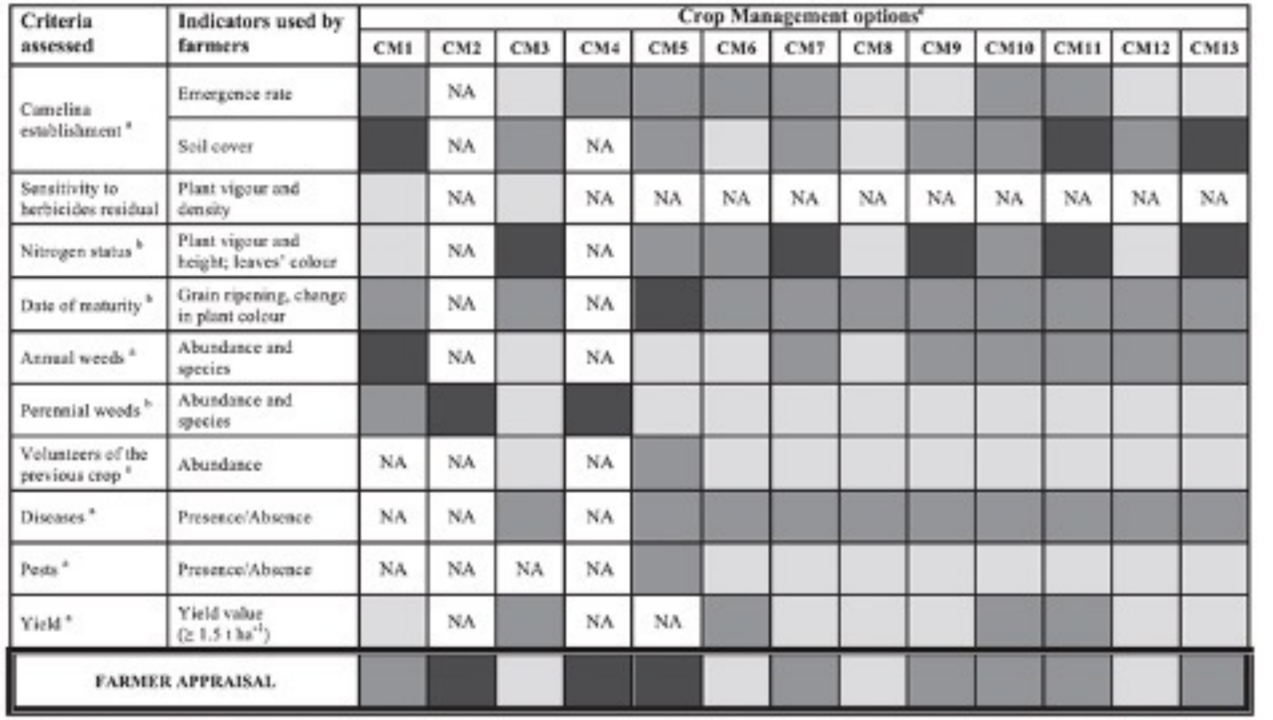
Participatory design with actors: development of camelina for a biorefinery

Multi-local field experiments designed by scientists

Introduction of camelina designed and assessed by farmers



Quantitative knowledge on a specific process



Criteria assessed	Indicators used by farmers	Crop Management options[c]												
		CM1	CM2	CM3	CM4	CM5	CM6	CM7	CM8	CM9	CM10	CM11	CM12	CM13
Camelina establishment [a]	Emergence rate	▒	NA	░	▒	▒	▒	▒	░	░	▒	▒	░	░
	Soil cover	█	NA	▒	NA	▒	░	▒	░	▒	▒	█	▒	█
Sensitivity to herbicides residual	Plant vigour and density	░	NA	░	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nitrogen status [b]	Plant vigour and height; leaves' colour	░	NA	█	NA	▒	▒	█	░	█	▒	█	░	█
Date of maturity [b]	Grain ripening, change in plant colour	▒	NA	▒	NA	█	▒	▒	▒	▒	▒	▒	▒	▒
Annual weeds [a]	Abundance and species	█	NA	░	NA	░	░	▒	░	▒	▒	▒	▒	▒
Perennial weeds [b]	Abundance and species	▒	█	░	█	░	░	░	░	░	░	░	░	░
Volunteers of the previous crop [a]	Abundance	NA	NA	░	NA	▒	░	░	░	░	░	░	░	░
Diseases [a]	Presence/Absence	NA	NA	▒	NA	▒	▒	▒	▒	▒	▒	▒	▒	▒
Pests [a]	Presence/Absence	NA	NA	NA	NA	▒	░	░	░	░	░	░	░	░
Yield [a]	Yield value (≥ 1.5 t ha^{-1})	░	NA	▒	NA	NA	▒	░	░	░	▒	▒	░	░
FARMER APPRAISAL		▒	█	░	█	█	░	▒	░	▒	▒	▒	░	▒

