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“On-farm research for efficient organic matter management in low-input farming systems”

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(Paradiso V, 41-2)

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Il dr. Carlo Ponzio ha richiesto di poter presentare la tesi in inglese dal titolo: "*On-farm research for efficient organic matter management in low-input farming systems*". La tesi è stata sviluppata con un approccio fortemente interdisciplinare e ha interessato lo studio di modalità alternative di gestione della sostanza organica - sia sotto il profilo qualitativo che quantitativo - in agroecosistemi diversificati, con l'obiettivo di osservare l'effetto di pratiche agronomiche peculiari del metodo dell'agricoltura biologica e biodinamica su produzione di biomassa, accrescimento ed architettura radicale e metabolismo microbico.

L'attività svolta dal Dott. Ponzio durante il triennio di dottorato si è articolata in attività formativa e attività di ricerca. Il dott. Ponzio ha partecipato a seminari e a corsi di approfondimento riguardanti principalmente i sistemi di studio della sostanza organica, della crescita delle radici e le modalità di ricerca "on farm". L'attività didattica è stata inoltre arricchita dalla partecipazione a convegni e ad incontri di tipo tecnico. Nell'ambito delle attività concordate con il Collegio dei Docenti ha tenuto un seminario bibliografico dal titolo "On farm research in agricultural studies"

L'attività sperimentale è stata svolta con un approccio "on-farm", in collaborazione con due agricoltori marchigiani e un gruppo di agricoltori dello Swaziland nell'ambito di un progetto internazionale. Questo approccio, pur con i suoi limiti, ha consentito di valutare l'effetto delle pratiche colturali in studio come integrate nel più ampio contesto aziendale. Nel caso delle Marche sono state effettuare prove anche *ex-situ*, cioè in laboratorio e in serra, utilizzando un approccio riduzionistico necessario ad isolare gli effetti dei trattamenti da sorgenti di variabilità non controllabili in pieno campo. Sono stati eseguiti 4 casi di studio:

Caso di studio 1: *On farm research* in aziende agricole marchigiane.

Una prova di comparazione agronomica con tre trattamenti a base di preparati biodinamici e di sovescio è stata effettuata in due aziende agricole, una biodinamica (con rotazione triennale) e l'altra biologica (oliveto), entrambe nel comune di San Severino Marche (MC). Parametri di produzione di biomassa e accrescimento aereo e radicale in olivo sono stati misurati, anche verificando con gli agricoltori la praticabilità delle tecniche colturali eseguite.

Caso di studio 2. Misura di metabolismo microbico in substrato costituito da terreno di azienda biologica con aggiunta di sostanza organica vegetale e "500 preparato". Con questo esperimento, condotto in laboratorio in condizioni controllate, si è voluto verificare se e in che misura il “500 preparato” influenza l’attività microbica in un suolo agrario, con presenza o assenza di materiale vegetale facilmente degradabile (sovescio). E' stata pertanto misurata la respirazione giornaliera e la respirazione cumulativa al termine del periodo d'incubazione (42 giorni). E' stato inoltre misurato il C da biomassa microbica relativo ai quattro trattamenti.

Caso di studio 3. Osservazione della crescita e dell'architettura radicale di piante di olivo in rizotroni da tavolo. L’esperimento, effettuato in serra in condizioni di temperatura e umidità controllate, ha avuto l'obbiettivo di valutare la potenziale capacità del “500 preparato” di mitigare l’azione fitotossica della sansa e di influenzare la radicazione.

Caso di studio 4. Esperienze di on-farm research in Swaziland. Per l'esecuzione di questo caso di studio è stato trascorso in Swaziland un periodo complessivo di 4 mesi, nel corso del triennio di Dottorato, nell'ambito di un progetto internazionale gestito da una ONG italiana e dal locale Ministero dell'Agricoltura. Lo studio effettuato dal candidato ha interessato le modalità di svolgimento di un programma finalizzato all'introduzione di innovazioni tecniche a livello comunitario (4 comunità di piccoli agricoltori coinvolti). Pratiche colturali finalizzate al miglioramento della gestione della sostanza organica e della fertilità del suolo sono state applicate sperimentalmente su piccola scala e discusse con gli agricoltori partecipanti alla prova, per testarne l'applicabilità ed efficacia in seno all'agroecosistema.

Il dott. Ponzio nell’ambito del triennio di dottorato ha trascorso un periodo di 2 mesi presso General Commission for Scientific Agricultural Research - GCSAR (Siria) e di 3 mesi in Swaziland presso la sede del progetto di cooperazione oggetto di tesi. Queste esperienze internazionali sono state importanti nella formazione dell’approccio multidisciplinare e on farm utilizzato nella tesi.

Nel corso del triennio il dott. Ponzio ha presentato al "4th International QLIF Training and Exchange workshop. Soil nitrogen: research and extension" tenutosi al Louis Bolk Instituut, Driebergen, The Netherland nel febbraio 2008, un poster su “Effect of biodynamic preparation on biomass production”. Nel giugno 2008 ha partecipato in qualità di relatore alla conferenza tematica “Organic Fruit”, organizzata dall’International Society for Horticultural Science (ISHS), Commission “Sustainability Through Integrated and Organic Horticulture”, nell’ambito del 16th IFOAM Organic World Congress con una relazione dal titolo *Olive Root Growth With Different Organic Matters* (Autori: V. Giorgi, C. Ponzio, S. Polverigiani, G. Savini, E.M. Lodolini, F. Massetani and D. Neri) e incluso negli Atti ISHS. Nel 2009 è stato organizzatore e relatore al convegno tenutosi a Jesi in giugno sulle attività di ricerca svolte nell'ambito del progetto regionale "Agricoltura Biologica – Incremento della fertilità nei terreni".

Il Collegio dei Docenti, considerata l'entità del lavoro svolto, il costante impegno profuso, la difficoltà dell'approccio on farm e i buoni risultati raggiunti, esprime la sua completa soddisfazione ed il suo apprezzamento sull'attività svolta dal dott. Carlo Ponzio nell'intero periodo di dottorato.

Il Collegio dei Docenti delibera pertanto di ammettere il dott. Carlo Ponzio all'esame finale per il conseguimento del titolo di Dottore di ricerca in "Produzioni vegetali e ambiente" con la presentazione di una tesi redatta in lingua inglese dal titolo: "*On-farm research for efficient organic matter management in low-input farming systems*", SSD AGR03.

Abstract

This thesis work has the objective to study alternative ways of managing the organic matter in diverse agro-ecosystems, focusing on both quantitative and qualitative aspects.

The effect of several organic matter-based farming practices, that are characteristic of the organic and biodynamic method, on biomass production, productivity, and soil microbial activity has been investigated through a multidisciplinary approach that embraced on-farm trials as well as reductionist greenhouse and laboratory experiments.

The open field trials have been conducted in organic commercial farms in the Marche region and in low inputs small subsistence farms in the African Kingdom of Swaziland. In both cases, the farmers were involved as "partners" in the research, which allowed to get a system perception on the efficacy and feasibility of the investigated techniques, and helped to highlight main constraints in organic matter management.

Over the three years of the PhD study, five experiments were carried out:

- Laboratory experiment to test phytoxocity effect due to diverse organic matters;
- Greenhouse experiment to assess the effect of one biodynamic preparation on the germination of a highly-diversified green manure mixture;
- On-farm research in two biodynamic and organic farm in the Marche region (Italy) to investigate the effect on arable crops productivity and olive growth of diverse combinations of organic matters (qualitative and quantitative);
- Laboratory experiment to investigate the effect of one biodynamic preparation on soil microbial metabolism;
- On-farm research in Swaziland (Africa) to assess alternative organic matter managements in a small-scale subsistence farming system, through a community-based approach.

It is concluded that when low inputs cropping systems have to be performed, the appropriate use and recycling within the farm of organic matter becomes crucial to optimize nutrients flows as well as maintain overall soil fertility at acceptable levels. Highly humified organic matter showed to be quite effective in stimulating soil microbial activity, even in low doses, whereas the practice of "massive" green manuring proved to promote plant production although its feasibility is highly bound to the site characteristics.

The on-farm methodology turned to be useful in formulating applicable research objectives, close to the farmers needs, and to test the field feasibility and adaptability of the technical solutions under the farmers' perspective in two far socio-economic and cultural contexts. However, the inevitable experimental simplification did not allow to achieve highly significant statistical results.

Abstract

Il presente lavoro di tesi ha l'obbiettivo di studiare alternative modalità di gestione della sostanza organica in diversi agroecosistemi, evidenziando sia gli aspetti qualitativi che quantitativi.

L'effetto di differenti pratiche colturali basate sulla gestione della sostanza organica, caratteristiche del metodo biodinamico e biologico, sulla produzione di biomassa, produttività e sul metabolismo microbico del terreno è stato investigato attraverso un approccio multidisciplinare, che ha compreso prove di campo on-farm e anche esperimenti in serra e in laboratorio con metodo riduzionistico.

Le prove in pieno campo sono state condotte in aziende commerciali nella regione Marche e in piccole aziende basate sull' auto-sussistenza alimentare nello stato africano dello Swaziland. In entrambi i casi, gli agricoltori sono stati coinvolti nell'iniziativa alla stregua di veri e propri partner della ricerca; ciò ha consentito di ottenere una visione di sistema sull'efficacia e fattibilità delle tecniche investigate; inoltre questo approccio ha aiutato a mettere in luce i principali inconvenienti nella gestione della sostanza organica.

Durante i tre anni di ricerca di dottorato, cinque esperimenti sono stati effettuati:

- *Esperimento di laboratorio per testare la fitotossicità di diverse sostanze organiche;*
- *Esperimento in serra per valutare l'effetto di una determinata preparazione biodinamica sulla germinazione di un miscuglio polifita da sovescio;*
- *Ricerca on-farm in due aziende commerciali biodinamiche e biologiche nella regione Marche (Italia) per investigare l'effetto di diverse combinazioni di sostanze organiche sulla produttività di seminativi e crescita di olivo;*
- *Esperimento di laboratorio per valutare l'effetto di una preparazione biodinamica sul metabolismo microbiologico del terreno;*
- *Ricerca on-farm in Swaziland (Africa) per valutare modalità alternative di gestione della sostanza organica in un sistema colturale di piccola scala, basato sull'auto-sussistenza alimentare, mediante un approccio comunitario.*

Si conclude che sistemi colturali basati su bassi inputs richiedono un uso appropriato della sostanza organica, fondato sul suo riciclo aziendale, per ottimizzare i flussi di nutrienti e per mantenere la fertilità del terreno a livelli accettabili. Sostanza organica altamente umificata ha mostrato di stimolare efficacemente l'attività microbica del terreno, anche a dosi molto basse, mentre dosi elevate di concimazione verde hanno favorito la produzione di biomassa vegetale, sebbene la sua applicabilità sia molto legata alla tipologia del sito. La metodologia "on-farm" si è rivelata utile per formulare obbiettivi di ricerca vicini ai bisogni degli agricoltori, e per testare in campo la fattibilità delle soluzioni tecnologiche proposte dal punto di vista di agricoltori appartenenti a contesti socio-economico-culturali molto lontani tra loro. Tuttavia, la semplificazione del disegno sperimentale, inevitabile in questa tipologia di esperimenti, non ha consentito di ottenere risultati altamente significativi sul piano statistico.

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PREAMBLE

During the last decades, agricultural production and yields have been increasing in the industrialized countries along with global fertilizer and pesticide consumption. The growing global trade with agricultural products and the improved access to pesticides and fertilizers have changed agricultural systems. Easier transportation and communication have enabled farms to buy their inputs and sell their products further away and in larger quantities. This development resulted in increased food security, whereas a greater variety of food has been offered and diets have changed towards a greater share of meat and dairy products.

However, such trend has led to a growing disparity among agricultural systems and populations, where especially developing countries in Africa have seen very few improvements in food security and production. At the same time, the application of inappropriate farming techniques and the sharp increase of farming inputs use have contributed, in more exposed sites, to the rise of environmental problems such as drastic reduction in biodiversity, soil degradation, pollution of surface and groundwater with nitrates and pesticides and, to a less extent, global warming (Tilman et al., 2002).

Modern high-inputs agriculture is highly relying on fossil energy. However, only one third of the fossil energetic input is used to run farm operations (e.g. diesel fuel): the other two thirds are spent off-farm, to produce farming inputs (Helsel, 1992). According to Loomis and Connors (1992), most of the agricultural industry's energy requirement is attributable to the manufacturing of mineral nitrogen, that takes from 30% to 50% of the overall fossil energy use in agriculture. This aspect, despite the fact that the production of nitrogen fertilizers accounts just for about 1.2% of the overall fossil energy used worldwide (Erisman et al., 2009), becomes rather worrying when it is considered from the standpoint of reactive nitrogen and greenhouse gas emissions (Ceotto and Di Candilo, 2010).

Nitrous oxide (N_2O) is the most worrisome greenhouse gas with a 100-year average global warming potential (GWP), 296 times larger than that of CO_2 (Crutzen et al., 2009). Farming N_2O emissions are represented by all the "newly-fixed nitrogen" both under the shape of synthetic fertilizers, added to the soil, and biologically-fixed N (Ceotto and Di Candilo, 2010). Nitrous oxide originates from the process of denitrification, and its rate of emission is directly proportional, among others, to the availability of mineral nitrogen in the soil (Mosier, 2001; Crutzen et al., 2009). Hence, agricultural methods that make use of relevant and systematic inputs of synthetic nitrogen fertilizers, without particular care in recycling that nitrogen, are those most likely to cause higher nitrous oxide emissions, potentially contributing to global warming to an important degree.

In the more industrialized countries, the growing concern from the consumers community and from part of the farmers on the negative environmental consequences of the intensive agricultural activity, also coupled with the increased demand for healthy food, have both contributed to develop agricultural methods based on sustainable farming practices, chiefly targeted to preserve the natural resources while ensuring reliable food productivity.

Organic and biodynamic agriculture represents one of the several approaches to sustainable agriculture, and many of the techniques used in such method (e.g. inter-cropping, rotation of crops, minimum tillage, organic manuring, mulching, integration of crops and livestock) are in fact practised under diverse agricultural systems.

What however makes organic agriculture unique, as regulated under various laws and certification programmes, is that: (i) almost all synthetic inputs are prohibited, (ii) nitrogen can be supplied to the crops exclusively under organic form, (iii) genetically-modified organisms (GMOs) are banned, (iv) "soil building" crop rotations are mandatory; (v) the soil ecosystem is considered as the pivotal "living organism", thus great emphasis is given to organic matter cycling (FAO, 1999).

This thesis work has the objective to study alternative ways of managing the organic matter in diverse agro-ecosystems, focusing on both quantitative and qualitative aspects.

The effect of several organic matter-based farming practices, that are characteristic of the organic and biodynamic method, on biomass production, productivity, and soil microbial activity has been investigated through a multidisciplinary approach that embraced on-farm trials as well as reductionist greenhouse and laboratory experiments.

The open-field trials have been conducted in organic commercial farms in the Marche region (Italy) and in low inputs small subsistence farms in the African Kingdom of Swaziland. In both cases, the farmers were involved as "partners" in the research, which allowed to get a system perception on the efficacy and feasibility of the investigated techniques, and helped to highlight main constraints in organic matter management.

1. INTRODUCTION

1.1 Organic and Biodynamic agriculture

1.1.1 Origin, concept and definitions

The term "organic agriculture" dates back to the beginning of the last century, and it was coined to underline the systemic vision that characterizes this new concept of agriculture. According to Besson (2009), the original theory behind organic agriculture integrates ancient philosophy, agronomy and social thoughts on agriculture. The biology of the founders of the concept of organic agriculture in the last century, i.e. A. Howard, R. Steiner, H.P. Rusch, M. Fukuoka, stands between various philosophical and esoteric speculations, empirical observations, and scientific approaches.

According to the ancient philosophy, these authors are suggesting an imitation of nature based on a cyclic understanding: however, the human intrusion in nature, although founding element of farming, remains hard for them to legitimate. Indeed the founders were anxious about the agricultural chemistry's consequences on ecology and society. Nevertheless, the holistic ethic of organic farming remains an innovating source for its contemporary development (Besson, 2009).

However, it should be noted that a "doing next-to-nothing" approach became on fashion in the 70' within the international organic movement and it is still followed today by some amateurs. In this exploitative approach, not only pesticides are avoided, but also sound farming practices that built the soil are largely ignored. The results achieved on such farms are predictable, as yields are low and the quality poor. These approaches became collectively known as *organic by neglect* and are quite far from the responsible farming models proposed by the founders of organic agriculture.

It is unclear how many farmers actually chose to farm "by neglect" and advertise themselves as organic over the years. However, this extreme representation of organic agriculture was quickly taken up by critics who tried to characterize all of organic agriculture as soil depleting and unproductive. To counter this, current standards for certified organic production require an "organic plan" outlining the use of soil building activities and natural pest management (Kuepper and Gegner, 2004).

Since its origin, several countries and a multitude of farmers associations and private certification organizations have defined organic agriculture and its operational field standards. In the past, differences among the standards were significant but the demand for consistency by multinational traders has led to great uniformity. The standards of organic agriculture are nowadays internationally adopted, largely unified, regulated and legally enforced by many nations. The International Federation of Organic Agriculture Movements (IFOAM), a non-governmental organization internationally networking and promoting organic agriculture since 1972, has established guidelines that have been widely adopted for organic production and processing by several national legislations (including the EU) (IFOAM, 2005).

It has to be underlined that the standards - as very first case in the food sector - are subject to control and certification by third-party certification bodies, that have in their turn to be internationally accredited in compliance with the ISO 65 (EN 45011) standard norm. The requirements for organically produced foods differ from those for other agricultural products in that production and processing procedures are an intrinsic part of the identification and labelling of, and claim for, such products (Codex Alimentarius, 1999). An organic label, obtained through the certification system, indicates to the consumer that a product was produced using certain production methods (Figure 1). In other words, organic is a *process claim* rather than a product claim (FAO, 1999).

Figure 1. The new European logo for organic products

IFOAM defines the overarching goal of organic farming as follows: "Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved..".

A more pragmatic definition is provided by the US National Organic Standards Board (NOSB) — the federal advisory panel created to advise the USDA on developing organic legislation (2004): “An ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony”.

The Codex Alimentarius, namely the food standards elaborated by the Food and Agriculture Organization of the United Nations and the World Health Organization, on 1999 published the "Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods. The "Guidelines", among others, stress the strong link organic agriculture must have with the territory and the importance of recycling organic matter and nutrients, also providing a more comprehensive definition: "Organic agriculture is a holistic production management system which promotes and enhances agroecosystem health, including biodiversity, biological cycles, and soil biological activity.

It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, cultural, biological and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system.

An organic production system is designed to: a) enhance biological diversity within the whole system; b) increase soil biological activity; c) maintain long-term soil fertility; d) recycle wastes of plant and animal origin in order to return nutrients to the soil, thus minimizing the use of non-renewable resources; e) rely on renewable resources in locally organized agricultural systems; f) promote the healthy use of soil, water and air as well as minimize all forms of pollution that may result from agricultural practices; g) handle agricultural products with emphasis on careful processing methods in order to maintain the organic integrity and vital qualities of the product at all stages; h) become established on any existing farm through a period of conversion, the appropriate length of which is determined by site-specific factors such as the history of the land, and type of crops and livestock to be produced.

1.1.2 Organic agriculture worldwide

As stated by Willer and Kilcher (2010), agricultural land organically managed in the world had exceeded at the end of 2008 the area of 35 millions of hectares, with around one million and three hundred thousand operators producing and processing according to certified standards. On 2000, there were 10.5 millions of certified organic land (Willer and Youssefi, 2000).

1.1.2.1 Europe

At the end of 2008, 8.2 million hectares in Europe were managed organically by more than 220,000 farms. In the European Union, 7.5 million hectares were under organic management, with almost 200,000 organic farms. That is, 1.7 per cent of the European agricultural area and 4.3 percent of the agricultural area in the European Union is organic. Twenty-three percent of the world's organic land is in Europe. The countries with the largest organic agricultural area are Spain, Italy and Germany. In Italy there are about 50,000 organic farms on more than one million hectares of organic and under conversion agricultural land. There are four countries now in Europe with more than 10 percent organic agricultural land: Liechtenstein, Austria, Switzerland and Sweden (Willer and Kilcher, 2010).

Support for organic farming in the European Union and neighboring countries includes grants under rural development programs, legal protection, and a European as well as several national action plans. One of the key instruments of the European Action Plan on organic food and farming, an information campaign, was launched during 2008, with the aim of increasing awareness of organic farming throughout the European Union.

1.1.2.2 North America

In North America, almost 2.5 million hectares are managed organically, representing approximately 0.6 percent of the total agricultural area and the 7 percent of the world’s organic agricultural land.

In the U.S. the major part of the organic land is regulated through the National Organic Programme (NOP) that was issued following the Organic Foods Production Act (OFPA) passed by the Congress on 1990. Interestingly, as clearly stated by the USDA, neither NOP nor OFPA address food safety and nutrition, rather they are deemed regulations to norm the marketing of organic products in USA.

The year 2009 was an important year for the organic sector in Canada: on June 30, 2009, the Canada Organic Regime was established. It includes mandatory national standards, consistent labelling rules and a new national logo (Willer and Kilcher, 2010).

1.1.2.3 Latin America

In Latin America, 260,000 producers managed 8.1 million hectares of agricultural land organically in 2008. This constitutes 23 percent of the world's organic land. The leading countries are Argentina, Brazil, and Uruguay. The highest shares of organic agricultural land are in the Falkland Islands (37 percent), French Guiana, the Dominican Republic and Uruguay. Most organic products from Latin American countries are sold on the European, North American or Japanese markets. Important crops are tropical fruits, grains and cereals, coffee, cocoa, sugar, and meats.

Eighteen countries have legislation on organic farming, and three additional countries are currently developing organic regulations. The types of support in Latin American countries range from organic agriculture promotion programs to market access support by export agencies. In a few countries, limited financial support is being given to pay certification costs during the conversion period (Willer and Kilcher, 2010).

1.1.2.4 Asia

The total organic agricultural area in Asia was nearly 3.3 million hectares in 2008, which constitutes nine percent of the world's organic agricultural land. 400,000 producers were reported. The leading countries by area are China and India. Organic wild collection areas play a major role in India and China, while aquaculture is important in China, Bangladesh and Thailand. Even though most of the production is for export, markets continue to support domestic growth in the region.

Mixtures of regulatory frameworks co-exist in the region. Voluntary organic standards by government standard-setting bodies have been set in Laos, Malaysia, Nepal, Thailand, the United Arab Emirates, and Vietnam. Policy makers have begun to integrate organic agriculture into sustainable agriculture development initiatives; as the positive impacts of organic agriculture on local communities and economies, climate change and the carbon footprint of agriculture are increasingly recognized (Willer and Kilcher, 2010).