Fig. 3. Farmers' qualitative appraisal of the on-farm trials (Light grey = satisfactory, Dark grey = satisfactory but with some concerns, Black: unsat Non-assessed).

Qualitative assessment of camelina introduction by farmers

DiverIMPACTS

(Leclère, 2019)

Farmer Innovation Tracking

Characterization of farmer innovation tracking projects

Testimonies (video, stories

Functional knowledge

Diversity of options to reach a target

Generic action logics

Decision rules

Contributions of farmer innovation tracking to design processes:

- giving rise to « creative anomalies »
- shedding light on systemic mechanisms to fuel design processes on other farms
- uncovering research questions
- stimulating design in orphan fields of innovation
- circulating innovation concepts
- connecting farmer-designers with each other practices.

Salembier et al., 2021. A theoretical framework for tracking farmers' innovations to support farming system design

Which implications for LTE?
Learnings from the platform CA-SYS - INRAE Dijon (2018-)

S. Cordeau & V. Deytieux

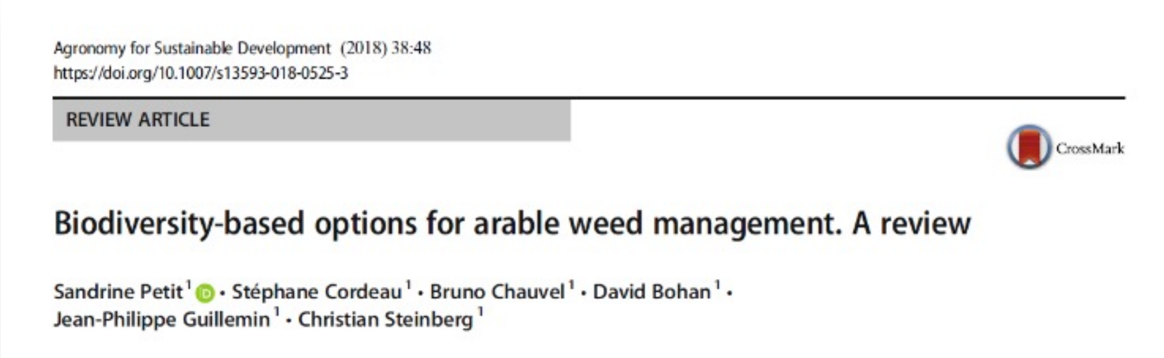
Design and test the feasibility and performances of pesticide-free agriculture (no biopesticide either) using (cropped and wild) biodiversity in support of production

= Biodiversity-based agriculture

Aspects of Applied Biology ***128***, *2015*
Valuing long-term sites and experiments for agriculture and ecology

Towards the establishment of an experimental research unit on Agroecology in France

By STEPHANE CORDEAU[1], VIOLAINE DEYTIEUX[2], PHILIPPE LEMANCEAU[1] and PASCAL MARGET[1,2]



Agronomy for Sustainable Development (2018) 38:48
https://doi.org/10.1007/s13593-018-0525-3

REVIEW ARTICLE

CrossMark

Biodiversity-based options for arable weed management. A review

Sandrine Petit[1] · Stéphane Cordeau[1] · Bruno Chauvel[1] · David Bohan[1] · Jean-Philippe Guillemin[1] · Christian Steinberg[1]

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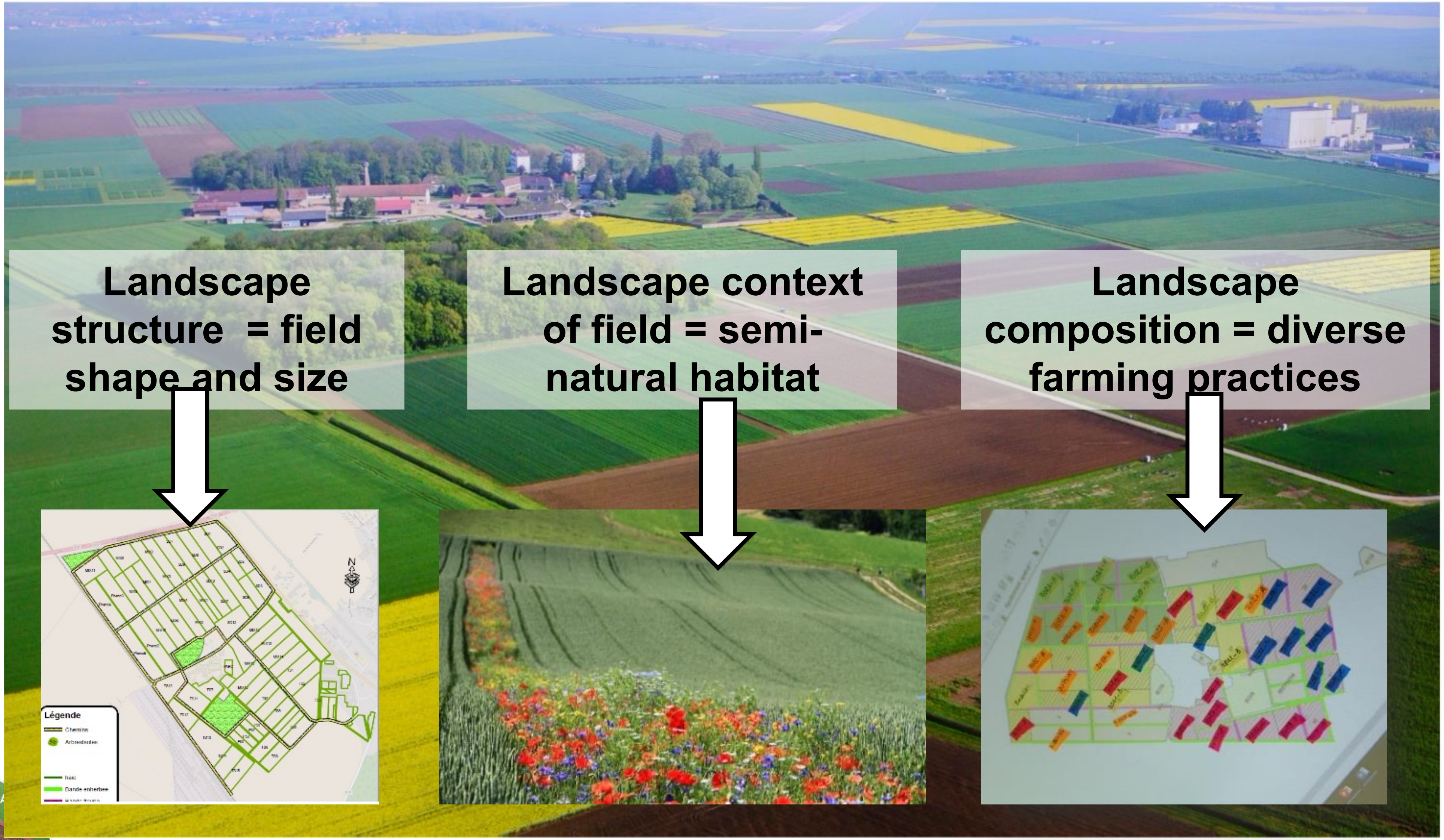
CA-SYS = transformative landscape change



Landscape structure = field shape and size

Landscape context of field = semi-natural habitat

Landscape composition = diverse farming practices

Plateforme CA-SYS

Co-designed Agroecological System Experiment
Plateforme d'expérimentation collaborative en agroécologie à différentes échelles