1.1.2.5 Africa

In Africa, there were almost than 900,000 hectares of certified organic agricultural land in 2008, which represents about 2.5 percent of the world's organic agricultural land. 470,000 producers were reported. The countries with the most organic land are Uganda, Tunisia, and Ethiopia. The highest shares of organic land are in Sao Tome and Prince (5 percent), Tunisia (1.8 percent), and Uganda (1.7 percent).

The majority of certified organic produce in Africa is destined for export markets. The European Union, as the major recipient of these exports, is Africa's largest market for agricultural produce. Tunisia has an organic regulation (Willer and Kilcher, 2010).

1.1.3 Organic agriculture within the scientific paradigm

According to Raviv (2010), organic agriculture is still perceived by the majority of people as a simple "back to nature" trend, whereas it is not well known that it consists of a complex production process based on sound scientific principles and careful observation of natural phenomena occurring in the farm. In his review Raviv stresses the need for organic agriculture to close the knowledge gap due to a period of 170 years of extensive research devoted to conventional agriculture: this gap is actually having a tremendous impact on the performance of organic agriculture as implemented in the various agro-ecosystems, which exposes it to critics by its opponents when some drawbacks arise (e.g. lower yields, higher management costs, higher agronomic complexity, need of further knowledge on control and certification issues, etc.).

Nevertheless, over the last 20 years scientific research in organic agriculture has been gradually spreading in the industrialized countries as response to the growing demand from farmers, policy-makers and the increasing global market. Among the various tipologies of experiments, the comparative long-term trials are particularly worth to be mentioned because they offer the advantage to study the effect over the time of the combination of various farming practices, as tipically provided by the organic standards, on animal and crop production as well as environmental aspects (e.g. soil biology; biodiversity; water and soil pollution, etc.).

Raupp (2009) reported about 25 running long term experiments in organic agriculture worldwide. These kinds of experiments allow to study the farm performance in an agro-ecosystem perspective, consistently with the "organic" vision; in addition, the long-term approach permits to observe the evolution of certain phenomena (e.g. soil organic matter dynamics; pests population; etc.) that otherwise in short experiments would not significantly vary. On the other hand, such experiments present the limitation to be strictly site-specific thus not yielding outcomes to be applicable in diverse agro-ecosystems (Pimentel et al., 2005).

An interesting long term experiment is the "DOK trial", the oldest long term farming system comparison in Europe, carried out in Switzerland by the Research Institute of Organic Agriculture (FiBL): it has been comparing the effects of bio-dynamic (D), organic (O) and conventional (K) arable farming systems in a randomized plot experiment since 1978 (Mader et al., 2006). Interesting to note, it was the farmers' idea to initiate the DOK trial: three groups of farmers participated actively in planning the management of the respective farming systems and many of them are still guiding the staff running the experiment.

Today several research groups are working in the field of soil fertility, soil carbon transformation, soil-plant interface, crop yields and quality, etc. The results obtained so far show that although the yields of the organic-biodynamic systems have been systematically lower than the conventional ones over 28 years (on the average - 20%), the fertilizer input (total N, P, K) has been reduced by 35 to 40% in the organic systems. In addition, several soil fertility indicators showed more favourable values for the organic systems, pointing out the higher sustainability of the organic method basically based on organic fertilisation and a 7 years crop rotation (Mader et al., 2006).

Another relevant long-term field experiment is being run by the Rodale Institute (USA) in collaboration with several universities and public and private research bodies: the Farming Systems Trial (FST) started in 1981 in Pennsylvania (USA). The FST compares three strategies, or 'systems,' for grain production: one conventional, one livestock-based organic, and one legume-based organic.

The conventional system follows a 5-year rotation typical of many farms across the Midwest, namely corn, soybeans, corn, corn, soybeans, and receives fertilizer and pesticide applications according to the local standard recommendations.

The livestock-based organic system follows a 5-year rotation of corn, soybeans, corn silage, wheat, red clover and alfalfa hay, with aged cattle manure applied in the two corn years.

The legume-based organic system is structured around a 3-year rotation of hairy vetch/corn, rye/soybeans, and wheat. The two organic systems receive no chemical inputs for fertility, weed or pest control.

As documented by Pimentel et al. (2005), on year 2002 after 20 years of observations, it had emerged that: (i) average yields of corn and soybeans in the two organic systems were significantly lower with respect to the conventional ones, during the initial 5 years conversion period, but in following years yields were the same in all the three systems; (ii) in the drought years, grain yields of the organic systems were higher than the conventional ones; (iii) the level of soil carbon was significantly higher in the two organic systems: even if the aboveground biomass input of the conventional and the legume-based organic system was almost the same, the latter showed to retain in the SOM a higher amount of the applied carbon.

A significant correlation was observed between the increased soil carbon and the higher soil capacity to retain water in both the organic systems; (iv) nitrate leaching was almost the same in the three systems and peaked when mineral nitrogen fertilizer, and farmyard manure and green manuring were applied prior to sowing corn, in the conventional and the organic systems, respectively. It is emphasized by the author that any kind of heavy nitrogen input (either mineral or organic) is likely to leach in case the subsequent crop is not able to uptake it for some reason; (v) in general, weeds could be mechanically controlled in the organic systems, except for soybean that rather suffered from the competition.

The Raviv's review (2010) on latest research outcomes obtained on organic horticulture gives emphasis to progresses on several agro-environmental aspects:

1. Energy use efficiency in organic farms is usually higher because of the non use of mineral nitrogen (Corre et al, 2003), however in some cases the necessary mechanical weed control drastically decreases the output/input ratio, thus suggesting to dedicate more investigation to identify ways to optimize energy-efficient weed control measures (Pimentel et al. 2005, Gundogmus, 2006).

2. The common organic agriculture practices as crop rotation, minimum tillage, animal manuring and cover crops, especially when applied at once, have shown to enhance soil fertility in terms of nutrients availability, soil organic matter accumulation, impulse to soil life (microflora and soil fauna), prevention of soil erosion and re-establishment of the top soil (if lost due to intensive farming) (Bending et al., 2004; Grandy and Robertson, 2007; Milgroom et al., 2007). However, Raviv recommends to assess the actual extent of soil restoration by these practices with respect to the individual site, crop and season.

More research is still needed to investigate short- and long-term availability of plant nutrients from organic and raw mineral fertilisers usually characterized by low solubility and scarcely predictable release rates. In fact, the application of high amounts of animal manure in certain soil types and season is likely to cause serious nutrients leaching and pollute the water table if organic matter mineralization fails to match crop uptake. However it has been demonstrated that through proper integration between crop and animal production, proper application of soil protection measures and careful organic matter recycling within the farm it is possible to conserve and minimize the losses of plant nutrients (Gransted, 2000; Honisch et al., 2002).

The optimization of use of various natural sources of nutrients - chiefly nitrogen - in diverse agro-ecosystems, like green manuring, inter cropping, symbiotic nitrogen fixation by legumes and soil organic matter decomposition is another very relevant topic to be addressed by targeted research.

3. The beneficial effect of organic agriculture on biodiversity has been demonstrated by many authors (Bengtsson et al., 2005) consistently with the goal to replace the use of external inputs with reinforced local ecosystems' autonomy. Enhanced biodiversity in fact is a concrete tool to strenghten farm efficiency by enabling important ecological services as pollination, pest control and maintenance of soil fertility.

However, as demonstrated by Scherber et al. (2006), increased biodiversity in organic farms not always suffices to adequately control harmful pests, which forces the farmer to use organically-accepted pesticides that are likely to negatively affect the biodiversity. Therefore, further investigation is required to identify site-adapted stategies to manage the pests in organic systems while keeping high the degree of on farm biodiversity.

1.1.4 Biodynamic agriculture in the anthroposophic vision

Biodynamic agriculture has much in common with organic farming: in particular, it relies heavily on composted farmyard manure (FYM) as main fertiliser (Zaller and Kopke, 2004). Additionally, biodynamic farming uses field sprays and compost preparations consisting of specific minerals or plants treated or fermented with animal organs, water and/or soil.

Biodynamics can be understood as a combination of “biological dynamic” agriculture practices. "Biological” practices include a series of well-known organic farming techniques that improve soil health, whereas “dynamic” practices are intended to influence biological as well as metaphysical aspects of the farm (such as increasing vital life force), or to adapt the farm to natural rhythms (such as planting seeds during certain lunar phases) (Diver, 1999).

The first conception of what today we recognize as "organic agriculture" stemmed at the very beginning of the 20th century from the philosophical though of Rudolf Steiner, the undisputed founder of the biodynamic method, who in the 20's anticipated the nowadays's mainstream concern for environmental pollution and food unsecurity when due to the over-exploitation of natural resources (Steiner, 1924). Steiner assumed a fundamental knowledge of Anthroposophy, the spiritual science developed by himself. Without such knowledge, biodynamic agriculture can be applied but not fully understood with its essentials, e.g. the biodynamic preparations. The fact that a fundamental background exists means that deeper involvement in biodynamic farming should be accompanied by a study of Anthroposophy. This is valuable to scientists as well as to farmers, advisers or even to consumers, as it offers another approach also to human nutrition (Raupp, 1999).

According to the Antroposophy's doctrine, Steiner suggested that being crops and livestock strongly subjected to cosmic influences, biological laws cannot be the only agents governing the agricultural performance: most importantly, there is the need to be aware and to understand the function of the forces, the impulses and the organizing principles that play a crucial role behind the visible matter. Interesting to note that according to Steiner the farm has to be conceived as an "autonomous individuality", within which closed cycles of nutrients and organic matter are enabled (Catellani, 2006).

The idea of the farm as an "organism" will be next taken up by the agriculturalist Lord Northbourne on 1940, who asserted that "the soil and the microrganisms in it together with the plants growing on it form an organic whole" (Paull, 2006), and nine years later by the agronomist Alfonso Draghetti who suggested to look at the farm through the methaphor of the human body, that is an unique entity but also a whole of self-organized organs, thus requiring a physiological approach to study it (Draghetti, 1991). According to Steiner, the farm must have a certain degree of internal diversification that is similar to the one of the wild natural environment, since the links among the parts (both in farm and natural environment) are of the same nature and complexity (Steiner, 1924).

Another aspect emphasized by Rudolf Steiner in his famous eight agricultural lectures held on 1924 is the paramount importance of soil fertilisation, the main goal of which is not just to supply the soil with nutrients but to provide it with a certain extent of vitality, which cannot be obtained by the simple mineral manures: "Fertilisation can be accomplished by using organic matter only, and processed in a such a way that it will organize and give life to the solid component of the soil" (Steiner, 1924).

As a consequence, the livestocks (producing FYM), wide crop rotations inclusive of fodder plants and minimum soil disturbance represent the most characteristic aspects/strategies of the biodynamic farm prototype. By adding composted organic manure to the soil, the farmer would facilitate the concentration in it of the "vital forces" coming from the Cosmos: such forces will induce plant growth and ensure food quality (Steiner, 2003). To successfully allow such a determinant "bridging action" between Cosmos and land, as operated by the organic matter, specific biodynamic preparations have to be added to the FYM or directly to the soil, in minimal concentration (homeopathic dilutions).

1.1.4.1 The biodynamic preparations

The preparations are classified as "technical means" by the international standards on organic farming; they are not to replace common farming practices neither can remedy possible technical mistakes. The preparations result from conditioning - in general within the farm - both plant and animal organic matter according to definite procedures, and mostly they are under highly humified form; they are deemed active under infinitesimal concentrations (Wistinghausen, 1998). According to the way of use, biodynamic preparations belong to two classes: preparations sprayed directly onto the soil or crops (500 and 501) and preparations added to composting FYM (502 - 507) (Raupp, 1999). Table 1 presents the preparations and their ingredients, as described by Steiner in his lectures (1924).

The preparation 500 consists of high quality FYM, fresh or aged, put in bovine horns, then buried at the end of September and dug up in April; after that it can be stored under controlled conditions for some months and finally sprayed to the soil. From one horn, 60-80 grams of "horn manure" can be obtained that, dissolved in 20-30 liters of water at 35°C, are enough to treat one hectare (Koepf et al., 2001).

The horn manure is energetically dissolved in water by clockwise and counter-clockwise stirring, manually or through a mechanical device according to a specific procedure, named "dynamization", that should ensure a good penetration of the "cosmic forces" inside the liquid mixture (Wistinghausen, 1998). Then the mixture is distributed on the bare or freshly-tilled soil in big drops through a knapsack sprayer or a tractor-pulled big sprayer (Figure 2). Ideally, all the cultivated fields receive horn manure twice a year (springtime and autumn).

Figure 2. Field distribution of biodynamic preparations

Horn silica (501) is powdered quartz (rock crystal) put in a bovine horn and processed as horn manure. A very small quantity of the 501 is then dynamized in water and sprayed on the standing crop, mostly at flowering stage: it would reinforce the plant against pests and diseases and improve its nutritional properties, flavours and shelf-life (Koepf et al., 2001; Catellani, 2006).

Table 1. The biodynamic preparations after Steiner (1924)

Spray preparations applied to soils and crops:	
500	Horn manure
501	Horn silica
Compost preparations:	
502	Yarrow (Flower heads from *Achillea millefolium*)
503	Camomile (Flower heads from *Matricaria chamomilla*)
504	Stinging nettle (stalk from *Urtica dioica*)
505	Oak bark (Quercus robur)
506	Dandelion (flower heads of *Taraxacum officinale*)
507	Valerian (juice of flowers of *Valeriana officinalis*)

Besides the two traditional preparations described above, the Australian agriculturalist Alex Podolinsky devised in the 70' a new preparation with the goal to better adapt the classic biodynamic method to the Australian agricultural conditions, characterized by very extensive fields that would require high amounts of composted FYM usually not available.

The Podolinsky's method is actually based on frequent polyphytic green manuring, crop rotation and conservative soil tillage plus the use of the new "Prepared 500" preparation.

The new Podolinsky's preparation derives in fact from the combination, via a specific procedure, of the original Preparation 500 + all the compost preparations, as provided by Steiner (1924). After dynamization in water, the "Prepared 500" is sprayed to the tilled soil, just prior to sowing: the "Prepared 500" would induce - together with all the above mentioned farming practices - a sort of "sheet composting" (Podolinsky, 1985; Podolinsky, 1997; Podolinsky, 1999), through which the fresh organic matter accumulated by crop residues and green manuring would quickly turn into stable organic matter, as it happens in a composting heap of FYM.

It has to be stressed that biodynamic preparations are added to the soil or to composting organic material always in very low doses of a few grams per ton of soil/compost material: therefore, it is hypothesized that the primary purpose of these compounds is not to add nutrients, but to stimulate the processes of nutrient and energy cycling, to affect decomposition/building of humus and to improve soil and crop quality (Raupp, 1999).

1.1.4.2 The biodynamic preparations and main interactions with soil properties and crop yield

Carpenter-Boggs et al. (2000c) studied the effect of biodynamic preparations (BD) on compost development of cow manure and woodshaving bedding, emphasizing noticeable changes in compost chemical and microbial parameters. They found higher thermophilic microbial activity through the 8-weeks active composting period in the material with BD treatment. In the final ripening stage, the BD-treated piles respired CO_2 at a 10% lower rate and had a larger ratio of dehydrogenase enzime activity to CO_2 production. Final samples of BD-treated compost also had 65% more nitrate than control.

However the same authors, in another experiment to determine whether biodynamic preparations (compost preparations as well as field sprays) affect the soil biological community after one cropping season beyond effects of organic management, did not found any significant difference between BD and non-BD treatments on parameters as: soil microbial biomass, respiration, dehydrogenase activity, soil C mineralized, earthworms population, metabolic quotient of respiration (Carpenter-Boggs et al., 2000c).

The effects of applications of traditionally vs. biodynamically composted FYM were studied over 9 years on soil chemical, biochemical and biological properties, and yields, in a 6 year crop rotation based on cereals, legumes and fodder crops. Results showed that the FYM with biodynamic preparations significantly decreased soil microbial basal respiration and metabolic quotient compared to non-prepared FYM. The prepared FYM however did not affect soil microbial biomass, dehydrogenase activity and crop yields (Zaller and Köpke, 2004).

Raupp and Oltmanns (2006), in a long term field experiment comparing FYM in a crop rotation in two treatments with and without biodynamic preparations and inorganic fertilizer, after 18 years found that (i) the organic C content was higher with manure than inorganic fertlization and (ii) the highest content was found in the treatment with biodynamic preparations.

Therefore, applying the same quantity of manure, but without the preparations, led to higher decomposition of soil organic matter. To interpret such result the authors argued that (i) soil life was changed by the preparations with different effect on the soil organic matter decomposition, which is in accordance with the observed increase of dehydrogenase activity in the biodynamic treatment; or (ii) the quality, rather than the quantity, of manure made the difference as manure properties were possibly changed by the preparations; or (iii) both factors had an influence.

The biodynamic treatment increased the potato yield, but no significant effect was recorded on the yields of the other crops in the rotation. Nevertheless when observing the yields of spring wheat over a period of 11 years, the effect of the preparations varied depending on the prevailing conditions of growth.

Figure 3 shows that when the yields of the treatment without the preparations (CM) increased under environmental favourable conditions, the treatment with the preparations (CMBD) gave slightly lower yields; whereas, during the years with prevailing drought conditions, CM yield was low and the CMBD yielded higher.

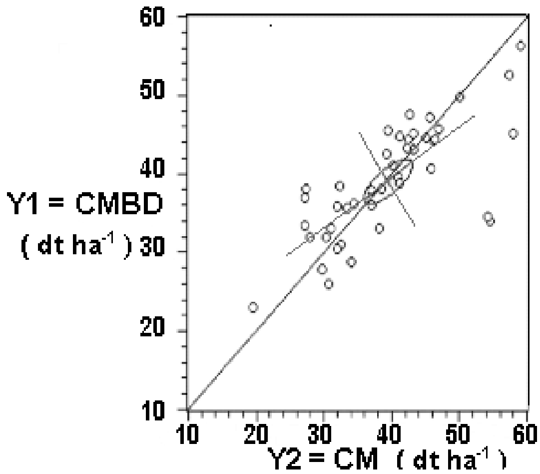


Figure 3. Spring wheat yield (dt/ha) in 11 years after FYM without (CM) and with biodynamic preparations (CMBD), each at the high rate in 4 replicates (n = 44). Ellipse shows the 95% confidence area of the mean value (Raupp and Oltmanns, 2006).

The same "regulatory" effect by biodynamic preparations on yield was described by Raupp and Konig (1996) after a trial with cereals, carrots, beetroots and potatoes from 28 different field plot and pot experiments to determine the influence of the biodynamic preparations 500 and 501 on yields. The term "system adjustment" was suggested for this relationship of preparations'effect and yield level (Raupp, 2009).

Fliessbach et al. (2007), in the long term "DOC trial" compared five farming systems, typical for Swiss agriculture: (i) livestock based bio-organic (BIOORG), (ii) biodynamic (BIODYN), (iii) integrated farming system (CONFYM), (iv) stockless integrated system (CONMIN) and (v) one control without any fertilization (NOFERT), in a 7 year crop rotation.

In the third crop rotation period soil organic carbon in the 0-20 cm layer of the BIODYN system remained constant, but in CONFYM as well as in BIOORG it decreased of 7 and 9%, respectively, as compared to the starting value: according to the authors, this can be explained by the more stability of the organic matter in the biodynamic composted manure vs. the uncomposted dairy manure utilized in the other treatments.

More drastic reduction of C_{org} occurred in CONMIN and NOFERT. After 21 years, the BIODYN and BIOORG systems showed the highest soil microbial biomass content among all the treatments. BIODYN showed the highest dehydrogenase activity and lower metabolic quotient for CO2 (qCO2) with respect to CONFYM, meaning that micro-organisms in BIODYN need less energy to maintain their biomass than the ones of CONFYM.

1.1.4.3 The relevance of Rudolf Steiner's intuition to the present day

In despite of the difficulty to provide objective evidence, at least with the state-of-the-art technology available for investigation, of the effects of many of the Steiner's "renewal forces" - this mostly stands for the more dogmatic statements about the supposed interactions between Cosmos and living organisms (Kirchmann, 1994) -, it has to be however acknowledged to Steiner the capacity to have, as first, emphasized the importance of the systemic approach when studying biological phenomena - in this case the activity of farming -, and this without considering the level of scale (single plant, cultivated field, cropping system, whole farm, etc.), thus anticipating concepts that would have been addressed 30 years later by Cybernetics and Ecology and that would have led, in subsequent years, to the elaboration of complex concepts in science as "system thinking", holistic approach, and so on.

In particular, it is topical the major emphasis Steiner puts on the "soil factor" as well as on the qualitative aspects of the organic matter cycling, so predicting - without the aid of modern and sophisticated analitycal means - the strategic importance of maintaining a high soil biodiversity in the farm, which is in turn functional to the roots growth, pests and diseases control, and, more widely, to the optimum operation of the entire farm "physiology" (Draghetti, 1991).

1.2 Potential and limitations of farmer participatory research

The concepts of "farmer participatory research" or "on-farm research" started to spread and be implemented around the '70 by the acknowledgment that the active participation of the final users of the research products to the research activity itself would have enhanced the efficiency of the identified technological solutions and facilitate their adoption, also enabling the farmers to become active proposers of key research objectives from their side, in line with their actual emerging needs (Lockeretz, 1987; Bachinger et al., 2000).

Until that time, the typical research model in agriculture, as generated by the so-called "Green Revolution", was mostly characterized by a top-down approach fully managed by the scientists uniquely in the experimental stations: obtained innovations - often driven by the manufacturers of agro-inputs and machinery - were to be used by the farmers however without involving them in the formulation of the subjects to be investigated, and related findings.

Later on, with the onset of the innovative approaches of agro-ecology and rural sociology, a new "client-driven" concept was developed that requires decentralized technology development and devolves to farmers a high responsibility for adaptive testing (Ashby and Sperling, 1995).

Nevertheless, consumers as well play a role in indirectly orientating agricultural research, as stated by Guttman (1978), being the primary beneficiaries of the research's products. Consumers more and more demand healthy food, and they become aware of the negative externalities due to intensive agricultural and agro-processing practices (see various food scandals of the last decade, such as the "mad cow" disease; hormones found in broilers; nitrates in the drinking water, etc.). Evidence of this high attention by consumers to the way the food is actually produced is given by the fact that representatives of consumers associations actively participate to the works of the certification committees of the organic agriculture certification bodies, in order to closely monitor the conformity to the standards "from the field to the fork".

Today, research in agriculture typically occurs under three modalities that in turn affect the choice of the physical site hosting the investigation activity (Figure 1): basic research, applied research and on-farm research, this being principally executed within real operational farms (commercial farms). In the latter case, the researcher establishes a direct relationship with the farmer, which may occurr at various levels of intensity: from a mere formal collaboration (the farmer limits himself to implement the experimental protocol) to a shared knowledge process to be developed through a full partnership: in this way, the farmer becomes totally involved in the phases of experimental design, assessment and discussion of the results.