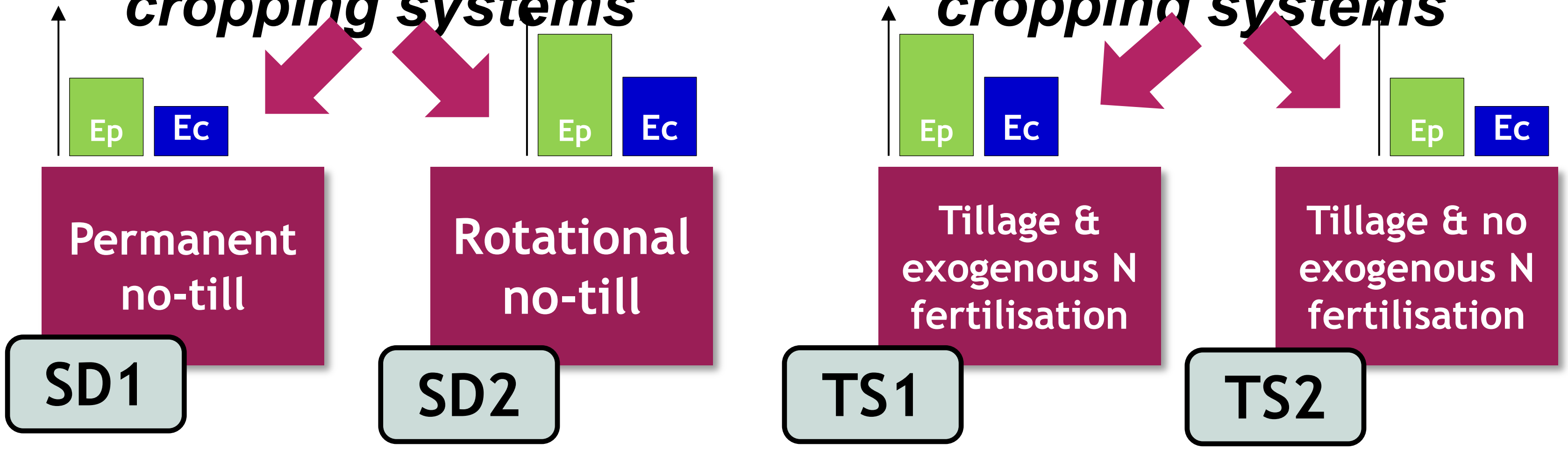
Testing four cropping system strategies

Conservation Agriculture

Two direct-drilling cropping systems

Tillage (T)

Two plowing-based cropping systems



Permanent no-till

SD1

Rotational no-till

SD2

Tillage & exogenous N fertilisation

TS1

Tillage & no exogenous N fertilisation

TS2

Energetic efficiency = Ep : Energy produced (productivity) / Ec : Energy consumed

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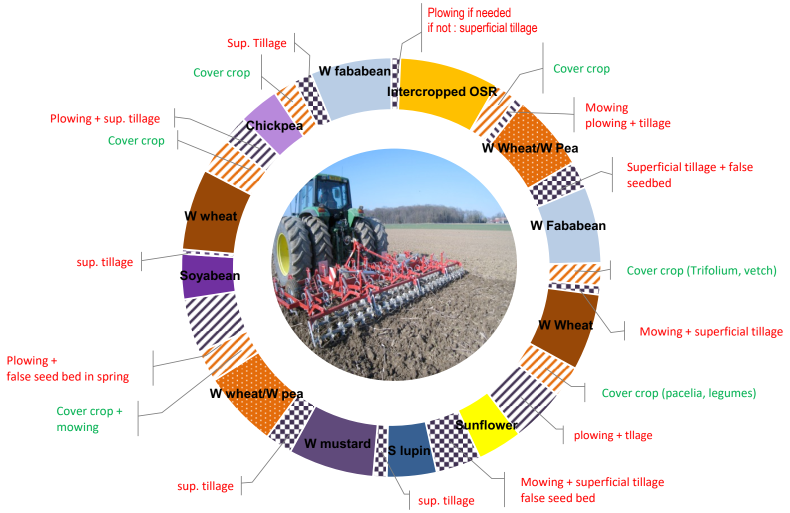
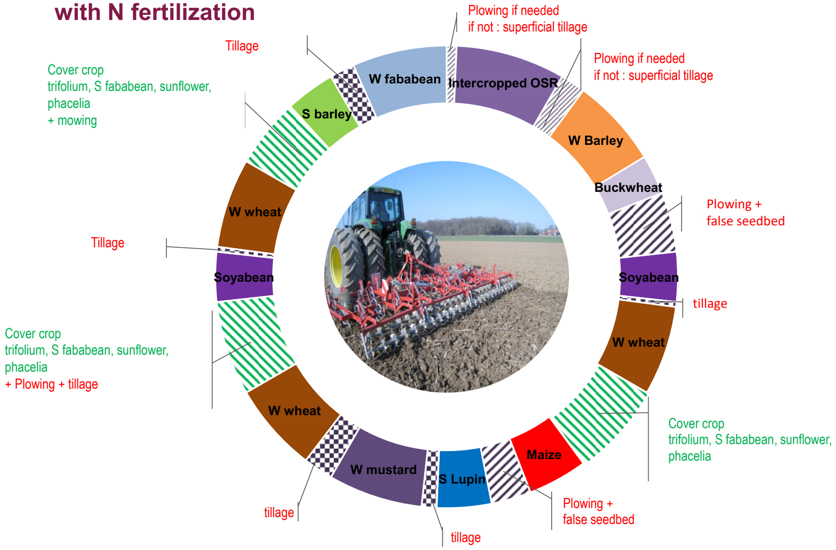
Plateforme CA-SYS