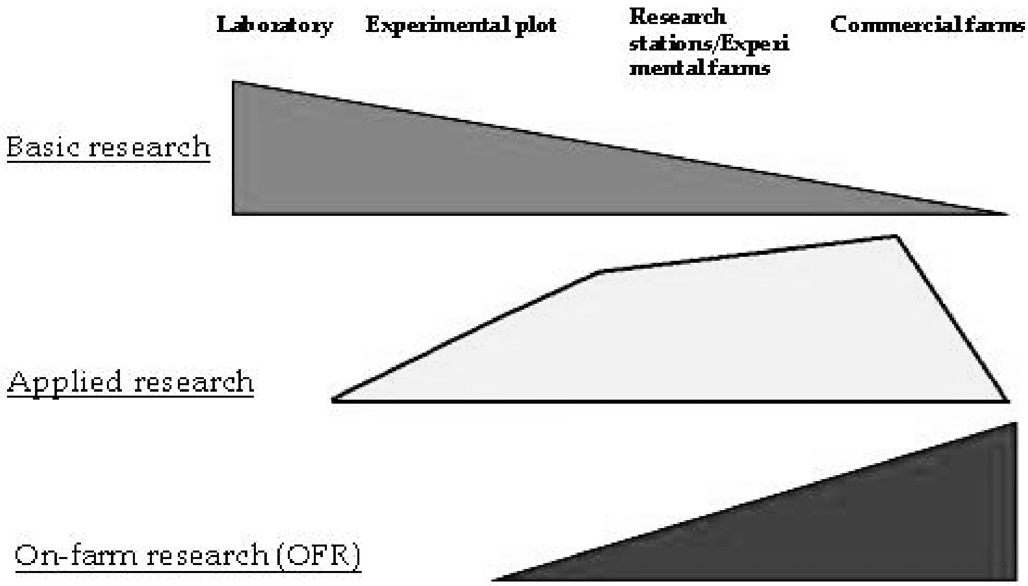


Figure 1. Agricultural research by site of operations

Sutherland (1999) described four modes of participation which link farmers with researchers: a) contractual, where the researcher is all-powerful; b) consultative, where most of the key decisions are with the researcher but a certain emphasis is put on farmer consultation in problem identification and priority setting; c) collaborative, when farmer and researcher exchange knowledge and share decision-making; d) collegiate, where the farmer has greatest power, with the researcher responding to farmer specific requests of investigation.

About the quality of the researcher/farmer relationships, Okali et al. (1994) argued that "farmer participatory research, in principle, aims to operate at the interface between knowledge systems: it can be described as a people-centred process of purposeful and creative interplay between local individuals and communities on the one hand, with formal agricultural and research knowledge on the other - the collegiate interface". According to the authors, the knowledge systems at stake are basically represented by the farmers' (local) knowledge on one hand and formal research (generic) knowledge on the other. Such knowledge systems may be therefore interfaced through 'creative interplay', so involving dialogue between different groups (local farmers and researchers): this dialogue will be respectful and serve to draw the two parties together in partnership ('collegiate interface').

While most of these assumptions may hold in optimal situations, however projects often face difficulties in linking ideas and actors in order to exemplify good practice (Sutherland, 1999).

Eksvard (2009) described the functions of a Participatory Learning and Action Research (PLAR) group in Sweden, composed by horticultural farmers, researchers and extensionists, that was set up to test on-farm and evaluate the output of conventional research trials targeted at studying the best organic manuring options in organic horticulture. After pointing out the difficulties encountered inside the PLAR in harmonizing opinions and action plans among the farmers as well as between the groups of researchers and farmers, the author concludes that moving from conventional research approaches to trans-disciplinary approaches is not easy and strongly demands a common effort to relate the contextual knowledge of farmers to the abstract knowledge of scientists.

Sukkel et. al (2006) indicated in the Dutch Organic Farmers Network for Research, Development and Innovation (BIOM) a valid initiative for the improvement of the environmental and economic performance of the participating farmers. A wide range of practical experiments, resulting from specific bottlenecks highlighted by the network farmers, were carried out in 40 farms in cooperation with the agricultural scientists: the trials' outputs mostly turned to increase yields, reduce labour input for handweeding and decrease nutrient surpluses. The authors strongly recommend the participatory approach to research through farmers networks, however they state these tools also demand specific skills and attitudes from researchers, advisors and farmers.

Jones et al. (2006) reported about an on-farm research carried out to evaluate the performance of two soft wheat varieties in UK, by involving 14 organic farmers who grew the crops in their farms according to their standard cropping methodology. Measurements and laboratories analyses were carried out by the researchers but several field assessments were requested to the farmers (e.g. early and late crop groundcover, number and size of ears, straw lenght, etc.) who, however, showed a certain reticence in doing it. Farmers actually put forward the need for greater researcher-led assistance, which raised the issue whether the farmers well understood the concept of participatory approach and/or felt a poor ownership of the research project itself.

Yet the authors stated that new and valuable information was produced and both researchers and farmers considered useful the information on winter wheat variety performance under a range of organic systems; furthermore, farmers recognized the difficulty to reconcile the appearance of varieties in the field with their actual performance. However, authors recommended: i) to spend more time in introducing the project and its objectives to the farmers; ii) to discuss and develop the trial design in much closer link with them; iii) to ascertain the full willingness and motivation of all the participants to cooperate over the entire project (farmers and researchers).

The latter aspect was studied in depth by Barretau et al. (2010) who devised a conceptual analytic procedural framework to make participants' roles explicit in the implementation of different participatory research processes, thus preventing possible disappointment, reticence and project abandonment. The framework embraces three aspects: i) the flows of information among participants and the control over these flows for each step in the process; ii) the timing of involvement of participants in the different steps of the research process; iii) the modalities of communication among participants for each information flow (i.e. bilaterally or as a group, mediated or face to face). The authors elaborated the framework from various experiences with participatory research; the framework is meant to be used from the very beginning of a participatory research process as a conceptual guide for researchers.

Basic-, applied- and on-farm research are interdependent and mixed approaches are very likely to occurr; e.g. results from randomized block designs in other regions can be tested under local farming conditions (Figure 2; Tripp, 1991; Bachinger, 2000; Gibbon, 2002).

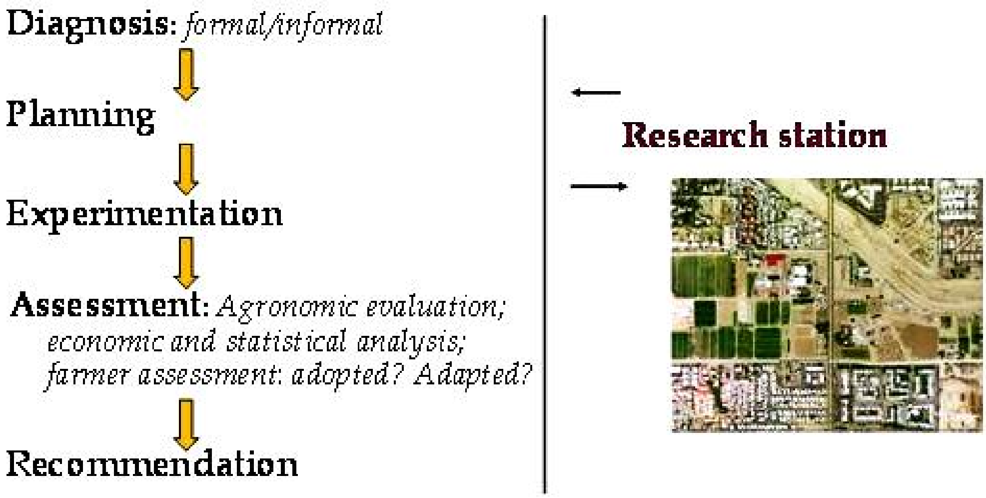


Figure 2. Typical stages for the execution of on-farm research: interactions with basic- and applied research conducted inside laboratories and experimental stations are likely to occurr (Tripp, 1991; Bachinger, 2000)

Drinkwater (2002) put the emphasis on the relevance of studying "intact systems", in order to understand how a complex agroecosystem works as a whole in opposition to the typical factorial experiment approach, that aims at breaking down a complex system in order to isolate and study specific components and identify cause-effect relationships.

Two different experimental approaches are discussed, both yielding meaningful results: i) field station trials, where simulated cropping systems are run in replicated plots, and ii) studies on whole agroecosystems in commercial farms. According to the author, an integrated research approach combining systems experiments with appropriately designed factorial experiments is highly recommended for a deep understanding of ecological processes in agricultural systems (Figure 2).

When approached from within, the investigated agroecosystem results more realistic in terms of scale of observation, interconnected farming practices and management constraints to which the farmer is subjected: on-farm research therefore is likely to offer the opportunity to study it in a more integrated manner (Drinkwater, 2002). Through on-farm experiments farmers are given new skills, and confidence in problem-solving is enhanced (Bachinger et al., 2000).

Researches carried out by Dougill et al. (2002) in South-african small-scale farms allowed to study in depth the nutrients flow through the local agro-ecosystem and analyze in an interdisciplinary way the environmental, economic, political and social factors influencing nutrient management, often main cause behind the severe soil degradation occurring in the region.

The authors followed an original research methodological pathway (depicted in Figure 3) that started from holistic discussions on rural livelihoods, then turning to an in-depth participatory assessment of the key constraints likely to affect the natural resource management. It is stressed the importance to give to the farmers involved in the research process a good feedback on the research findings, that have to be discussed widely within local communities together with extension workers and, possibly, policy-makers.

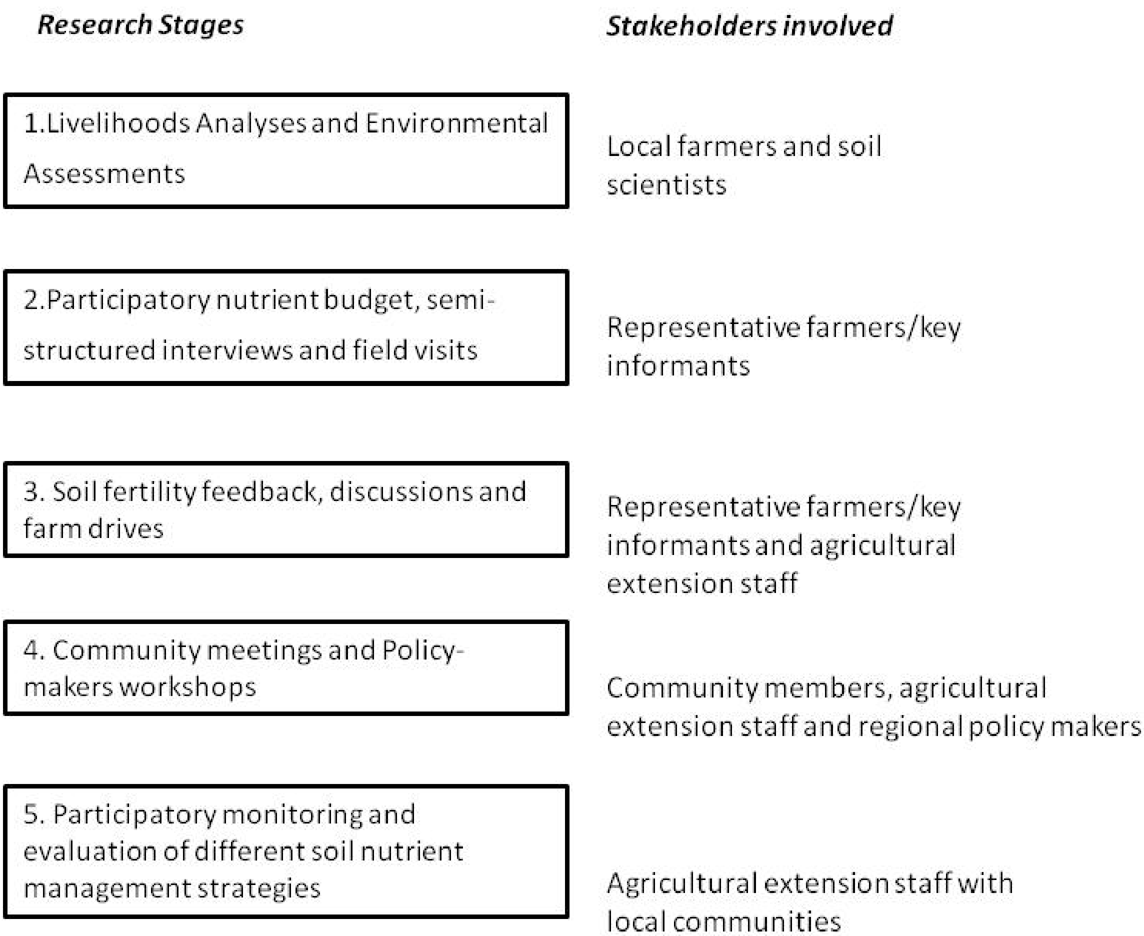


Figure 3. Stages of the methodological research framework followed by Dougill et al. to conduct interdisciplinary participatory research on land degradation in South Africa (from Dougill et al., 2002)

Hard red spring wheat varieties were compared at six locations in organic farms in Minnesota and Nord Dakota, USA, over a three-year period. A basic scoring system was developed by researchers and farmers together. The farmers eventually indicated certain traits of the varieties under evaluation (e.g. grain yield, protein content, diseases resistance) as much more valuable than others (e.g. straw and stubble production, impact on succeding crop), thus playing an active role in defining the variety prototype to be selected (Kendel et al., 2008).

Ceccarelli and Grando, researchers of the International Center for Agricultural Research in the Dry Areas (ICARDA), in 2007 described a successfull participatory plant breeding system (PPB), currently utilized in several Asian and North African countries. According to PPB, genetic variability is generated by the breeders in the experimental stations whereas the selection process of the most suitable varieties is carried out by the farmers and field extensionists in the farms (Figure 4).

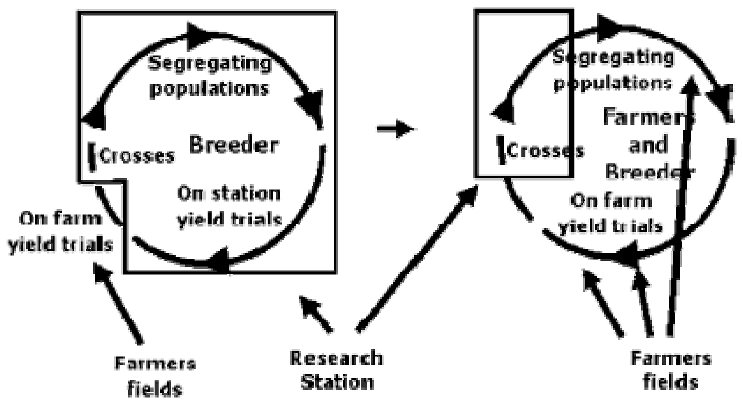


Figure 4. Conventional plant breeding is a cyclic process that takes place largely within one or more research stations (left) with the breeder making all decisions; decentralized participatory plant breeding is the same process, but takes place mostly in farmers' fields (right) and the decisions are taken jointly by farmers and breeders (Ceccarelli and Grando, 2007)

In this way, the newly identified varieties are released faster with respect to the conventional breeding system, and, most importantly, they result better adapted to the farmers needs and environment.

The PPB advantages are particularly relevant in developing countries where multinational seed companies do not usually invest in big research programs because of low profitability and where many imported "improved" varieties are not in fact suitable for the local marginal cropping conditions. The authors conclude that on-farm breeding research, besides offering economic benefits, is characterized by psychological, moral and ethical added value stemming from the progressive empowerment of the agricultural communities, partners in the research activities.

A similar decentralized approach to assess new crop varieties was described by Dorward et al. (2006) through the method of Participatory Varietal Selection (PVS), conducted throughout Ghana in two agro-ecological zones, the Savannah and the Forest, by involving more than 2,000 small-scale farmers who evaluated, in several steps, in their own fields the performance of around 100 upland rice varieties, identified by the rice breeders. Once the farmers identified the most suitable varieties according to their own selection goals, the seeds of them were distributed to a small number of farmers, and the authors found that after a couple of years about 850 farmers in communities had already obtained the seeds from other farmers via informal mechanisms (gift, exchange or purchase), which gives the evidence of the good acceptance of the new seeds.

A semi-decentralized participatory approach was used by Baidu-Forson (1997) for the identification of the best farmers appreciated varieties of pearl millet (*Pennisetum glaucum L. Br.*). Fourteen varieties were comparatively tested in a research station and thirty farmers, from six villages across a north-south transect of western Niger, were selected to evaluate the varieties over two phases, by the support of structured questionnaires: the first, when the plants were at the reproductive stage (farmers visited the station and checked for the specific traits of millet plants and grain that were deemed by them more significant); the second, when post-harvest processing and food-quality traits of the grain were assessed at home, by the female sample farmers.

Unexpectedly for the author, the majority of farmers did not go for the highest productive varieties, rather they preferred the one characterized by early crop cycle; higher tillering capacity; large grain size and plant height > 2.5 metres, all characteristics that offer higher probability of yield stability in the harsh environment of Sahel, thus indicating that farmer-led research objectives may somewhat differ from those of crop improvement programs devised by the scientists.

The participatory farmer approach to research is likely to present however negative facets, that have to be carefully assessed and addressed prior to begin the experiment. One aspect is about the difficultness to implement complex experimental designs and treatments due to the limited availability of time of the farmer, her/his lack of specific technical preparation and the structural inadequacy of the farm land: as a consequence, the potential of the analysis is drastically reduced (Selener, 2005).

The flexibility and the simplicity which are important traits of successful participatory research often lead to poor scientific validity of research results (Poudel, 2000; Wivstad and Natterlund, 2008).

Riley and Alexander in 1997 reviewed the statistical methods utilized in sixty participatory on-farm research papers and emphasized the complexity of analyzing quantitative and qualitative sets of data often coming from heterogeneous disciplines, which demands a very sophisticated statistical approach. Nevertheless, from the review it emerges that statistical methodology was often poorly defined and inadequately used.

Typically, the more farmer participation that was involved, the more complex the underlying design structure however followed by poor statistical analysis. Confounding of effects and inadequate sampling were encountered frequently due to lack of clear design structure. The authors conclude that the kind of statistical methodology suitable for use in participatory on-farm trials is in fact available, and is capable to add high value to the quality of modern, unstructured multidisciplinary design and to the summary of collected data, whether they are quantitative or qualitative. However such powerful methodology is not documented in a form easily used by non-statisticians, nor it is easily accessible.

The participatory process is indeed very time-consuming; it demands a lot of commitment and hard work both from the researchers and farmer cooperators. In addition, participatory on-farm research is cost sharing, which means that farmer cooperators are usually expected to do their research at their own expense, and this results hard for farmers above all in the context of developing countries, especially when they are subjected to the risk of negative financial return from their farming enterprise (Poudel, 2000).

Another hindrance is represented by a possible conflict of interests which can arise, if not properly prevented, between the scientist - more oriented to identify technical and innovative solution of general value, suitable for more farming environments and "communicable" to the international scientific community - and the farmer, much more interested in specific, locally-adapted, solutions for her/his farm (Sutherland, 1999; Lockeretz and Stopes, 2000).

In a sociological study Eshuis and Stuiver (2005), analyzing the process of "learning in context" in a sustainable dairy-farming project that involved the participation of farmers and scientists, emphasized how difficult was the interaction between the two groups because of the differences between the heterogeneous forms of farmers' knowledge and scientific knowledge. However, such differences were progressively reduced during recurrent phases of alternating conflict and alignement over the validity of knowledge, highlighting the relevance of such phases for progress in learning and generation of innovation.

As underlined by Sutherland (1999), effective on-farm research - blending formal and farmer-led approaches - principally requires a cross section of expertise. The end result is likely to be a compromise of methods and approaches to fulfill the expectations of all stakeholders: over time, there will be possibly iteration from formal to informal and back again. As the level of understanding improves, there may be scope for the further development of methods to improve research efficiency.

1.3 The importance of effective interactions between the soil microbial community and organic matter in low-input farming systems

1.3.1 Introduction

Soil quality has been defined as "the capacity of a soil to function within ecosystem and land-use boundaries, to sustain biological productivity, maintain environmental quality and promote plant and animal health" (Doran and Parkin, 1994). This definition does efficaciously emphasize the high relevance of the role soil plays eventually in sustaining life, at any level (Bloem et al., 2006).

Therefore, soil in nature cannot be considered just a support to hold plants, but rather it is a living and complex entity in itself. Together with soil physical and chemical properties, the status and the degree of activity of microrganisms in the soil represent fundamental aspects of the overall soil quality. In fact, microbial life processes occurring in the soil play a crucial role in regulating the basic soil functions (food producing, environmental filter to clean air and water, recycling of nutrients, energy and organic matter, etc.) (Jenkinson and Ladd, 1981; Kennedy and Smith, 1995; Fließbach et. al., 2007). Soil hosts large numbers of many different types of microorganisms assembled in complex and diverse communities, each susceptible to specific stimulations and stresses. Those microbes that flourish are best adapted to the given environmental conditions and this adaptation potentially allows microbial analyses to be discriminating in soil quality investigations (Kaiser et al., 1992). A healthy soil, full of active microorganisms in correct balance, is essential to productive agriculture, especially in organic farming systems that are based on biodiversity and maximisation of cycling of elements within the farm (Fließbach et al., 2000; Fließbach et al., 2007; Araùjo et al., 2008).

Although scientists have so far accumulated plenty of knowledge, soil microbiology is still viewed to some extent as a "black box", with little understanding of the community and ongoing processes. Our knowledge of the soil microbes and the communities that make up soil is in fact still limited: the number of different species in a gram of soil may be in excess of 10,000, however only a small fraction of the microbial portion of the soil has been isolated and adequately characterized. This genetic resource of soil microbiology is vast and needs to be explored for the benefit of agriculture, environmental quality and biological well-being (Powlson, 1994; Anderson et al., 1994; Bloem et al., 2006).

As suggested above, soil microorganisms contribute to the maintenance of soil quality in that they control many key processes: in particular, they are responsible for beneficial processes such as organic matter decomposition, humus formation and nutrient cycling (Reganold, 1995; Sequi et al., 2000). Moreover, microorganisms can alter nutrient solubility making otherwise unavailable nutrients available to the plant. N-fixing bacteria form nodules on plant roots and transform N_2 gas to plant-available nitrogen (Reganold, 1995; Gliessman, 2007). Mycorrhizae are usually non-pathogenic fungi that form symbiotic associations with plant roots (Gliessman, 2007).

Microbes also play a major role in the formation of good soil structure. Bacterial mucigel and hyphal structures produced by fungi and actinomycetes bind the soil particles together (Reganold, 1995; Gliessman, 2007). Microbial activity helps to aggregate the soil, which reduces erosion, allows for good water infiltration, and maintains adequate aeration of the soil. Soil microbes also affect the persistence of organic compounds applied to soil (Sequi et al., 2000; Gliessman, 2007).

When the soil system experiences a very drastic microbial simplification, some harmful effects may arise, such as the occurrence of soil-borne pathogens resulting in frequent plant diseases; production of plant-suppressive compounds; loss/temporary immobilization of plant-available nutrients, etc. On the opposite, environmental and/or farming practices encouraging soil microbial biodiversity are likely to enhance the phenomenon of suppressiveness, namely a more balanced microbial status in the soil ensuring stability through the establishment of complex food web.

Microbes also have the potential to be used for biological control: to control insects, pathogens and weeds as a result of their ability to lower the populations of the pest or reduce the pest's impact (Kaiser et al., 1992; Powlson, 1994).

Soil microorganisms and their communities are continually changing and adapting to changes in their environment. The dynamic nature of microbes makes them a potential sensitive indicator to assess modifications in natural and cultivated soils resulting, for instance, from management changes (Anderson & Domsch, 1989; Sequi et al., 2000; Araùjo, 2008) or from pollution (Wang et al., 2007; Yiguang et al., 2010). As a consequence, meaningful biological indicators can assist in determining best management practices for a certain environment (Bastida et al., 2008).

Alterations in the soil physical and chemical properties can affect the soil environment that supports the growth of the microbial population (Wang et al., 2007; Yiguang et al., 2010). For example, in no-till agricultural systems, microbial activities drastically differed with depth, with the greatest microbial activity occurring near the surface; while in the tilled system activities were more evenly distributed throughout the plow layer (Doran, 1980; Govaerts et al., 2007; Treonis, 2010). Cropping system, tillage, and pesticide effects on the soil microbial community have been widely characterized (Dick, 1984; Anderson & Domsch, 1989; Fließbach et al., 2007; Govaerts et al., 2007; Lagomarsino et al., 2009).

Microbial populations can effectively provide advanced evidence of subtle changes in soil, long before it can be accurately measured by changes of the more "statical" descriptors as soil organic matter, C/N ratio and others parameters that vary in the long term (Anderson & Domsch, 1989; Pavan-Fernandes et al., 2005).

1.3.2 Basic physiological indicators of soil microbial activity

The most commonly used parameters for assessing soil microbial activity are described in the following.

1.3.2.1 The microbial biomass carbon (C_{mic})

The quantitative measurement of microbial biomass carbon (C_{mic}) is expressed as $\mu g\ g^{-1}$ of dry soil (Anderson and Domsch, 1978; Jenkinson et al., 1981; Jenkinson, 1988; Sequi, 2000).

1.3.2.2 The ratio of microbial biomass carbon to total soil organic carbon (C_{mic}/C_{org})

This ratio expresses the amount of microbial biomass carbon within the pool of soil organic carbon. Several authors put forward the hypothesis that soils that exhibit a level of bioactivity per unit C_{org} higher than an empirical average are "developing" soils with a net accumulation of organic carbon, and those with a lower level belong to more stable systems (*in equilibrium*) and are losing organic carbon from a pool of relatively stable humic materials. That is, small amounts of C_{mic} within a large pool of C_{org} are likely to mean that the average availability (but not the actual amount) of the carbon source must be low, due to the very stable quality of the soil organic matter, hardly attackable by the microflora (Insam & Domsch, 1988).

Experiments studying the chronosequence of reforested soils showed a decrease of the C_{mic}/C_{org} ratio over time, thus meaning that the availability of carbon decreased in the target horizon at the expenses of the microbial community, as the ecosystem was moving toward steady state (Sequi et al., 2000; Jenkinson et al., 2004). After a three-years extensive survey of 134 plots located in 26 different sites, Anderson and Domsch (1989) found that, regardless the soil tipology, the C_{mic}/C_{org} ratio was significantly higher in plots under continuous crop rotation than in plots with a long history of monoculture (expressed as percentages, 2.9% vs. 2.3%, respectively): the authors therefore considered the crop rotation system as taking a less advanced position in the ecological succession to steady state with respect to the monoculture one. However, when organically fertilised by green manuring, both the systems exhibited equal values of the C_{mic}/C_{org} ratio, just one year after the amendment, meaning that the microbes soil population became capable to suddenly grow thanks to a sort of "priming effect", probably caused by the high amount of easily decomposable organic matter in the rizhosphere and detritusphere (Kuzyakov, 2010).

1.3.2.3 The microbial respiration

The microbial basal respiration is function of the soil organic matter decomposition by the microorganisms and it is expressed as mg C-CO_2 kg^{-1} dry soil. Another version is represented by the substrate-induced microbial respiration - SIR (mg C-CO_2 kg^{-1} dry soil) consisting in the addition of a certain amount of glucose to the soil sample to stimulate microbial respiration. Moreover, the microbial respiration rate is also utilized, given by the C-CO2 released by the soil over a certain time *t*: by measuring the rate it is possible to graphically depict the respiration curves, obtained from both cumulative and daily measurements (Anderson and Domsch, 1978; Anderson and Domsch, 1993; Sequi et al., 2000; Bloem et al., 2006).

1.3.2.4 The metabolic quotient (qCO_2)

The metabolic quotient (qCO_2), also known as specific respiration rate, represents the ratio of respiration to microbial biomass: this index actually describes the substrate mineralized per unit of microbial biomass carbon (Anderson and Domsch, 1993). The metabolic quotient is conceptually based on Odum's theory of ecosystem succession (1969), that is, a low value of the quotient would indicate a more efficient use of the energy thus reflecting a more stable (mature) ecosystem (Insam and Haselwandter, 1989; Anderson, 1994); higher values of qCO_2 would instead denote situations of disturbance or youthful traits of the ecosystem (Anderson and Domsch, 1985). Higher qCO_2 of microbial communities from young sites have been observed compared to matured sites (Insam and Domsch, 1988).

In addition, this ratio has been widely used as a good indicator of the alterations that take place in soil due to heavy metal contamination (Brookes, 1995; Liao and Xiao, 2007), deforestation (Bastida et al., 2006a), temperature (Joergensen et al., 1990) or changes in soil management practices (Dilly et al., 2003).

However, the index has also been criticised for its incapacity to distinguish between an actual ecosystem development process from microbial stress/ external disturbance: e.g. low pH and/or low nutrients availability are likely to keep low the microbial biomass thereby causing a high qCO_2, even in a mature ecosystem; likewise, disturbance factors, as fertilisation and/or cultivation, may affect the qCO_2 (positively or negatively) merely because microbial respiration/biomass are temporarily affected too (Wardle and Ghani, 1995).

Wang et al. (2003) studied the relationships among soil respiration, microbial biomass, clay content and substrate availability and argued that the latter, instead of the size of microbial biomass, was the principal determinant to soil respiration under favourable temperature and moisture conditions: according to the measurements, the variations in soil respiration could be presumably attributed to the changes in the chemistry of soil organic matter. Given these findings, the authors concluded that relationships of soil respiration and organic C turnover to the size of microbial biomass remained unclear.

1.3.2.5 Other indicators

There are other analyses that can be used to assess soil microbial activity. These can include various other methods of biomass appraisal and estimates of nutrient cycling (Sequi, 2000; Bloem et al., 2006). Microbial activity can be assessed in a number of ways that indicate the status of either the total community or in some cases specific members of that community. Individual strains can be studied to determine fluctuations in population or activity with perturbation. For example, specific pathogens may be an important indicator of soil quality in some systems (Ritz et al., 1994; Sequi, 2000; Bloem et al., 2006). Nitrifier populations, besides being a key group in the nitrogen cycle, are very sensitive to environmental stress and therefore may be a group of interest in soil quality assessment (Bock et al., 1989).

Enzyme assays may provide information on the microbial activity in soil (Dick, 1994; Bandick and Dick, 1999). Dehydrogenase, phosphatase, arginine and arylsulfatase are just examples of useful enzymes that can be utilised (Badiane et al., 2001). Lagomarsino et al. (2009), in an experiment comparing organic vs. conventional management in a Mediterranean environment, observed a general increase of hydrolytic enzymes activities in soil under organic management. The authors identified the β-glocosidase as a suitable indicator to predict organic C accumulation in soil.

Fatty acid profiles are characteristic of specific genera and species (DeBoer and Sasser, 1986) and may play a role in assessing the soil microbial community (Zelles, 1999).

The heterogeneity of the DNA recovered from soil is a reflection of community diversity (Torsvik et al., 1990; Faoro et al., 2010). DNA/RNA fingerprints may be intrinsically representative of the microbial community of a given soil (Holben et al. 1988; Asbhy et al., 2007).

Soil microorganisms may also be characterized on the basis of their functional diversity, namely their specific metabolic fingerprint: patended methods as the "BIOLOG Plates technique" allow to identify, in a very simple way, more than 1,500 different species of fungi and bacteria.

1.3.3 Interactions between the soil microbial community and the organic matter

As explained above, microbial processes are closely driven by the fate of soil organic matter, that is in turn affected by the physical, chemical, and biological components of the soil. Farming practices however may drastically change the overall soil properties thus affecting the behaviour of the soil microbial community (Treonis et al., 2010).

The application of organic amendments to soils (e.g. cover crops, green and animal manures, compost, crop residues, etc.) contributes to organic matter and has great potential for influencing the structure and functions of the soil food web. Organic amendments are known to increase the size of various components of the soil food web, including the soil microbial community (Widmer et al., 2002).

Treonis et al. (2010) studied the effect of the addition of organic amendments (fresh plant residues and straw) to soil, combined or not with tillage, on different components of the soil microbiota. Besides the effects recorded on the microfauna, the amendments determined a dramatic increase of soil microbial activity near the soil surface (0-5 cm), but the same effect, however less pronounced, was extended deeper by soil tillage. The authors concluded that the organic amendments enhanced the activity and abundance of decomposer organisms as a direct consequence of qualitative and quantitative improvement of the soil organic matter content.

Govaerts et al. (2007) investigated the long term effects of several cropping practices on maize and wheat, grown in succession in Mexico under rainfed conditions. They found that the soil microbial biomass and the micro-flora physiological and catabolic diversity were significantly 1.2 and 1.3 times respectively higher in the treatment of crop residues retention in the field compared to residues removal. When examining the whole set of cropping practices, the authors concluded that, in the target area, a cropping system that includes zero tillage, crop rotation, and crop residues retention is likely to increase overall biomass and micro-flora activity and diversity compared with common farming practices. Such a system is in fact meant to create favourable conditions for the development of antagonists and predators, fostering a new ecological stability.

Saffigna et al. (1989), by an analogous experiment, found, in the soil surface 0-10 cm layer, higher percentage increment of microbial biomass and respiration in the above-ground Sorghum residues-retained treatment compared with the residues-removed treatment.

Similar outcomes were highlighted by Powlson et al. (1987), who, despite a small increase of total soil organic carbon (5%), after 18 years found large increases in microbial biomass in fields where annual barley stubble and straw had been incorporated into the soil, with respect to the fields where the straw had been always burned with no increase in soil organic carbon: the authors highlighted the usefulness of the more dynamic microbial biomass parameter that gave an early indication of the slower changes in soil organic matter carbon.

The nature of the crop residues and the degree of soil organic matter content can affect the functional diversity of the soil microbial community in the top soil, as demonstrated through soil enzymes analysis (Bending et al., 2002). Singh et al. (2007) speculated that microbial biomass levels are rather subordinate to the specific decomposition rate of the added amendment, however a severe competition may occur for available nutrients between the miocrobial biomass itself and crop roots, which is likely to lead to reduced development of the former one, even in presence of fresh organic material.

In contrast with the above, Bending et al. (2000) observed that the changes in the microbial community metabolic profiles, following the input of organic material, were remarkably similar despite the different types of crop residues materials added to soil in the diverse treatments and the modes by which the organic materials were applied (soil tillage vs. mulching). This could have reflected similarities in the biochemical composition of the substrates incorporated, which consisted largely of N-rich leguminous materials in all the treatments.

Calbrix et al. (2007) drew same conclusions after applying to a mixed cropping system three kinds of organic amendments of animal origin, composted with ligneous material or otherwise. They observed that the bacterial functional and genetic structures were deeply modified between 3 and 6 months, however this modification was not related to the type of amendment, even if the typical decomposition rate of the diverse substances markedly varied. The authors therefore suggested that organic amendments have less effect on microbial activity than seasonal variations or others anthropic factors, such as the mechanical management of the soil.

Fernandes et al. (2005) studied the effect of application of four increasing doses of sewage sludge on soil biology parameters on a crop rotation in a tropical environment: the results showed that basal respiration, microbial biomass carbon, metabolic quotient (qCO_2) and enzymatic activity in the soil increased as sewage sludge was added, and their values were positively correlated with sewage sludge doses. Similarly, the activities of soil urease and amylase increased as sludge doses increased and were significantly correlated with soil microbial biomass.

Interestingly enough, field experiments targeted to evaluate responses of the soil microbial community to organic and biodynamic management led to noteworthy results and attractive hypotheses.

Fließbach et al. (2007), in a long term trial (DOC) carried out in Switzerland, comparing biodynamic, organic, integrated and conventional farming systems over a 7-years crop rotation, found the biodynamic approach - characterized by application of well-composted farmyard manure (FYM) with biodynamic preparations - as the more efficient one in maintaining the original soil organic carbon content in the plough layer (0 - 20 cm), whereas all the other treatments led to a diminishment of this parameter. After 21 years of trial, the highest value of dehydrogenase activity was recorded in the biodynamic treatment but basal respiration was the same in all the treatments. The metabolic coefficent (qCO_2) presented the lowest value in the biodynamic and organic treatments, suggesting, according to the authors, a higher maintenance requirement from microbial biomass in soils of the integrated and conventional systems, in harmony with the Odum's theory (1969). Birkhofer et al. (2008) focused their observations to the wheat plots of the same DOC trial. They found that the microbial biomass progressively increased from the conventional to organic and biodynamic systems: C_{mic} in the biodynamic system in fact exceeded that in the conventional one (with no FYM application) by more than twofold. Basal respiration was the same in all the treatments, hence leading to the lowest value of specific microbial respiration (qO_2) for the biodynamic system. The C_{mic}-to-C_{org} ratio was similar in the biodynamic and organic systems but significantly higher than the ones calculated in the integrated (with FYM) and conventional systems, that should classify both the organic systems as less stable (say, further from the steady state) than the integrated/conventional ones, according to Insam & Domsch (1988).

Equivalent results were obtained on 2008 by Araùjo et al. in a comparative experiment between organic and conventional farming systems in Brazil: the combination of green and farmyard manures, featuring the organic treatments, actually enhanced the soil microbial activities, confirming however the lower values of qCO_2 in the organic than in the conventional systems. Similar results were found by Tu et al. (2006) in a long term field experiment in USA, where they evaluated the effect of transitional farming strategies from conventional to organic agriculture on soil microbiological activities.

Zaller and Kopke (2004) studied the effect of two kinds of FYM - i.e traditionallly prepared and prepared according to the biodynamic method with the fermented residues of six plant species - on diverse soil chemical, biological and crop productivity parameters in a 6-years crop rotation, over a period of nine years. They found microbial biomass as well as dehydrogenase activity markedly higher in the treatments with the two kinds of FYM with respect to the control (no-FYM), but the addition of any kind of FYM did not affect microbial basal respiration and the metabolic quotient. However, the biodynamic FYM significantly decreased soil microbial basal respiration and metabolic quotient when compared to the traditional FYM, suggesting a more efficient microbial turnover of the organic matter, namely an use of the available organic substances more for growth than for maintenance, as also argued by Mäder et al. (2002).

Moreover, lower values of qCO_2 may also indicate a less stressed soil environment and a more diverse microbial community structure, thus leading to higher metabolic efficiency of the soil microbes. Finally, the lower basal respiration and metabolic quotient due to biodynamic FYM could also reflect differences in compost quality, indicating that FYM prepared with all six preparations is possibly more mature, with less available C hence with a greater proportion of humified material than the traditional FYM type. The authors conclude that how the very low-dose biodynamic preparations can affect soil processes is still not clear; however, there is evidence that biodynamic preparations can alter the composting process resulting in increased temperature within the compost piles, affecting the microbial community and phospholipid fatty acid concentration of dairy manure compost, as observed by Carpenter-Boggs et al. (2000).

2. ORGANIC MATTER STUDIES IN BIODYNAMIC FARMING SYSTEMS IN MARCHE REGION

2.1 Effect of increasing concentrations of different highly-humified organic matters on the germination of *Lepidium sativum*

2.1.1 Introduction

Soil amendment is a cultural practice of high agronomic value, because it increases the soil organic matter and the availability of nutrients, essential for plant growth, and it improves the soil physical properties with respect to air and water circulation (Gliessman, 2007). However, organic matter may also have a phytotoxic effect on plants as consequence of its chemical composition and the relative concentration in the growing media, both in open field and *in vitro*, as it has been widely demonstrated by several authors (Zucconi et al., 1981; Zucconi et al., 1984; Gigliotti et al., 2005; Komilis et al., 2005; Neri et al., 2005; Sampedro et al., 2007; Droussi et al., 2009).

It has been however observed that the degree of phytotoxic effect may vary to a large extent, according to:

- the plant capacity to timely adapt to the disturbance, through anatomic modifications, biochemical mechanisms of tolerance, etc. (Neri et al., 2005; Giorgi et al., 2010);
- the ability by the existing microbial communities to decompose the phytoxic substances (Zucconi, 2003);
- the degree of plasticity of the root system, allowing the plant to actively avoid the phytotoxic molecules by exploring toxic-free sectors of the substrate (niche effect) (Giorgi et al., 2008; Giorgi et al., 2010);
- the specific phenological phase of the plant.

The combined outcome of the above variables results in a diversified effect on plant growth by the application of a given organic matter, that could be used as dead mulching for a while then be incorporated into the soil, or as green manuring.

During the early phases of the composting process, the microbial decay of fresh animal and plant residues leads to the syntesis of phytotoxic metabolites, that will be subsequently re-arranged by other microrganisms by turning the original organic matter into more stable substances (humus) (Zucconi et al., 1984). The soil application of "fresh" organic matter is therefore likely to temporarily limit crop development, whereas the incorporation of "mature" organic matter yields beneficial effects on physical, chemical and biological soil fertility (Gliessman, 2007; Droussi et al., 2009).

Among the diverse stable fractions of soil organic matter, humic acids were found to exert an auxine-like effect on root growth, by stimulating the production of fine roots, thereby enhancing the nutrients uptake (Cacco and Dell'Agnola, 1984; Trevisan et al., 2010). Humified substances may also exert a "microbial inoculum effect" on the resident soil microbial community (Elo et al., 2000; Remans et al., 2008) as well as a direct nutritional effect to the plants (Prescott, 2005).

Such evidences, although still under debate among scientists, have facilitated the spread in the agricultural sector of a class of products denominated "biostimulants", represented by humic substances extracted from fossil deposits of leonardite or lignite. Such products, generally highly expensive, are characterized by a high content of organic matter with a high percentage of humified organic matter. The "biostimulants" are applied in very low dosages to high-valued cash crops (usually, vegetables under greenhouse or fruit orchards), in combination with mineral fertilizers.

The "500 prepared", the "Fladen" and the "500" biodynamic preparations (BPs) are made by fresh, pasture-fed cattle manure which is put into a cow's horn and buried in the soil over winter (Steiner, 1924), respectively with ("500 prepared" and "Fladen) or without the addition of fermented plant extracts ("500").

The BPs exhibit high contents of organic matter and humic substances (Table 1). Research revealed that significant internal changes do take place in the manure during overwintering in the soil, namely a significant drop in pH, an increase in aerobic status, lowered CO_2 content, production of nitrate (Brinton, 1997).

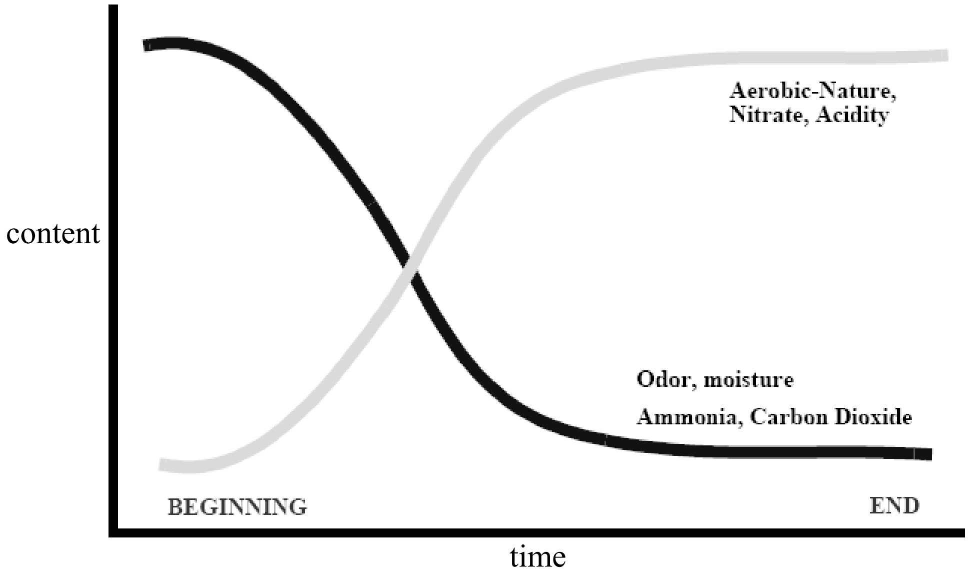


Figure 1. Chemical and sensorial changes observed during preparation of manure in cow horns underground for BP 500 (after Brinton, 1997).

Perumal and Vatsala (2002) analyzed the microbial content of the BP 500, during the ripening period. Although their research was not peer-reviewed, it is noteworthy to report here their outcomes (Table 1), that show the sharp increase of nitrogen-fixing bacteria in the BP, associated to an analogous growth of the fungi population.

Table 1. Time scale study on microbial analysis of cow horn manure (BP 500), adapted from Perumal and Vatsala, 2002.

Days	Rhizobium*	Azospirillum*	Azotobacter*	Fungi*
0	Nil	Nil	Nil	$11X\ 10^5$
30	$9 X 10^3$	$23 X 10^5$	$42 X 10^4$	$9 X 10^3$
60	$26 X 10^6$	$45 X 10^6$	$29 X 10^6$	$11 X 10^4$
90	$80 X 10^6$	$96 X 10^6$	$45 X 10^6$	$21 X 10^6$
120	$128 X 10^6$	$178 X 10^6$	$98 X 10^6$	$45 X 10^6$

TVC* = Total Viable Count per gram DW of BD 500

The BPs are usually prepared on-farm by the farmers themeselves, and when ready they are highly diluted in lukewarm water via the "dynamization" process, then sprayed on the just-tilled soil, before sowing the crop: ultimately, the amounts applied to the field are as the same as the commercial "biostimulants".

In this experiment, the effect of increasing concentrations of three biodynamic preparations and one well-known commercial "biostimulant" on the germination index of

Lepidium sativum has been investigated. The concentration range includes the working values utilised by biodynamic farmers and those ones recommended by the manufacturer.

2.1.2 Materials and Methods

The seeds of *L. sativum* were exposed to different concentrations (0.2, 2, 20 and 40 g L^{-1} on dry matter basis) of the biodynamic preparations (BPs) "500", "500-prepared" and "Fladen", and one commercial "biostimulant" named CIFOUMIC, made of leonardite (by CIFO S.p.A., Bologna, Italy) (Figure 2).