Co-designed cropping systems

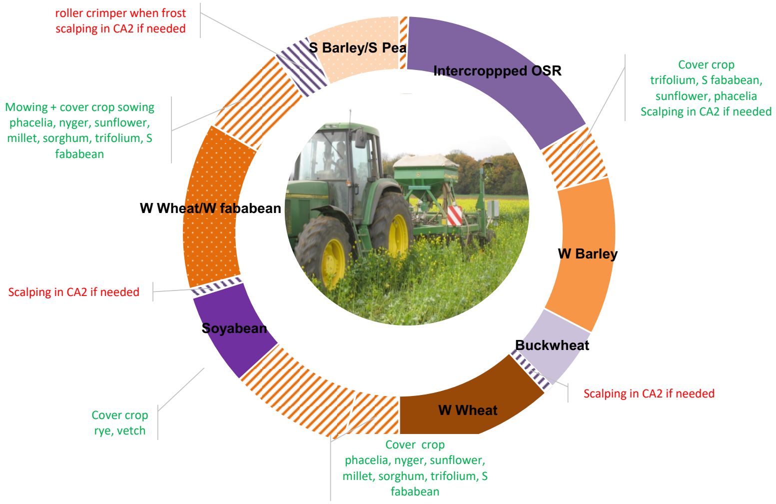
Plowing-based system P2
without N fertilization