Dry weight of the four organic matters were determined in oven at 70°C for 72 hours.

The composition of the BP 500 shown in Table 2 was taken from literature (Brinton, 1997); the composition of BP 500p together with dry weight of Fladen were preliminarily determined for this experiment; and the composition of the CIFOUMIC is given by the manufacturer.

Table 2. Ingredients and chemical composition of the tested organic matters: dry weight, % of total organic carbon (TOC), ratio between humic acids (HA) + fulvic acids (FA) and TOC. Last column presents the concentration rates usually applied by farmers.

Item	Ingredients	DW (%)	TOC (% DW)	HA+FA /TOC (%)	Concentration of the dispersal to be applied in the field (g L^{-1} DW)	Total product amount to be applied in the field (g DW/ha)
BP 500	composted cattle dung - solid	29.5	31.8	*	1.00 - 5.00	30 - 200
BP 500p	composted cattle dung + plant extracts - solid	18.6	31.0	60.6	1.00 - 5.00	30 - 200
BP Fladen	composted cattle dung + eggshells + plant extracts - solid	58	*	*	2.5 - 4.00	100 - 150
CIFOUMIC	humic extracts from leonardite - liquid	21.0	36.6	54.18	0.50 - 1.00	100 - 200

* not determined

Figure 2. Left, a sample of the BP "500-prepared", used in the experiment; center, "horn-manure", i.e. the BP "500" (source: www.biodynamics.in); right, the liquid extract of leonardite.

The three substances were dissolved in water following the method of "dynamization" (Steiner, 1924), i.e. by dissolving the products in separated beackers with 500 ml of water at 35 °C, by stirring energetically clockwise and counterclockwise for sixty minutes (Figure 2). The water used for dynamization was put in a container 24 hours before beginning the process.

Figure 3. Dynamization of the three organic matters, according to the biodynamic method.

Four replicates were used per each treatment; each replicate was represented by one Petri dish (Ø 8.5 cm) with fifteen seeds of *L. sativum* and blotting paper. To each Petri dish, 2 ml of dispersal and 2 ml of distilled water were added respectively for the treatments and control. All the Petri dishes were arranged in a large plate, according to a randomised block design, then placed in a growth chamber under ideal light conditions and at 20°C, for 24 hours. At the end of the incubation, the sensitivity of *L. sativum* germination to the treatments was assessed by seedling count and measurement of root lenght. Germination was described as a visible cracking of the seed coat with or without a measurable root production. The germination index (Ig) was calculated by the following formula (Zucconi et al., 1984):

$$I_g = \frac{R_t \cdot L_t}{R_c \cdot L_c} \cdot 100$$

where Rt and Rc indicate the rooting of treatments and the control, and Lt and Lc the average root lenght of treatments and the control, respectively.

The experiment was replicated twice.

2.1.3 Results and Discussion

As depicted in Figure 4, germination was not inhibited by the BP "500" and "500 prepared" at any concentration; and even at the highest concentration of the dispersal the inhibition effect is unnoticeable.

The BP Fladen caused inhibition starting from the 2 g L^{-1} dose, however at the highest concentration the inhibitory effect was less pronounced.

The CIFOUMIC showed the more marked phytotoxic effect at the concentrations of 20 and 40 g L^{-1}.

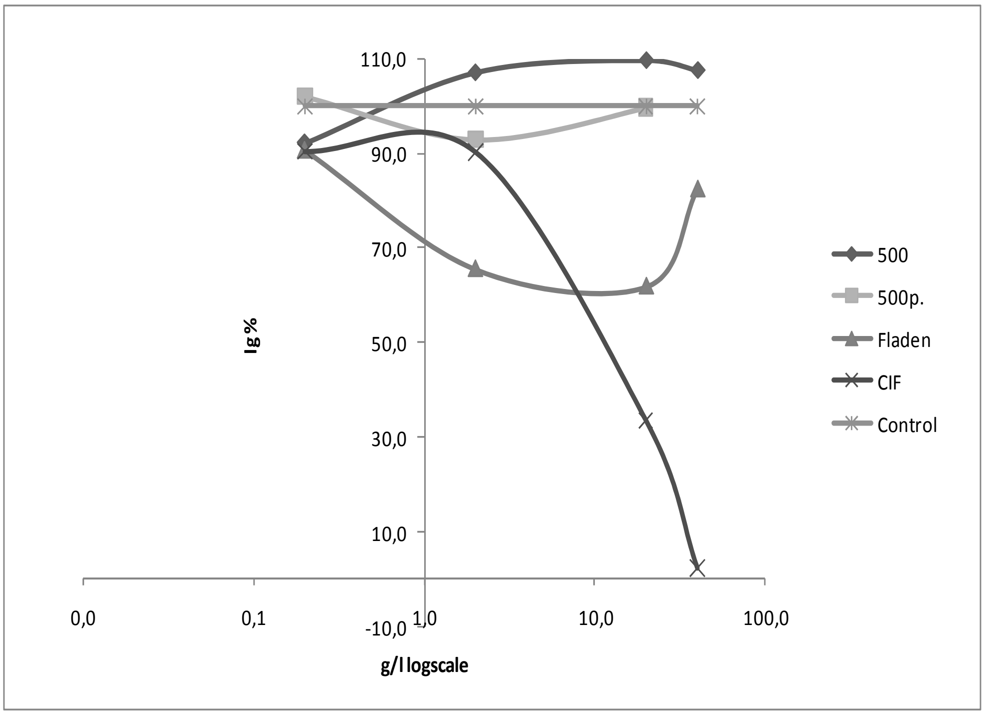


Figure 4. Sensitivity of *L. sativum*, as expressed by the Germination Index (Ig), to increasing concentrations of 3 biodynamic preparations and one commercial "biostimulant", CIFOUMIC, based on leonardite extracts. The X axis values are expressed on a logaritmic scale.

The results show that both the BPs "500" and "500 prepared" do not exert evident phytotoxic effect on seed germination of *L. sativum*, even within a large concentration range and despite of having a chemical composition very similar to that one of the commercial "biostimulant".

It is then argued that the observed difference in response among the tested organic matters could be in part explained by a sort of "osmotic effect", bound to the possible presence of dissolved salts within the dispersal, thus preventing for a certain expent seed germination.

In addition, it might be hypothesised that, being the BPs quite "lively substances" characterized by an active microbial community, as claimed by biodynamic farmers and demonstrated by research (Steiner, 1924; Podolinsky, 1985; Perumal and Vatsala, 2002), they are likely to be potentially able to mitigate phytotoxic effects due to the high dosages of the organic matter. Such "living" feature is however absent in the commercial "biostimulant", because of its mineral derivation as well as the sterilization process to which it was subjected through manufacturing.

An in-depth microbial characterization of the biodynamic preparations and their effect on plant physiology are therefore highly envisaged, through further research.

2.2 Effect of biodynamic preparations on biomass production

2.2.1 Introduction

Since early Steiner's recommendations (Steiner, 1924), biodynamic farmers have been using a number of 'preparations' (BPs) made up by fermented herbs to inoculate compost, and field sprays that are either made from cow manure and silica fermented in cow horns (Koepf et al., 1989).

Two special mixtures of the earliest BPs, i.e. the "500" (cow horn manure) and other fermented herbs ("502" to "507"), have been subsequently elaborated by biodynamic practitioners, yielding two new preparations: the *Fladen*, by Maria Thun and the *500 preparation*, by the Australian A. Podolinsky, with the intention of turning crop/green manuring residues into stable soil organic matter, in case of scarcity or unavailability of farm animal manure/compost (Podolinsky, 1985).

In some studies the BPs showed hormone-like effects on various crops with the potential to increase root growth (Goldstein and Koepf, 1982; Raupp and Koenig, 1996). However, very little research has been done on the more recent mixtures derived from the original Steiner's preparations. These materials are often utilized as field sprays in current biodynamic farming practice, markedly in stockless farming systems.

In this simple experiment, the effect of the oldest BP "500" and the more recent BP "500 preparation" on short-term biomass production of a herbaceous mixture for green manuring has been investigated.

2.2.2 Materials and Methods

The BPs had been manufactured by an experienced farmer according to biodynamic standard specifications (Steiner, 1924; Podolinsky, 1985). Dry weight of both preparations has been determined in oven at 70°C for 72 hours. Two spray solutions have been prepared by the method of "dynamization" (Steiner, 1924), i.e. by dissolving 2 g/DW of each product (corresponding to 6.78 g/FW of the "500" and 10.75 g/FW of the "500 preparation", respectively) in separated beakers with 500 ml of water at 35°C, by stirring energetically clockwise and counter clockwise for sixty minutes (Figure 1). Four grams DW of BPs per litre falls in the concentration range that is usually utilised in the biodynamic farming practices. Nine aluminium containers (30x25x4 cm) were filled with a peat substrate (1/2 blond peat: pH 4.5; 1/2 dark peat: pH 6.5) (Figure 1).

Figure 1. Left, dynamization; center, containers with peat substrate; right, spraying the BPs.

Three containers were sprayed with 2 ml of the "500" solution each; three other containers were sprayed with 2 ml of the "500 preparation" solution each; the remaining three containers were sprayed with 2 ml of distilled water (control) (Figure 1). All the containers were watered until field capacity. Seeds for an amount of 3.3 grams of the green manuring mixture “Arcoiris Multifloreale[1]”, made up by 24 different herbaceous species belonging to several families (i.e. Leguminosae, Asteraceae, Hydrophyllaceae, Apiaceae, Cruciferae, Cariofillaceae, Compositae, Malvaceae and Boraginaceae), were evenly distributed on the surface of each container, then covered by a thin layer of the same substrate.

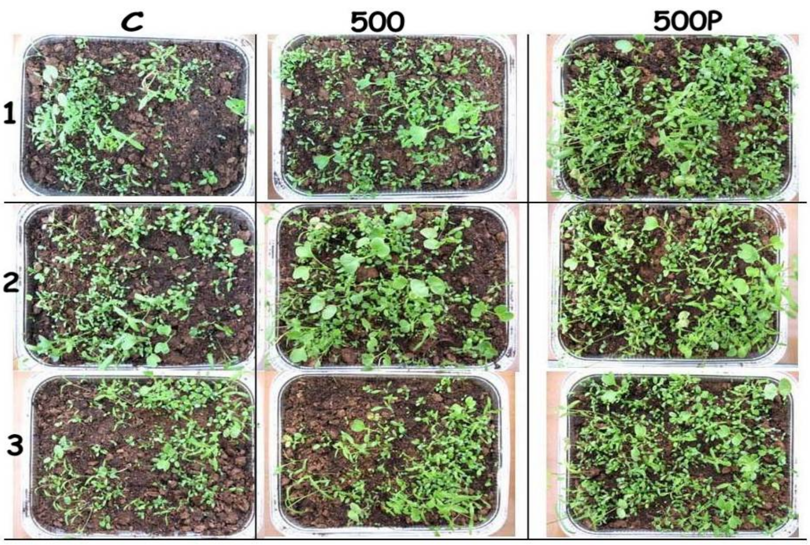
The nine containers were placed in a greenhouse at 22/17°C (day/night) in three randomised blocks. The trial lasted five weeks, and every week the containers were watered until field capacity and the blocks rotated in three ways, simultaneously: a) rotation among blocks; b) rotation of the 3 replicas within same block; c) rotation of each container of 180°.

At the end of the period, fresh and dry weight of the above-ground biomass was determined, and the dry matter content calculated for all the treatments.

2.2.3 Results and Discussion

Figure 2 is self-explanatory, showing a higher visual density of above-ground plant parts and roots at the end of the trial, in the containers with treatments. It is noteworthy that the same trend seemed to be already evident at about the half of the trial period (Fig. 2).

Figure 3 shows root development for replicas 1 and 3 only, due to occurred sampling problems: the (visual) roots density and distribution seems to be more pronounced and wider in the containers with treatments.



[1] Arcoiris srl; www.arcoiris.it

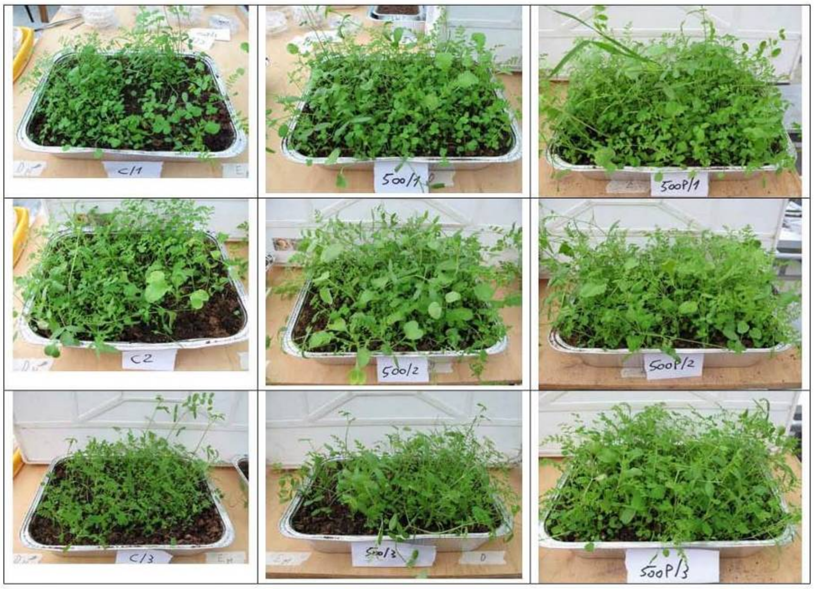


Figure 2. Top, above-ground growth after 16 days; bottom, plant growth at the trial's end, after 34 days.

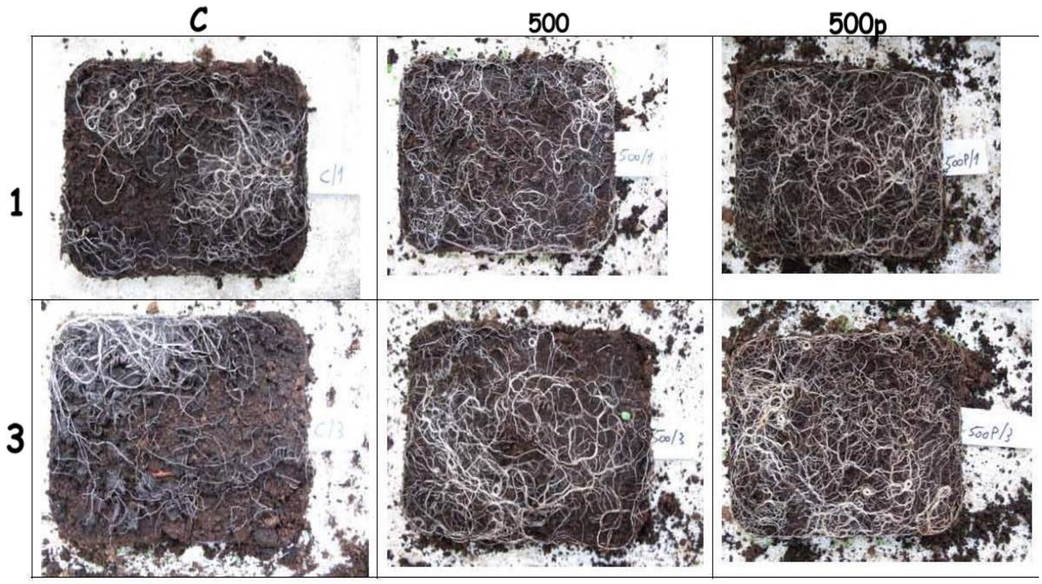
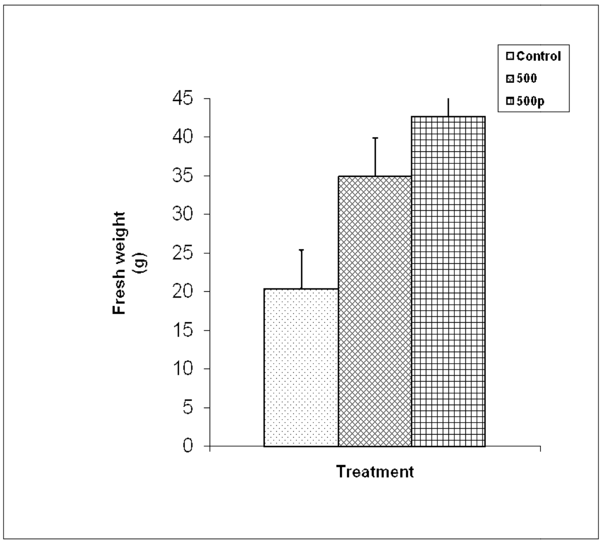


Figure 3. Root development and distribution at the trial's end, after 34 days.

Fresh and dry weights of the above-ground biomass are depicted in Figure 4 showing treatments effect vs. control, as measured at the end of the trial. Both the BPs showed to induce more growth with respect to the control. However, such an effect is rather less pronounced when examining the the dry matter content (Figure 5).



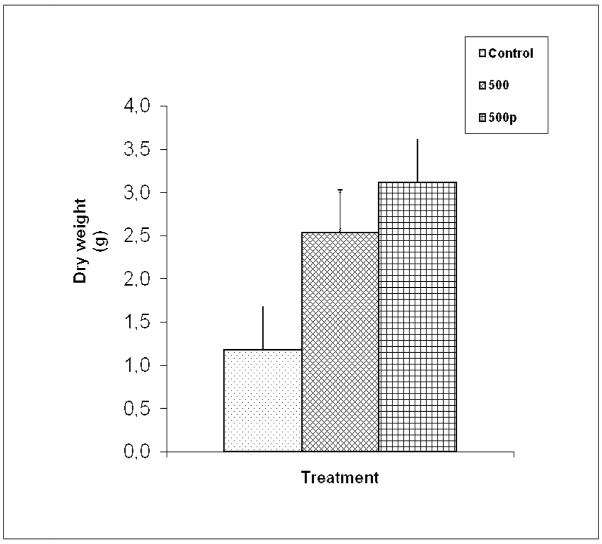


Figure 4. Fresh and dry weight of the above-ground biomass, at the end of the trial after 34 days. Bars represent the standard errors of the mean.

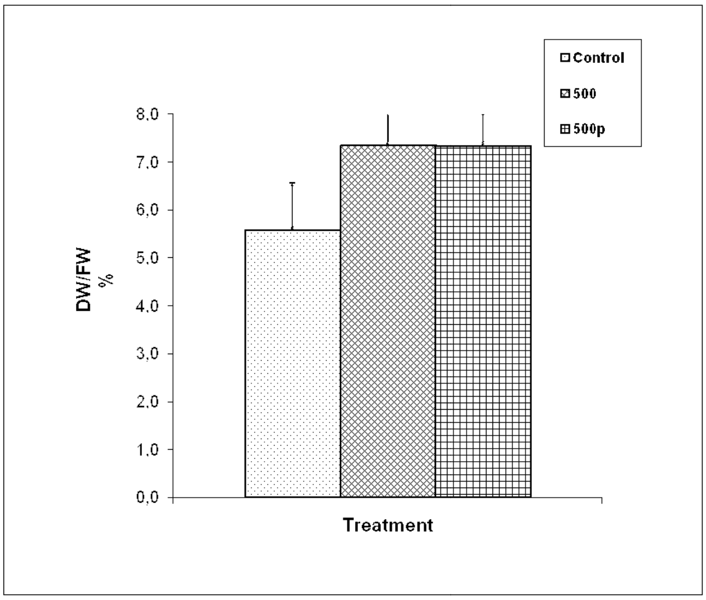


Figure 5. Dry matter content of above-ground biomass, after 34 days. Bars represent the standard errors of the mean.

Both the BPs seemed to exert a growth-promoting effect on the mixture of the herbaceous species utilized in the experiment. Sampling problems have not unfortunately allowed to sample and weigh the roots alone, but the visual observation seems to show a stimulus effect on the root system as well.

It could be hypothesized that the total nitrogen content of the BPs (about 2% DW, as indicated by literature - Brinton, 1997 - as well as by our direct measurements) might have played a role in inducing plant development, in comparison with the nutrient-poor control treatment: however, the amount of nitrogen supplied via the BPs (around 0.08 mg/container) cannot justify alone the final above-ground biomass produced on average, that is 2.53 g DW/container under BP "500", and 3.12 g DW/container under BP "500 prepared, respectively.

It is then argued that the BPs may have also directly interacted with some physiological aspects of the plants.

Therefore, the physiological mechanisms through which the BPs are likely to promote the above- and below-ground plant growth should be further investigated.

2.3 On-farm research in biodynamic farms

2.3.1 Introduction

This experiment had the objective to evaluate the effect of different modalities of managing organic matter in the field, through diverse combinations of biodynamic preparations (BPs), with or without green manuring (GM).

The experiment was carried out from 2006 to 2010 within a frame of on-farm research. Two farmers were in fact involved as partners in the research activity, which was promoted by the "Regione Marche" to reply to a specific demand formulated by the local association of biodynamic and organic farmers.

Both the farmers were highly motivated and committed over the entire duration of the experiment. They participated to the design of the experiment and carried out all the needed cropping operations in their farms, advising as well on the major adjustments to be done to the concerted research protocol in order to make it more suitable to the main experiment's objective, namely to identify the best way to manage in the farm organic matter sources under the typical hilly farming conditions of the Marche region. Eventually, the farmers participated to the evaluation of the results, in the light of the feasibility and efficacy of the new techniques proposed. The examination and discussion of the results were extended to the biodynamic and organic farmers of the regional associations involved, through open days organized in both the farms.

Two simultaneous field experiments were carried out: one, in a biodynamic arable farm; the other, in an organic arable and olive farm.

2.3.2 Materials and Methods

2.3.2.1 The experimental site 1: Azienda Agricola Biodinamica Demetra

The "Azienda Agricola Biodinamica Demetra" (hereafter "Demetra farm" - 13°12'24.16" E, 43°13'10.32" N) is localized in the municipality area of San Severino Marche (AN). The farm land, accounting for 9.7 hectares, has been controlled in compliance with the European organic and biodynamic standards (Demeter) since 2003, getting the first biodynamic certification on 2005. The farmer is member of the regional association of biodynamic farmers, and he actively participates to the association's initiatives to spread biodynamic agriculture and adapt its method to the local agricultural environment. The farm provides accomodation in the shape of agro-tourism and it is equipped to perform as "didactic farm" for the local school-children.

Since its establishment, the Demetra farm has been managing a diversified arable crop rotation, alternating winter cereals (wheat, barley and spelt) with pulses and leguminous fodder crops. Only organic manures have been applied. The products are predominantly sold in the local market.

The farm is localised in the typical hilly agroecosystem of the Marche region (Figure 1 and 2), at about 350 m a.s.l..

Figure 1. Agricultural landscape of the experimental area and cropland of the Demetra farm (in the red box).

Figure 2. The experimental parcel in the Demetra farm (inside the red perimeter).

Over the duration of the experiment, the mean rain precipitation per year was 653 mm and the annual mean temperature was 14 °C. Figure 3 shows the monthly precipitations and temperatures[2], as recorded by the closest weather station.

Soil characteristics of the experimental parcel are reported in Table 1.

Table 1. Soil physical and chemical characteristics of the experimental parcel, as measured at the beginning of the trial (2006). Values are the mean of 9 samples (each sample obtained by mixing 3 sub-samples) taken evenly throughout the parcel.

Tex-ture	**TOC** % dw	**C $_{HA+FA}$** % dw	**Humif. rate** (C $_{HA+FA}$ x 100)/TOC	**N** g/kg	**P** mg/kg	**K** mg/kg	**CEC** meq/100g	**pH**	**Active lime** (g/kg)
clay	1.06	0.40	36.98	1.08	7.80	212	26.40	8.33	94

TOC: total organic carbon (Springer and Klee, 1954); C_{HA+FA} (Ciavatta et al., 1990): C from humic acids and fulvic acids; CEC: cation exchange capacity.

[2] Data provided by the weather station of Serrapetrona (MC), network ASSAM, the regional agency for rural development. The station is localised at 3 km from the experimental site.

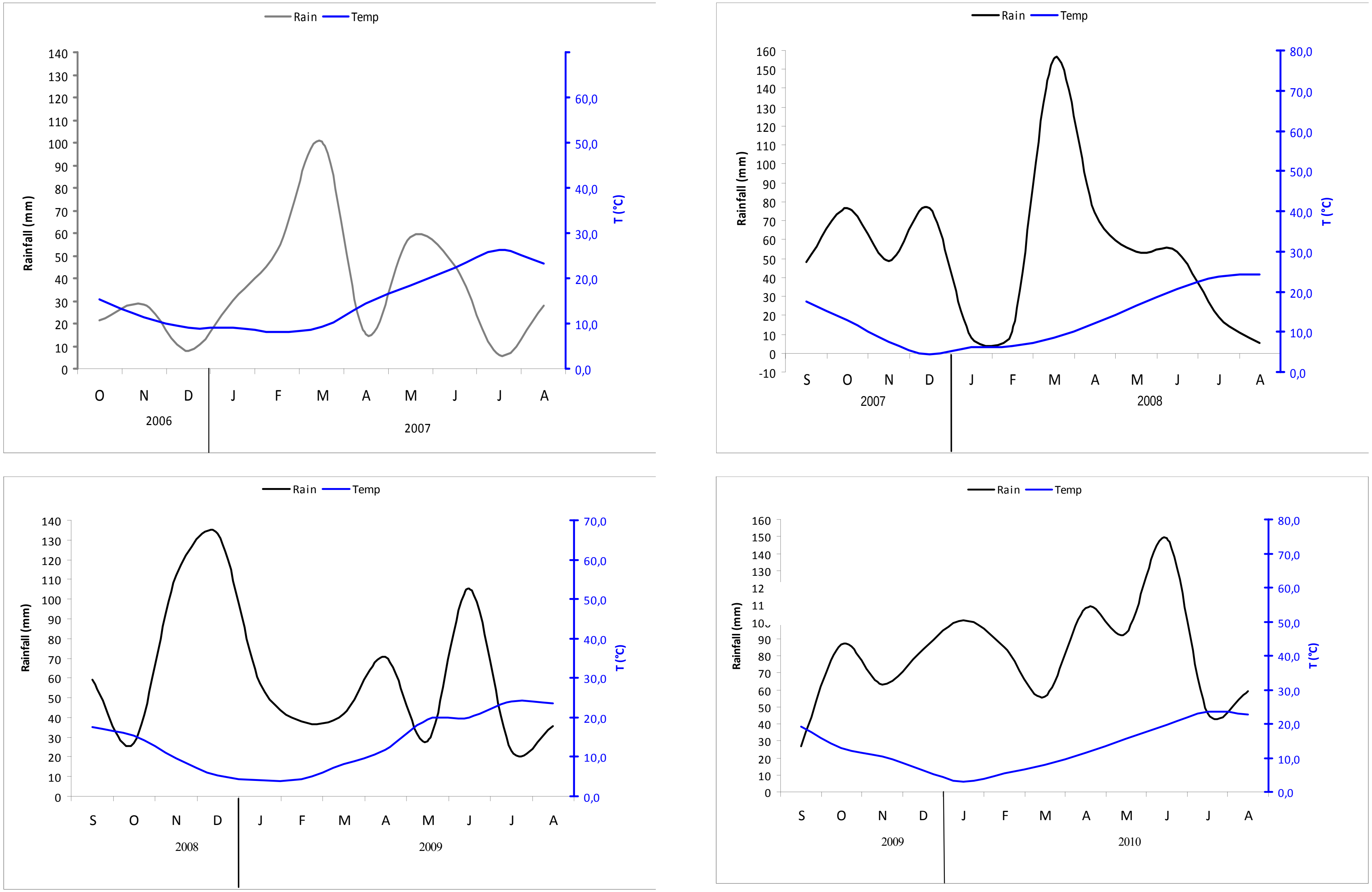


Figure 3. Monthly rain precipitations and temperatures in the experimental area during the trial.

2.3.2.2 The experimental site 2: Azienda Agricola Fattoria Le Origini

The "Azienda Agricola Fattoria Le Origini" (hereafter "Le Origini farm" - 43°16'22.95"N; 13°12'33.92"E) is localized in the municipality area of San Severino Marche (AN). The farm land, accounting for 29 hectares, has been certified in compliance with the European standards for organic agriculture since 2006, starting the conversion period on 2004; the farm provides as well accomodation and meals (agro-tourism). The farmer is a leader of the local section of a farmer Union (Coldiretti), and he is very committed in the matter of farm-generated renewable energy.

Since its conversion to organic agriculture, the Le Origini farm has been managing a diversified arable crop rotation, alternating winter cereals (wheat and spelt) with leguminous fodder crops. An olive orchard composed by autochthonous olive varieties is also present in the farm, and the oil is sold in the local market as well as consumed in the agro-tourism.

The Le Origini farm is placed at around 5 km from the Demetra farm, in the same hilly agroecosystem (Figure 4), at about 300 m a.s.l., and at 9 km from the weather station, being valid for this farm the same climatic conditions presented above.

Figure 4. The experimental parcel in the Le Origini farm (inside the red perimeter).

Soil characteristics of the experimental parcel are reported in Table 2.

Table 2. Soil physical and chemical characteristics of the experimental parcel, as measured at the beginning of the trial (2007). Values are the mean of 6 samples (each sample obtained by mixing 3 sub-samples) taken evenly throughout the parcel.

Texture	**OM** g/kg	**N** g/kg	**P** mg/kg	**K** mg/kg	**CEC** meq/100g	**pH**	**Active lime** (g/kg)
loam	9.23	0.65	15.33	97.67	17.48	8.29	175

OM: organic matter. CEC: cation exchange capacity.

2.3.2.3 Treatments and farming practices

The effect of three treatments, based on different arrangement of biodynamic preparations (BPs) and organic matter management, on crop production and soil parameters were studied from October 2006 to August 2010 in the Demetra farm, and from April 2007 to August 2010 in the Le Origini farm, respectively.

The treatments were applied to a three-years arable crop rotation field and to a newly-established olive grove, in the Demetra farm and the Le Origini farm, respectively.

The treatments were as follows:

- A: BP 500 + BP 501 (traditional)
- B: BP 500 + BP 501 + green manuring (GM)
- C: BP 500 + BP 501 + BP "500 prepared"

The BP 500 (horn-manure) was prepared directly on farm, by the local group of biodynamic farmers; the BP 501 (horn-silica) and the BP "500 prepared" (horn-manure + fermented plant extracts) were purchased by a well-known professional manufacturer (Carlo Noro, Rome).

All the BPs were "dynamized" in the Demeter farm according to the biodynamic method (Steiner, 1924 - Figure 5) and applied to the plots twice a year, as fine aqueous sprays.

Two hundreds grams (fresh weight) per hectare, dissolved in 30 liters of water, of 500 and "500 prepared" were sprayed on the bare soil at each application; and 8 grams (fresh weight) per hectare, dissolved in 60 liters of water, of 501 were sprayed on the plants at each application (Figure 6).

Figure 5. On farm dynamization by machine: water warmed at 35°C and the mixture energetically stirred clockwise and counter-clockwise for one hour.

Figure 6. Mechanical sprayer for the BPs, utilised in the Demetra farm.

The seeds for GM consisted of a commercial mixture ("Arcoiris Multifloreale[3]") of 24 different herbaceous species belonging to several families (i.e. Leguminosae, Asteraceae, Hydrophyllaceae, Apiaceae, Cruciferae, Cariofillaceae, Compositae, Malvaceae and Boraginaceae). Figure 7 shows the relative composition of the mixture and the species; Figure 8 shows an overview of the GM mixture.

An amount of 60 kg/ha of GM mixture was sown every year in treatment B, according to the crop rotation.

In both the sites, the GM mixture was cropped from autumn to springtime, taking the place of a winter crop in the arable crop rotation. At flowering stage and allowing the soil conditions, the GM crop was mowed and incorporated in the soil top layer by harrowing, after being cut into small pieces and left on the surface for 4 to 5 days for wilting (Table 3).

[3] Arcoiris srl; www.arcoiris.it

Table 3. Dates of GM sowing and mowing in both the experimental sites

Site	2007		2008	
	sowing date	mowing date	sowing date	mowing date
Demetra farm	02/11/06	15/03/07	13/10/07	14/04/08
Le Origini farm	-	-	26/11/07	26/05/08
	2009		**2010**	
	sowing date	mowing date	sowing date	mowing date
Demetra farm	16/10/08	04/05/09	27/09/09	14/05/10
Le Origini farm	22/10/08	16/06/09	25/09/09	15/06/10

The farming inputs and operations were the same in all the treatments, in both the experimental sites over the entire duration of the trial (Table 4).

Table 4. Farming inputs and operations as implemented in both sites, common to all the treatments.

Practice	Mode
Tillage	By cultivator and disk harrow
Fertilisation	No supplementary fertilisation was carried out
Pest&disease control	Any kind of pest&disease control intervention was made
Irrigation	Both the cropping systems were rainfed, only
Labour	The farmers could manage the trials on their own, without need of additional labour
Seed material	Organic seeds of grass bean, sorghum, maize and sunflower were purchased by a local retailer, every year. The biodynamic GM mixture was purchased by a specialized retailer, every year. The organic seeds of spelt sown on 2006 came from another biodynamic farm, as product of the first harvest (second generation): on 2007, 2008 and 2009 part of the harvest from the previous year was used as seeds for the new crop.

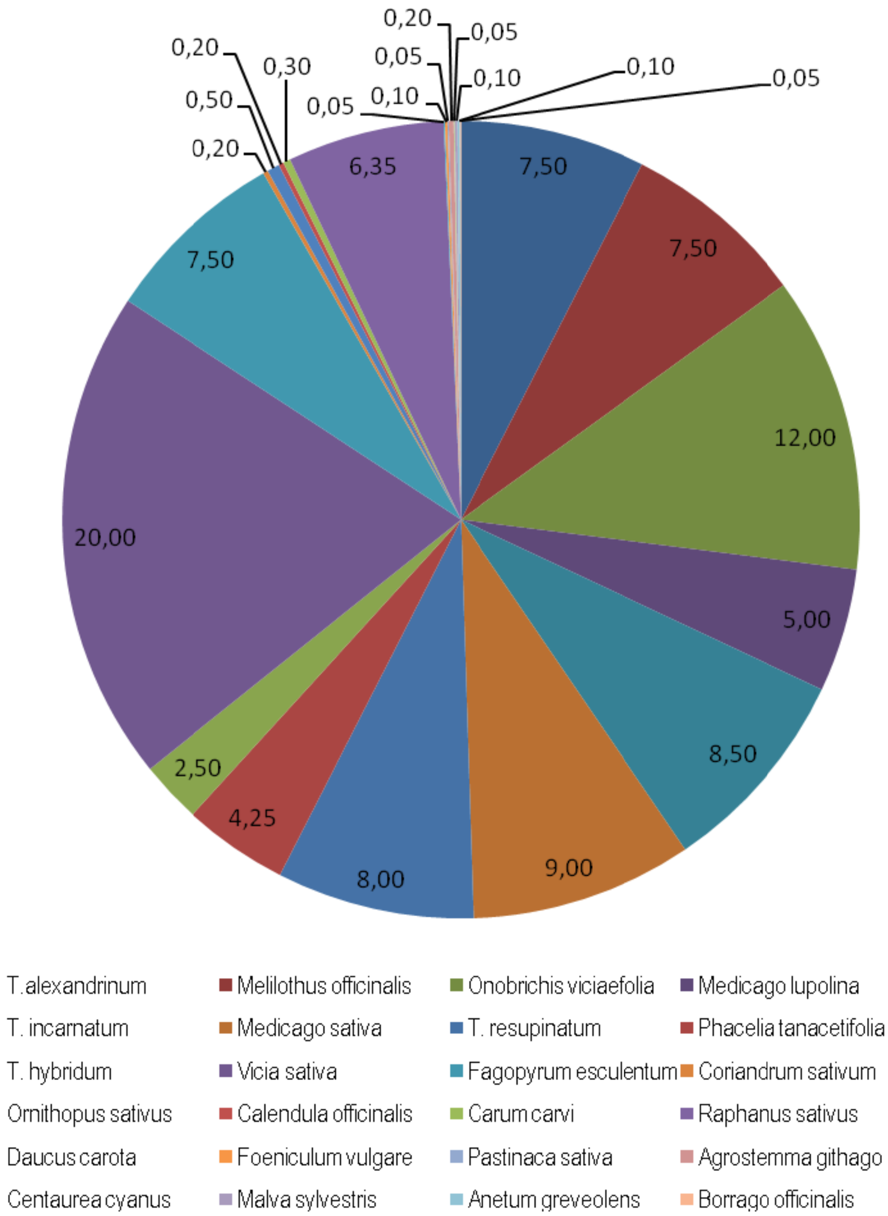


Figure 7. GM mixture % botanical composition.

Figure 8. An overview of the mixture used for GM in the experiment.

2.3.2.4 Experimental design

Each treatment was replicated three times in both the experimental sites.

In the Demetra farm, a 3-years rotation was arranged by alternating a winter crop (spelt, *Triticum spelta*) with spring crops (i.e. maize, *Zea mays*; sorghum, *Sorghum bicolor*; sunflower, *Heliathus annuus*; grass bean, *Lathyrus sativus*) (Figures 9 and 10). In treatment B, the GM always preceded the spring crop (Figure 9).

All the crop residues were left in the field: in particular, the whole biomass of sorghum and sunflower was incorporated into the soil, after the measurement.

Table 5 shows the dates of sowing and harvest. To be noted that maize 2007 and spelt 2010 failed production: the former, due to lack of rain, the latter, because of a severe weed infestation.

Table 5. Times of sowing and harvest of the crops in the rotation.

	2006/07		**2007/08**		**2008/09**		**2009/10**	
Crop	Sowing	Harvest	Sowing	Harvest	Sowing	Harvest	Sowing	Harvest
Spelt	5/11	9/7	24/11	7/7	6/11	13/7	8/11	n/a
Sorghum			6/5	13/8	8/6	6/8	-	-
Sunflower	-	-	-	-	-	-	7/6	11/8
Grass bean	18/4	16/7	21/4	7/7	10/5	6/8	7/6	11/8
Maize	19/4	n/a	-	-	-	-	-	-

The experimental parcel, sited on sloping land, was splitted in 9 plots, representing the A, B and C treatments replicated three times. Unfortunately, it was not possible to arrange the replicates in random order, since it would have been too much labour demanding for the farmer to properly manage each single plot with different crops and treatments.

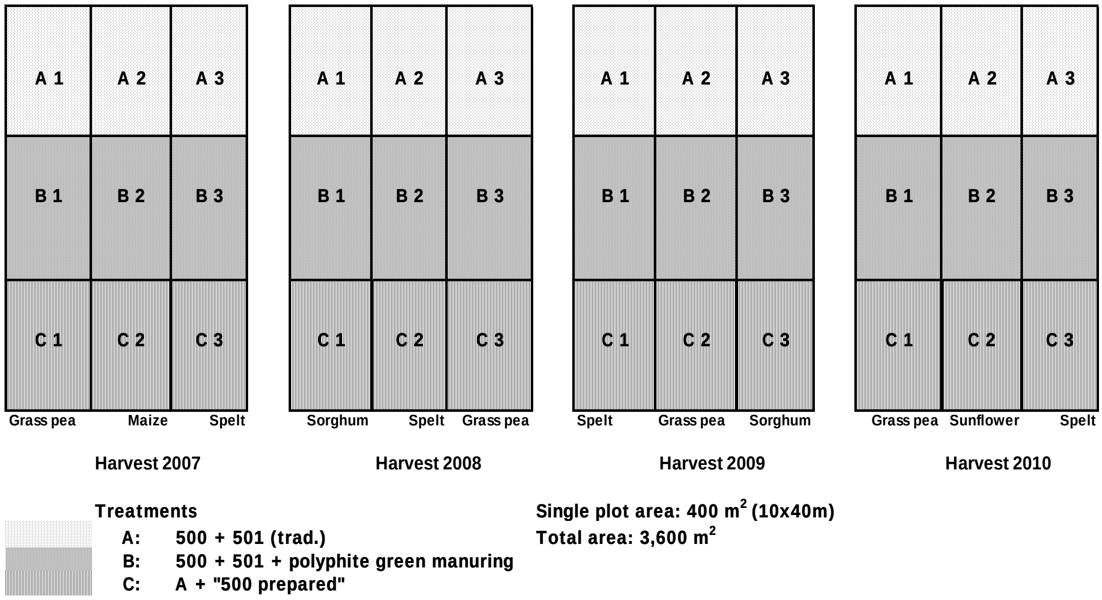


Figure 9. Experimental layout in the Demetra farm (2006-2010).

Figure 10. The experimental parcel in Demetra farm splitted in the 9 plots, with treatments.

In the Le Origini farm, the experiment was carried out in an olive orchard, purposely planted for the trial on April 2007. One hundred sixty two 12-months old grafted olive trees were planted in the sloping selected farm area (Figure 4); half of the plants belonged to the cultivar "Piantone di Mogliano", the other half to the cultivar "Orbetana" (Figure 11).

Figure 11. Spraying the BPs in the experimental olive orchard in Le Origini farm.

The randomization of the 3 replicates per treatment was arranged as in Figure 12.

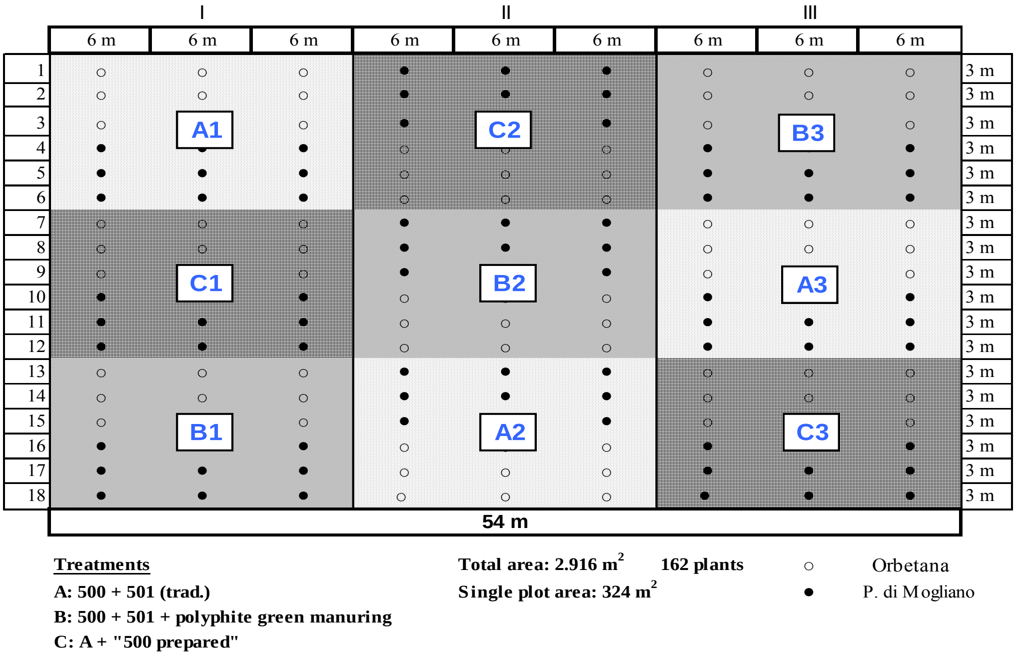


Figure 12. Experimental layout in the Le Origini farm (2007 - 2010). The replicates were randomized.

2.3.2.5 Measurements carried out in the Demetra farm

The following parameters were annually measured:

– Total above-ground biomass production for all the crops at harvest time (three 1 m^2 biomass samples, taken at random in each plot; measurement of fresh weight and dry weight, the latter obtained in oven at 70°C for 72 hours) (Figure 13);

- Grain production for spelt and grass bean at harvest time (sampling method as above);
- Total above-ground biomass of the green manuring, at the mowing stage (sampling method as above);
- Total organic carbon (TOC), carbon from humic acids and fulvic acids (C HA+FA), humification rate (HR) and total nitrogen were measured in the first 30-cm soil layer at the beginning (2006) and at the end of the trial (2010)[4].

Figure 13. The 1 m^2 frame utilized for random sampling of biomass.

2.3.2.6 Measurements carried out in the Le Origini farm

The following parameters were annually measured:

- Total above-ground biomass of the green manuring, at the mowing stage (sampling method as described above);
- Above-ground growth of each olive tree (Figure 14).

A qualitative assessment of the botanical composition of green manure at the mowing stage was made on springtime 2009 (Figure 14).

[4]All the analytical determinations were made by the Centro Agrochimico Regionale, Agenzia Servizi Settore Agroalimentare delle Marche - ASSAM

Figure 14. Left, olive growth measurement; right, botanical identification of harvested GM plants.

Statistical elaboration of the data was carried out through the software STATISTICA for Windows.

2.3.3 Results and Discussion (Demetra farm)

2.3.3.1 Green manure

The above-ground GM biomass production is shown in Table 5, together with the 2010 measure of wild vegetation biomass in the plots of treatments A and C (Figure 15).

Table 5. Above-ground biomass production of GM mixture in the 4 years of the experiment on dry matter basis (treatment B) and wild vegetation above-ground biomass in the plots of treatments A and C. The values are the means of 3 samples per plot.

2006/07 (t/ha)	**2007/08** (t/ha)	**2008/09** (t/ha)	**2009/10*** (t/ha)	**2009/10*** wild veg. (t/ha)
1.03	1.29	3.35	5.59	1.76

* measurements made in the same day

Figure 15. Sampling of wild vegetation in treatment A.

The data indicate an increasingly production of biomass, from 2007 to 2010. In particular, the increase seems rather marked on year 2009/10, which could have been caused by the highest rainfall occurred (Figure 3), in conjunction with a more extended length of the growing cycle, when compared with years 2006/07 and 2007/08 (Table 3). It is noteworthy the biomass difference between the GM- and non-GM plots, both in terms of quantity and quality (*Lolium spp.* were clearly dominant, Figure 15).