Plowing-based system P1
with N fertilization

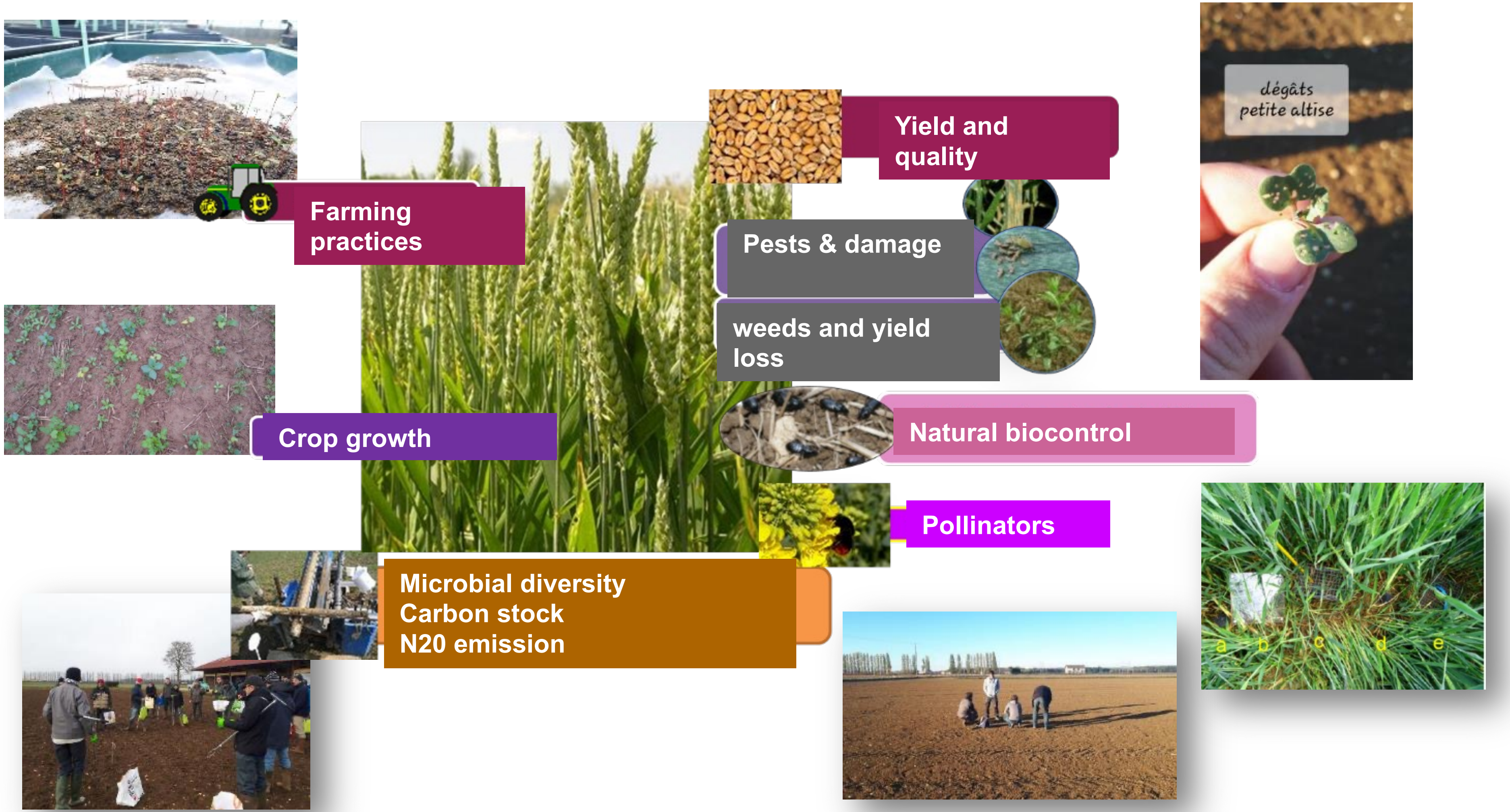


Conservation Agriculture systems
CA1 and CA2



Plateforme CA-SYS

Field measurements



Farming practices

Crop growth

Yield and quality

Pests & damage

weeds and yield loss

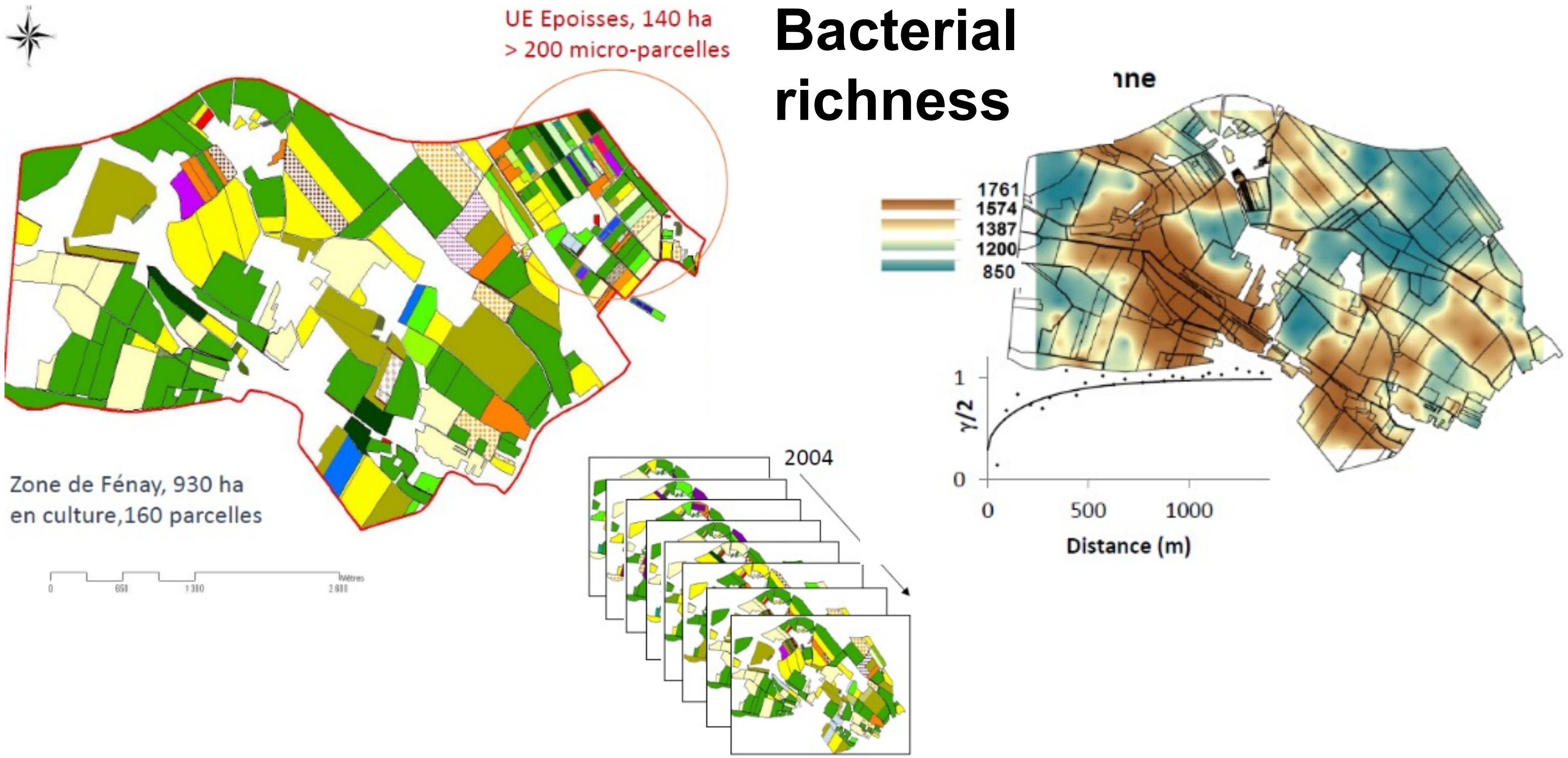
Natural biocontrol

Pollinators

Microbial diversity
Carbon stock
N20 emission

To study the transition toward agroecological systems …

- A need for a reference or baseline?



Bacterial richness

Plateforme CA-SYS - INRA Dijon
S. Cordeau & V. Deytieux

Issues and challenges

- Choice of control
    - Similar conventional territory in the vicinity → representativeness?
    - Baseline of the site and monitoring of changes over time
        - How to account for effects of external drivers (climate, markets)
        - Representativeness of the baseline
- Effects of semi-natural habitats vs those of in-field diversity
- Feasibility of estimating the costs of agroecological transition
- Conservation agriculture without herbicides has not been working so far

Conservation agriculture without pesticides has not been working

Permanent no-till area

- Management of crop volunteers and grass weeds
- Weed communities rapidly change towards Asteraceae, grasses and perenials
- N fertilisation do not enhance cover crop weed suppressiveness

→ Increase crop and cover crop seeding rate

→ Rethink the use of strip tillage and inter-row mowing to ensure crop establishment

→ Adapt cover crop composition to pesticide-free termination method

Rotational no-till area

- Superficial tillage difficult to implement to ensure complete cover termination while limiting its impact on soil organisms
- Mechanical weeding challenged by crop residues on surface

Conclusion - discussion points on LTEs

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Foulum, 7 June 2022

How to accompany agroecological transition while we still need to understand the functioning of innovative agroecosystems

1. Step by step design of cropping systems with actors:
    - Pros:
        - Build on existing locally-adapted systems
        - Adaptive over time
    - Challenges:
        - How to draw generic lessons from on-site step-by-step design
2. Understanding of long-term effects of diversified systems on ecosystem services
    - Focus on processes
    - Challenges:
        - Crucial role of initial design
        - Tension between adaptation to fix problems and time necessary to yield benefits of agroecological practices
        -

DiverIMPACTS

How to articulate innovation tracking, on-farm experiments, on-station experiments and long-term experiments

- Towards a community of practitioners of “farmers-experimenters” and “researchers-experimenters”
    - Explore similar innovations – Share experiences
- Articulate experiments rather than integrating them?

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