However, it has to be underlined that the higher GM biomass production was obtained at the expenses of the best period to grow the following spring crop, that had to be moved further in the dry period.

The green manure plots during the blooming phase improved the feeding of the bees bred on-farm, as stated by the farmer (Figure 16).

Figure 16. Green manure crop at flowering stage in the Demetra farm, as important source of feed for the bees.

2.3.3.2 Crop production

Figure 17 and 18 show respectively the production of the above-ground biomass and the grains of spelt and grass bean.

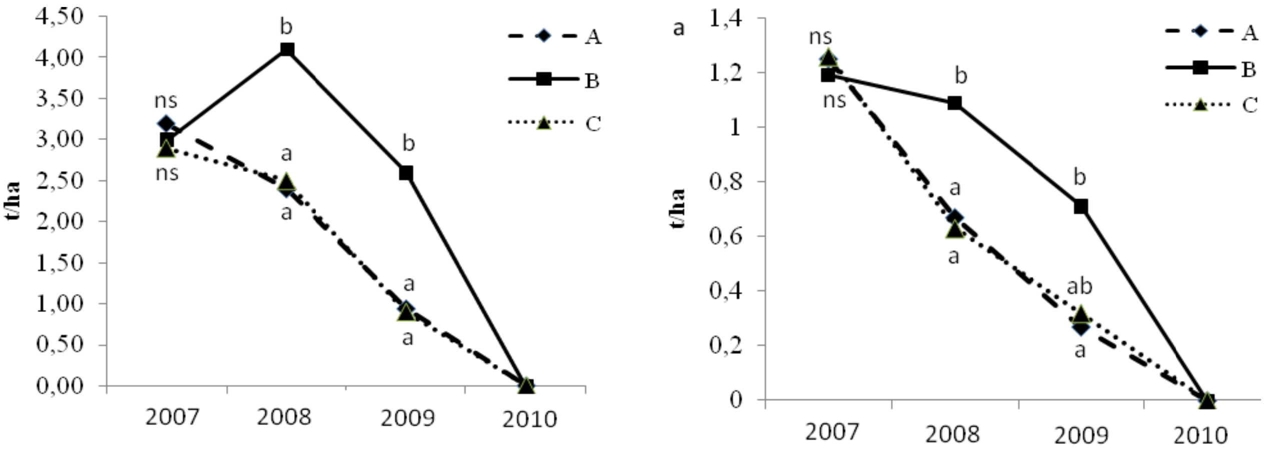


Figure 17. Left to right, above-ground biomass and grain production of spelt, on dry matter basis. Different letters indicate significative differences between the treatments (LSD $p < 0.05$), ns = not significative,

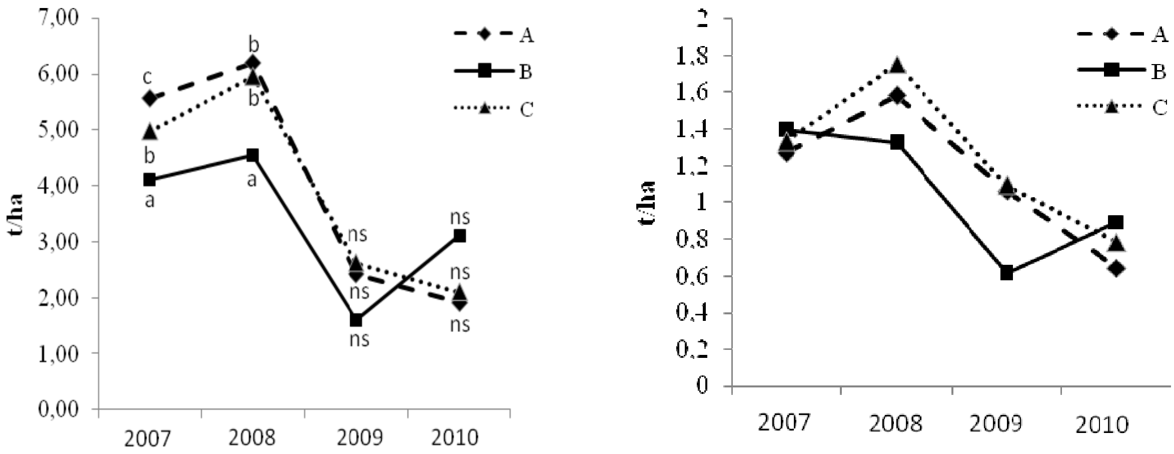


Figure 18. Left to right, above-ground biomass and grain production of grass bean, on dry matter basis. Different letters indicate significative differences between the treatments (LSD $p < 0.05$), ns = not significative.

Spelt production of year 2010 was negligible due to a severe weed infestation, and it was not measured. Presumably the loss of the genetic characteristics of vigour of the original variety, as result of having re-used the same seeds from generation to generation.

The same fact might have determined the observed fall in overall production progressively over the 4 years of trial, in conjunction with a possible diminished availability of soil nutrients, also taking into account that any supplementary fertilization was applied (Table 4).

However, on years 2008 and 2009 biomass and grain productions were significantly higher for the treatment B, which might have been provoked by the presence of the GM. Interestingly enough, the GM effect on spelt production was still marked after the growing of the spring crop.

In grass bean, treatment B seemed to have achieved the opposite effect with respect to spelt, namely restricting biomass production both on 2007 and 2008: this might be in part explained by a phytotoxic effect caused by the decomposition of the GM organic matter on the development of the grass bean - or just by a crop competition with the soil microbial community for the available nutrients. Nevertheless, the same effect was not observed in the following years of the trial, nor for grain production where statistical differences among the treatments were not recorded for the whole period.

The sharp drop of the 2009 production of biomass and grains of grass bean for all the treatments, in comparison with year 2008, was presumably the consequence of having moved the crop cycle of one month ahead (to give more room to the preceding GM), thus exposing the crop to the summer drought during the phases of flowering and fruiting.

Figure 19 and Table 6 show above-ground biomass production of sorghum and sunflower, respectively.

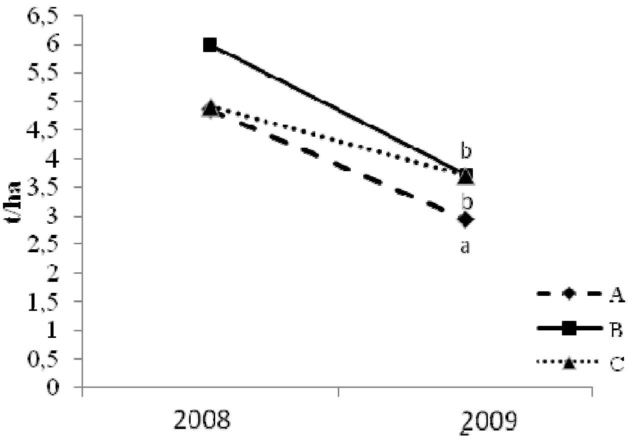


Figure 19. Above-ground biomass of sorghum, on dry matter basis. Different letters indicate significative differences between the treatments (LSD $p < 0.05$).

Table 6. Sunflower above-ground biomass 2010, on dry matter basis. Different letters indicate significative differences between the treatments (LSD $p < 0.05$).

	Treat.	**t/ha**
2010	A	4.22 ^{b}
	B	7.00 ^{a}
	C	6.34 ^{ab}

Overall sorghum biomass production decreased from 2008 to 2009 disregarding the treatments, presumably because of the shorter crop cycle on 2009 (Table 5); however on 2009 treatments B and C were likely to determine an increase of production; whereas the biomass production of sunflower seemed to be increased by treatment B, only. Therefore, GM showed to promote development of these two spring crops, unlike the grass bean.

2.3.3.3 Soil nutrients and organic matter

By comparing the soil measurements of 2006 (beginning of experiment) with 2010 (end of it), it emerges that the concerned soil parameters did not change, namely they were not plausibly affected by treatments. Table 7 and 8 present the data.

Table 7. Macronutrients, CEC and pH, measured at the beginning and at the end of the experiment, do not show any statistically significant variation among treatments and years (LSD $p < 0.05$). Means of 9 samples per treatment in the first 30-cm soil depth.

Treat.	**N g/kg**		**P mg/kg**		**K mg/kg**		**CEC meq/100g**		**pH**	
	2006	2010	2006	2010	2006	2010	2006	2010	2006	2010
A	1.08	1.05	7.80	7.83	212	206	26.40	23.79	8.33	8.11
B	1.08	1.06	7.80	6.61	212	217	26.40	25.06	8.33	8.13
C	1.08	0.95	7.80	5.21	212	208	26.40	25.82	8.33	8.10

CEC: cation exchange capacity

Table 8. Total organic carbon, carbon from humic acids and fulvic acids, humification rate and C/N, measured at the beginning and at the end of the experiment, do not show any statistically significant variation among treatments and years (LSD $p < 0.05$). Means of 9 samples per treatment in the first 30-cm soil depth.

Treat.	**TOC % dw**		**C_{HA+FA} % dw**		**Humif. rate (C_{HA+FA} x 100)/TOC***		**C/N**	
	2006	2010	2006	2010	2006	2010	2006	2010
A	1.15	1.07	0.40	0.44	36.98	34.81	10.27	9.65
B	1.14	1.15	0.44	0.44	36.98	38.30	10.36	9.94
C	0.90	1.02	0.36	0.33	36.98	40.45	8.83	10.41

*T.O.C.: total organic carbon (Springer and Klee, 1954); C_{HA+FA} (Ciavatta et al., 1990): C from humic acids and fulvic acids

;.

2.3.4 Results and Discussion (Le Origini farm)

2.3.4.1 Quantitative and qualitative aspects of green manure

Table 9 indicates the GM above-ground biomass production during the 3 years of the trial, and the wild vegetation biomass measured on 2009. In Figure 20, the GM plots in the experimental olive orchard are emphasized (late spring 2009).

Table 9. Above-ground biomass production of GM mixture in the 3 years of the experiment on dry matter basis (treatment B) and wild vegetation above-ground biomass in the plots of treatments A and C. The values are the means of 3 samples per plot.

2007/08	2008/09*	2008/09*	2009/10
(t/ha)	(t/ha)	wild veg. (t/ha)	(t/ha)
2.35	5.09	1.69	6.64

* measurements made in the same day

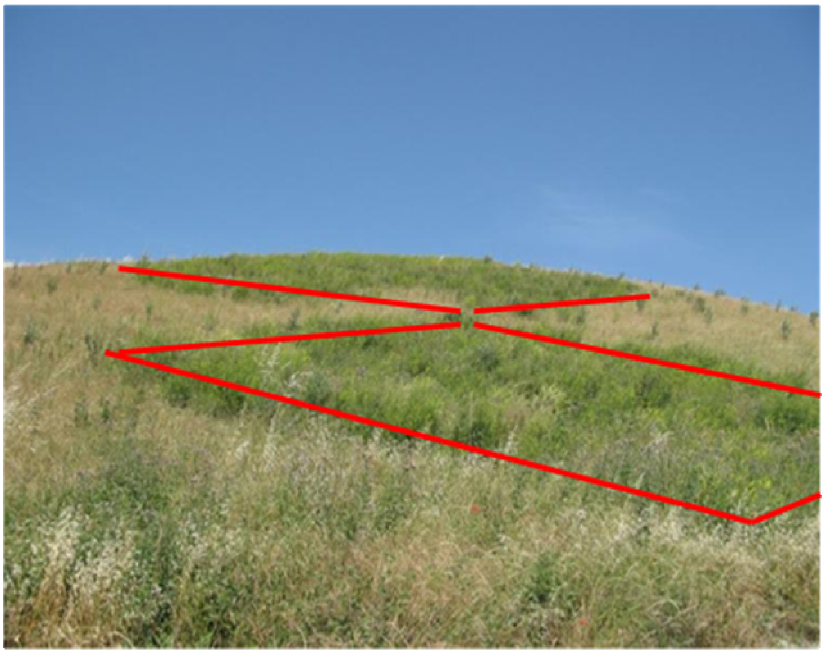


Figure 20. Darker green areas within red lines are the GM plots, alternating the non-GM plots with wild vegetation.

The data suggest a growing production of biomass from 2008 to 2010, as recorded in the Demetra farm. In particular, the increase was rather marked on year 2009/10, which could be linked to the high rainfall occurred in the period (Figure 3). Biomass variation between GM- and non-GM plots is remarkable, both in terms of quantity and quality of the composition.

However, it has to be underlined that the higher GM biomass production was obtained at the expenses of the best period to grow the following spring crop, that had to be moved further in the dry period.

Figure 21 describes the outcome of the qualitative measurement carried out in late spring 2009 to count the relative percentage of the single species out of the overall original composition of the GM mixture (Figure 7). Figure 22 shows the experimental field at the time of measurement.

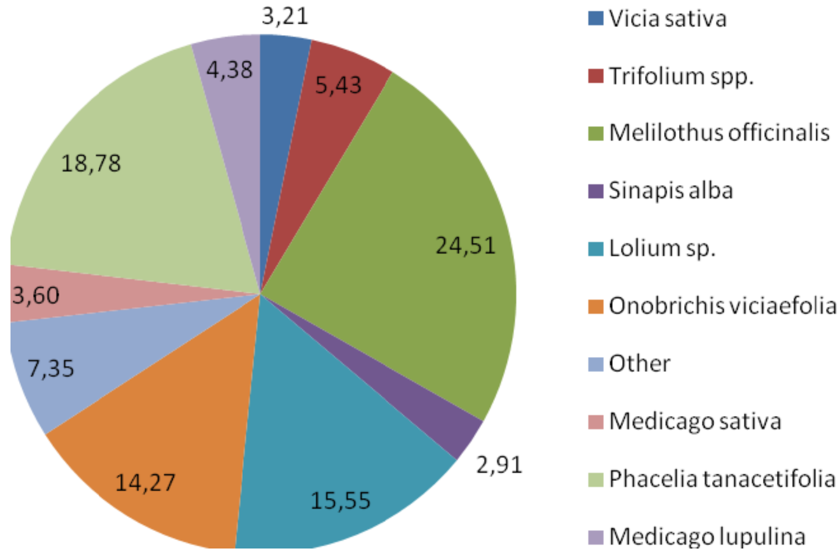


Figure 21. Relative percentage of the single species, expressed on dry matter weight, out of the original composition of the GM mixture, as measured on 16/06/2009 in the Le Origini farm.

As shown in Figure 21 and 22, the mixture is quite simplified with respect to the original composition, with *Melilothus spp.* and *Phacelia spp.* mostly represented in terms of dry matter. It should be also highlighted the significant presence in the GM plots of *Lolium spp.*, definitely the most important wild species in the non-GM plots, suggesting a high seed density of such species in the local seed bank, presumably inherited from the long wheat monocropping that had been performed in the past in the Le Origini farm.

Figure 22. GM plots in late spring 2009: top, *Melilothus spp.* appears to be dominant; botton, the sharp visual difference between the non-GM plot in the foreground and the GM plot, in the background.

2.3.4.2 Olive growth

No significant differences have been pointed out among the treatments in the same year for the absolute and relative growth rate of the main shoot (Table 10) in the two olive cultivars, examined together (Figure 23) or separated (Figure 24). Interestingly, the GM seemed to have not influenced negatively or positively the plant growth, even after three years from plantation.

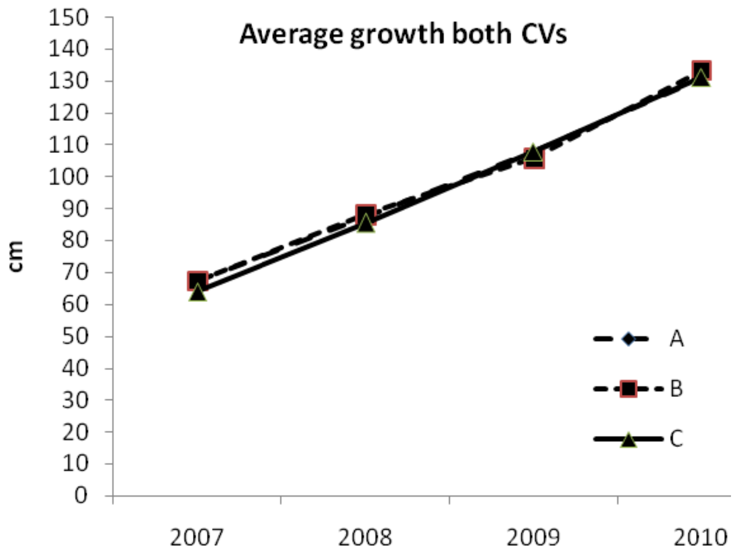


Figure 23. Olive growth (main shoot length), as average of the two CVs (LSD $p < 0.05$, n = 140).

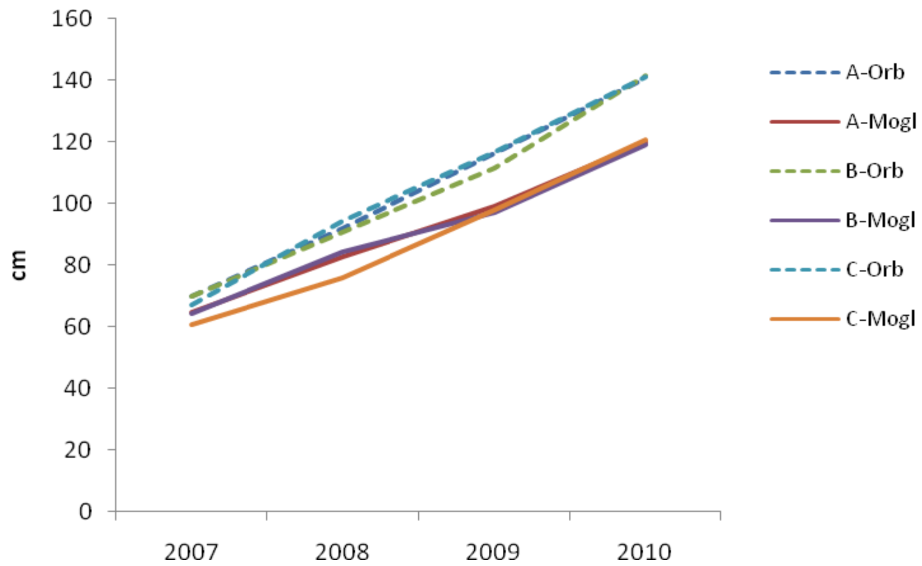


Figure 24. Olive growth (main shoot length), per treatment and per CV (Orbetana and P. di Mogliano) (n = 140).

Table 10. Absolute and relative growth rate of olive, as mean of the main shoot length of the two CVs.

Absolute growth rate										**Relative growth rate**		
Treat.	**Cultivar**	**2007**	**STDEV**	**2008**	**STDEV**	**2009**	**STDEV**	**2010**	**STDEV**	2008 (cm x 10^{-3})	2009 (cm x 10^{-3})	2010 (cm x 10^{-3})
A	Mean 2 CVs	**67.39**	**16.63**	**87.18**	**23.72**	**107.77**	**19.26**	**130.80**	**21.32**	0.73	0.60	0.55
A	Orbetana	70.05		91.92		116.29		140.77				
A	Mogliano	64.73		82.64		99.25		119.93				
B	Mean 2 CVs	**67.31**	**18.92**	**88.07**	**23.39**	**105.72**	**27.45**	**133.35**	**30.15**	0.77	0.52	0.66
B	Orbetana	69.81		90.73		111.30		141.45				
B	Mogliano	64.37		84.42		97.00		118.89				
C	Mean 2 CVs	**63.97**	**18.59**	**85.37**	**21.04**	**107.75**	**21.37**	**131.20**	**23.19**	0.82	0.66	0.56
C	Orbetana	67.26		94.36		116.75		140.95				
C	Mogliano	60.68		76.00		97.93		120.56				

RGR= $\ln G_2 - \ln G_1 \times 1/t_2 - t_1$

t2 - t1 = 351 days

G: growth (main shoot length)

2.3.5 Conclusions

A very challenging aspect of the experiment was definitely represented by the on-farm approach that, under the site-specific circumstances, was characterized by pros and cons.

2.3.5.1 Observed advantages of the on-farm approach

- The objectives formulation and the methods to run the experiment were elaborated in full participation with the farmers, thus ensuring to match their actual needs of innovation and capacities (e.g. the choice of the suitable period for GM; the best mode to apply the BPs);
- The farmers gave a very useful support to monitor and evaluate the experiment's results during and at the end of its implementation, also suggesting small adjustments when needed;
- The tested farming techniques (treatments) could be implemented within the whole farm activity, namely the techniques were not only tested *per se*, but as integrated in the farm agroecosystem, that allowed to get a realistic view of the feasibility (say, willingness to adopt) of the techniques themselves;
- The dissemination of the experimental results to other farmers/practitioners, together with the discussion in the two farms about the themes covered by the experiment, was carried out through small seminars and field visits being facilitated by the farmer-to-farmer approach, namely the farmers themselves presented the trial (Figure 25).

Figure 25. Farmer-to-farmer dissemination in a meeting held in the Demetra farm.

2.3.5.2 Observed constraints of the on-farm approach

- In the Demetra farm, the farmer refused to apply a fully-randomized experimental design, asserting that it would have been too much demanding. This compelled to arrange a simplified design that undoubtedly enhanced the degree of the experimental error, jeopardizing the quality of the results;
- Due to the several work commitments in the farm, the farmer could not closely follow the research protocol, i.e. in some cases the sowing was delayed; crop management was neglected; soil tillage was not timely and properly performed, etc.;
- The typologies of measurements had to be simple and in limited number, due to the lack of proper equipment in the farm and the rather long distance from the laboratory.

2.3.5.3 Seeking the best strategy for managing farm organic matter

Treatment B only seemed to have positively affected the biomass and the grain crop production in one farm, whereas no effect by any treatment was observed on soil nutrients and organic matter at the end of the experiment. Perhaps, such soil parameters may require a longer time to significantly vary.

In particular, the GM, coupled with biodynamic preparations, revealed itself as a positive practice to increase the biomass production of the crops in the rotation, except for the grass bean, which suggests to avoid to grow a spring leguminous crop after green manuring. However, in the olive orchard any effect was observed by any treatment on the vegetative growth.

Both the farmers judged the practice of GM as an interesting option for the agroecosystems under study, however the experiment showed that its management is likely to present constraints due to the unexpected seasonal variability, especially at the time of incorporating the green biomass in the soil. Sometimes the soil may be too wet which forces to postpone the operations to the detriment of the spring crop, that has to be planted in late with the risk to encounter the dry period.

The GM was also appreciated as a further feed source for the farm bee colonies and due to its improvement of the landscape as a whole.

The GM management in the olive orchard resulted quite simpler that in the crop rotation, not existing in fact strict time limitations for sowing and mowing operations. However, over the three years of the trial, olive growth was not significantly affected by the considerable amounts of GM biomass produced and incorporated in the soil via treatment B: no competition occurred between the GM crops and the olive trees neither the mineralisation of the huge amount of biomass turned into a fertilisation effect for the trees. Still, it should be noticed that the rich GM mixture kept the soil covered over the rainy months against erosion and brought diversity into the soil ecosystem.

Further research should be dedicated to investigate alternative and efficient strategies to exploit the already available organic matter in the farm, e.g. the crop residues, in order to overcome in the hilly rainfed agroecosystem of the Marche region the constraints highlighted by the practice of green manuring.

Finally, specific research should be dedicated to study the effect of the BPs, with or without GM, on the quantitative and qualitative aspects of the production of olives and olive oil, which could not be studied in this trial due to the young age of the trees.

2.4 Effect of biodynamic preparations on soil microbial biomass and respiration

2.4.1 Introduction

As discussed in previous chapters, numerous experiments have shown how organic amendments of diverse kind may exert a stimulating effect on soil microbial activity. The biochemical processes intervening in such phenomena are multiple and, sometimes, unknown.

Biodynamic farmers and practitioners do generally attribute to the biodynamic preparations (BPs) a sort of "vital effect", that would boost life in the soil by concentrating in it the "vital forces" coming from the Cosmos, by which the entire agroecosystem would greatly benefit (Steiner, 1924; Koepf et al., 2001; Catellani, 2006).

It is therefore hypothesised that the BPs might induce, among others, an impelling impulse to the soil microbial activity, being the BPs themeselves a microbial inoculum (Perumal and Vatsala, 2002), which in turn would determine temporary changes in the soil fertility status thereby affecting plant development. This hypothesis might explain how very diluted doses of BPs, applied to the cultivated soil directly or through farmyard manure, were found to be effective in stabilizing crop yields and harmonise the soil ecosystem (Raupp and Konig, 1996; Zaller and Koepke, 2004; Raupp and Oltmanns, 2006).

To test such hypothesis, an experiment to assess the effect of the biodynamic preparation (BP) "500 prepared", alone or with highly diversified plant organic matter, on the soil microbial metabolism was carried out under controlled environment conditions in order to reduce as much as possible the degree of experimental error.

Basal daily respiration and cumulative respiration after 42 days were measured in all the treatments, together with the microbial carbon (C_{mic}) content in the samples at the beginning of the trial.

2.4.2 Materials and Methods

Materials

- Clay soil taken from an organic farm with livestock at 30-cm depth, from a non-tilled field with wheat residues after harvest and following a 4-years alfalfa meadow (Table 1).

Table 1. Soil physical and chemical characteristics of the soil used in the treatments.

Texture	**OM*** g/kg	**N** g/kg	**P** mg/kg	**K** mg/kg	**Mg** mg/kg	**pH**	**Active lime** (g/kg)
clay	14.18	1.40	18	492	142	7.95	150

OM*: organic matter (method Walkley and Black, 1934)

- Dry plant organic matter, deriving from the mixture for green manuring (GM) "Arcoiris"[5], as mown at full flowering stage in the Demetra farm, then dried and stored at -18°C;
- BP "500 prepared"[6] (Table 2).

Table 2. Chemical characteristics of the BP "500 prepared", as measured at the beginning of the experiment.

Item	**Value**
pH	4.65
Total nitrogen %	1.95
TOC %	31
C_{HA+CFA} %	18.8
C/N	15.90
Humification rate (C_{HA}+$_{FA}$ x 100 TOC^{-1})	60.6

TOC: total organic carbon; C_{HA+FA}: C from humic acids and fulvic acids.

[5] For a detailed description of the "Arcoiris" mixture, see pag. 75

[6] For a detailed description of the BP "500-prepared" and the biodynamic dynamization procedure, see pag. 15

Treatments

- Treatment 1 (C). Soil (Control). One kilogram of soil was humidified and placed in an aluminum tray (30x25x4 cm), then 5 ml of water were evenly sprayed on it.
- Treatment 2 (GM). Soil + plant organic matter from green manure (GM). An amount of 2.5 g DM of organic matter was finely crumbled and mixed with 1 kg of soil, corresponding to 600 g DM/m^2 of a 20-cm deep soil layer, i.e. 6 t DM/ha comparable to a normal green manuring. One kilogram of such soil was humidified and placed in an aluminum tray (30x25x4 cm), then 5 ml of water were evenly sprayed on it.
- Treatment 3 (GM-BP). Soil + plant organic matter (GM) + BP "500 prepared". The dry organic matter was mixed with the soil as in treatment 2 (same amount and same modality). One kilogram of such soil was humidified and placed in an aluminum tray (30x25x4 cm), then 5 ml of readily-dynamized "500 prepared" in water were evenly sprayed on it, corresponding to the normal dose currently applied in biodynamic farming (Catellani, 2006).
- Treatment 4 (BP). Soil + BP "500 prepared". The BP was applied as in treatment 3.

Two replicates per treatment were made.

Methods[7]

Microbial biomass carbon (C_{mic}) was determined following the fumigation extraction (FE) method (Vance et al., 1987), after keeping the samples in incubation for 10 days at 25 °C.

Microbial respiration was measured as evolution of CO_2 (mg C-CO_2 kg^{-1}) after 1, 3, 5, 10, 15, 20, 25, 28, 35, 40, 42 days of incubation at 25 °C (Badalucco et al., 1992). The CO_2 evolved at the 42^{nd} day of incubation was used as the basal respiration value ($Basal_{mic}$), whereas the sum of the daily values of respiration during the whole period of

[7] All the analytical determinations were made by the Centro Agrochimico Regionale, Agenzia Servizi Settore Agroalimentare delle Marche - ASSAM

incubation was used to plot the curves of cumulative respiration (Anderson and Domsch, 1978; Anderson and Domsch, 1993; Sequi et al., 2000; Bloem et al., 2006).

The metabolic quotient (qCO_2), or specific respiration of the microbial biomass, was calculated as $Basal_{mic}$ per unit of C_{mic}, and expressed as mg CO_2-C mg^{-1} C_{mic} kg^{-1} soil h^{-1} (Anderson and Domsch, 1993).

Total organic carbon (TOC) (Springer and Klee, 1954), C from humic acids and fulvic acids (C_{HA+FA}) (Ciavatta et al., 1990), humification rate and total nitrogen of all the replicates were measured, before and after the 42-days incubation period.

2.4.3 Results and Discussion

Microbial biomass, basal and cumulative respiration (and consequently the qCO_2) seemed to be mainly influenced by the presence of the GM in the soil, that led to highlight two homogeneous groups of measurements, with GM and without GM (Figure 1 and Table 3), thus confirming the findings of several authors on the effects of organic amendments on soil microbial activity (Widmer et al., 2002; Treonis et al., 2010).

The presence of the BP "500 prepared" alone did not affect the C_{mic} content: however when combined with GM, it showed to enhance microbial activity more than the GM alone (Figure 1). But this occurred without increasing the net microbial population density, that is the C_{mic} values of treatment GM-BP and treatment GM were about the same. Therefore, the biochemical interactions among the BP, the organic matter and the soil microbes, that stay behind such stimulating effect, are not clear and would deserve further investigation.

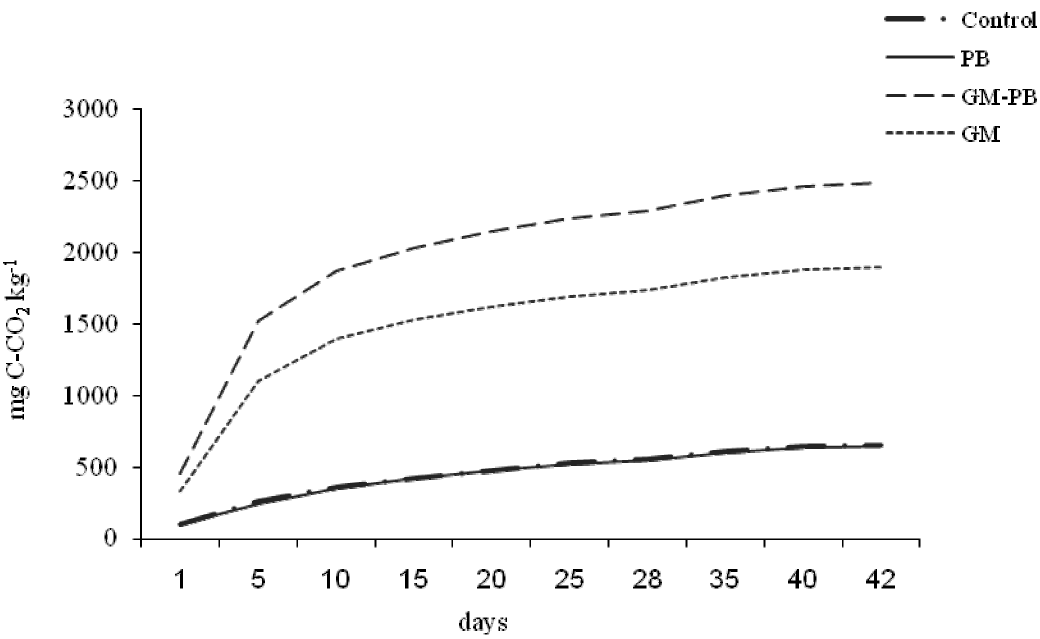


Figure 1. Cumulative microbial respiration after 42 days. Each value is the mean of the two replicates.

Table 3. $Basal_{mic}$, C_{mic}, and qCO_2 as mean of the two replicates.

Treatment	$Basal_{mic}$ (mg $C\text{-}CO_2$ kg^{-1})	C_{mic} (mg C/kg)	qCO_2 (mg $C\text{-}CO_2$ mg^{-1} C_{mic} kg^{-1} h^{-1})
C	6.10	329.80	$7.71\ 10^{-4}$
BP	6.10	259.84	$9.78\ 10^{-4}$
GM-BP	12.30	473.89	$1.08\ 10^{-3}$
GM	11.20	464.98	$1.00\ 10^{-3}$

The chemical status of the samples seemed to be not significantly influenced by the treatments, neither by the length of the incubation period (Table 4). It is however interesting to highlight the humification rate for the treatment BP calculated at the end of the period, that seems to be higher than the corresponding values of the other treatments, as result of a decrease of the TOC over the incubation period.

Table 4. Chemical characteristics of the treated samples, before (b) and after (a) the 42-days period of incubation.

Item	Treatments			
	C	**BP**	**GM-BP**	**GM**
N_{tot} (g/kg) (b)	1.40	1.30	1.70	1.50
N_{tot} (g/kg) (a)	1.40	1.40	1.65	1.45
TOC % (b)	1.46	1.47	1.53	1.53
TOC % (a)	1.47	1.08	1.44	1.32
C_{HA+FA} % (b)	0.53	0.57	0.78	0.58
C_{HA+FA} % (a)	0.62	0.69	0.64	0.61
Humification rate* (b)	36.30	38.78	50.98	37.91
Humification rate (a)	42.18	63.89	44.44	46.21

*Humification rate: C_{HA+FA} TOC^{-1}

2.4.4 Conclusions

This short term experiment, although executed under artificial conditions, confirmed the findings of several authors on the positive effect exerted by organic amendments on soil microbial activity.

In addition, the experiment highlighted a potential active role of the BP "500 prepared" in further stimulating microbial activity, in terms of enhanced cumulative and basal respiration when associated to highly-diversified organic matter, however without increasing the microbial biomass.

3. IMPROVING ORGANIC MATTER MANAGEMENT IN SMALL SCALE SUBSISTENCE FARMING IN SWAZILAND THROUGH AN ON-FARM RESEARCH APPROACH

3.1 Introduction

3.1.1 Background

Since 2000, the Italian NGO COSPE has been carrying out several development activities in Swaziland, Africa (Figure 1), as co-financed by the European Union, the Italian Ministry of Foreign Affairs and other organizations, with the aim to conserve the natural resources and improve their sustainable utilization by the indigenous people. A number of initiatives were started in the Lubombo Region (Figure 2), also in the sector of HIV/AIDS prevention and counselling in rural areas, as this disease has become a true calamity for the country over the last 20 years.

I have been supporting the technical activities of COSPE in Swaziland in the agricultural sector since 2004 with periodical visits to the projects and backstopping from home, and I cooperated with the local agronomists to devise an agricultural method suitable for the local environmental conditions as well as the social constraints occurring to small-scale subsistence farmers, main target of the development initiatives.

Figure 1. Swaziland is located between South Africa and Mozambique. It falls on the latitude of 26º 30’ South and longitude of 31º 30’ East.

Figure 2. Project area (red square) is in the north of the Lubombo district

3.1.2 The physical environment of Swaziland

The Kingdom of Swaziland covers a land area of 17,394 km^2, lies between 150 and 1,800 metres above sea level, and is situated about 30 degrees south of the Equator. It is a landlocked country surrounded to the north, west and south by the Republic of South Africa and to the east by the Republic of Mozambique with which shares the mountain range of the Lubombo Mountains.

The country is divided into six physiographic zones taking into account climate, elevation, landforms, geology, soils and vegetation (Figure 3).

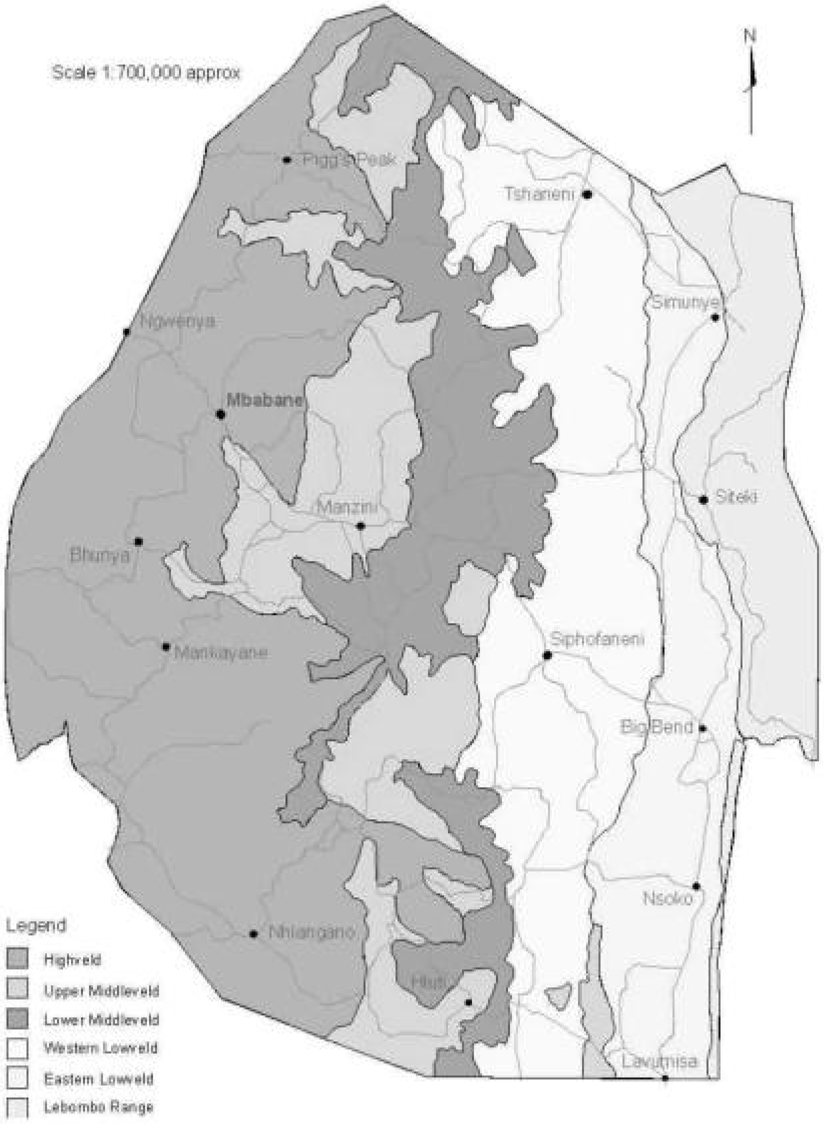


Figure 3. Physiographic zones of Swaziland (*from* Swaziland's National Report to the World Summit on Sustainable Development 2002**,** Johannesburg)

The Highveld (33%) of the country's total land area, is the upper part of an overall escarpment. It consists of a complex of steep slopes between low and high levels, dissected plateau, plateau remnants and associated hills, valleys and basins.

The Upper Middleveld (14%) consists of strongly eroded plateau remnants and hills at an intermediate level of overall escarpment. It also contains structurally defined basins in relatively protected positions, which are only weakly eroded.

The Lower Middleveld (14%) is basically the piedmont zone of the escarpment, characterized by generally strongly eroded foot slopes. The overall slopes are predominantly moderate and the zone classifies at the first level as a plain.

The Lowveld plain consists of sedimentary and volcanic beds versus the igneous and metamorphic rocks of the Highveld and Middleveld. The Lowveld is subdivided into the higher Western Lowveld (20%) on sandstone or clay stone, and the lower Eastern Lowveld (11%) on basalt.

The sixth zone is the Lubombo Range (8%), a steep escarpment bordering the Eastern Lowveld and a gradual dip slope descending east. As a major landform the Lubombo qualifies as a plateau.

The overall climatic characterization of Swaziland is subtropical with summer rains (75 percent in the period from October till March) and distinct seasons. The physiographic zones show clearly different climatic conditions, ranging from subhumid and temperate in the Highveld to semi-arid and warm in the Lowveld.

Swaziland lies at the transition of major climates zones, as it is influenced by air masses from different origin: equatorial convergence zone, subtropical eastern continental moist maritime (with occasional cyclones), dry continental tropical and marine west Mediterranean (winter rains, with occasional snow).

Table 1 gives an overview of some of the most relevant climatic conditions based on long term averages. The mean annual rainfall ranges from 1,500 mm in the Highveld to 550 mm in the Lowveld, but conditions vary considerably from year to year.

Years with lower than normal rainfall occur frequently, especially in the Lowveld, leading to drought. Drought has always been an inherent characteristic of the semi-arid climate (The Swaziland Environment Action Plan, Vol. 1, 2004).

Table 1. Annual rain and temperature ranges in the principal physiographic regions of Swaziland (from The Swaziland Environment Action Plan, Vol. 1, 2004)

Physiographic region	**Annual rainfall (mm)**	**Annual Temperature (°C)**
Highveld	900 - 1,500	16.3 - 17.6
Middleveld	580 - 810	19.3 - 20.5
Lowveld	550	21.3 - 22.4
Lubombo range	710	19.2

3.1.3 Relevant social aspects

Despite a gross domestic product per capita of $2,478 in 2009, Swaziland is categorized as a lower middle income country, as it faces socio-economic challenges akin to a least developed country.

These include pervasive poverty, high HIV infection rates, environmental fragility exacerbated by climate change, weak governance institutions, gender inequality, and capacity constraints at institutional and human levels.

The Gross Domestic Product (GDP) declined from 8% per year during the 1980s, to around 2.4% in 2008 and 0.4 in 2009, which is markedly below the 5% estimated as minimum required growth to impact poverty reduction (UNDP, 2010).

The 1995 Swaziland Household Income and Expenditure Survey indicated that the richest 10% control almost 40% of the national income while the poorest 40% control only 14%. In addition, the population is growing at 2.7% with the proportion of the youth above 40%.

Agriculture, despite offering just the 7% of the total GDP, provides an important source of livelihood for the rural people, that is hardly to be monetized, plus a certain source of inputs for the manufacturing sector. However, only 40% of the rural homesteads produce enough food to meet their needs. Within rural areas, the worst poverty levels are found in the Shiselweni and Lubombo Regions (Swaziland Environment Authority, 2002).

Figure 4. Children in a homestead in Lubombo

Agricultural productivity is nevertheless severely undermined by the high HIV/AIDS incidence at national level. With an estimated adult prevalence of 26.1 percent, Swaziland has the world's most severe HIV/AIDS epidemic, posing a serious challenge to the country's economic development (Table 2).

In 2008, the prevalence of the disease among pregnant women varied markedly by age group, from 12 percent in those 15 to 19 years of age to 49 percent among those 25 to 29 years of age (USAID, 2010). In general, the highest infection rates are found among the 15-49 years age group, who form the skilled and productive segments of society.

The whole society is vulnerable to HIV, but the poor are least able to cope with its illnesses and associated costs. It does result in increased impoverishment of households with the elderly and children being the most vulnerable.

The National Children's Coordination Unit estimates there are approximately 130,000 orphans and vulnerable children (OVC) in Swaziland (USAID Regional HIV/AIDS Program fact-sheet, 2010).

According to the 2008 Poverty Reduction Strategy and Action Programme, 69% of Swazis live in poverty (UNDP, 2010).

Table 2. Development indicators of Swaziland showing the serious incidence of HIV/AIDS on national population (World Bank, 2009)

Indicator	**year 2009**
Population, total (millions)	1.2
Population growth (annual %)	1.5
GDP (current US$) (billions)	2.9
GDP per capita (current US$)	2,478
Agriculture, value added (% of GDP)*	7
Industry, value added (% of GDP)*	49
Services, etc., value added (% of GDP)*	43
GDP growth (annual %)	0.4
Life expectancy at birth, total (years)	45.8
Mortality rate, infant (per 1,000 live births)	52.0
Literacy rate, youth female (% of females ages 15-24)	94.7
Prevalence of HIV, total (% of population ages 15-49)	26.1

* Data from 2008

3.1.4 Land uses and tenure system

Table 3 gives an overview of the present main land uses in Swaziland, based on the inventory available at scale 1:250,000 (Swaziland's National Report to the World Summit on Sustainable Development, 2002**)**.

Table 3. Main land uses in Swaziland

Code	Groupings of main land uses	km^2	%
SA	Small-scale subsistence crop agriculture (rainfed annual field cropping)	2,140	12.3
LA	Large-scale commercial crop agriculture (irrigated/rainfed field/tree cropping)	1,040	6.0
CH	Extensive communal grazing	8,670	50.0
RH	Ranching	3,320	19.1
F	Plantation Forestry	1,400	8.1
P	Parks, Wildlife Management	670	3.9
S	Residential, Industry, Recreation	80	0.5
W	Water Reservoirs	40	0.2
Total		17,360	100

The large-scale commercial crop agriculture can be subdivided into the following: rainfed field cropping (2.0%, mainly cotton and pineapple), irrigated field cropping (3.7%, of which 3.5% sugarcane) and irrigated tree cropping (0.3%, mainly citrus).

The above figures are however gross figures, and it should be stressed that several of these land uses are found in complex patterns, such as small-scale subsistence crop farming in close association with communal grazing. Often there is a primary and secondary use of the same land, e.g. about one third of the area occupied by subsistence cropping is also used for grass strips and infrastructure. In addition, part of the extensive communal grazing area is actually not utilized for grazing because of steep slopes and dense woodlands.

Land tenure arrangements play an extremely important role in the management of land and the environmental implications. The history of land tenure arrangements in Swaziland is very complex. There are three main categories of land tenure:

- Crown Land, 0.4% of total national agricultural land;
- Private Freehold or Title Deed Land (TDL), 25,1% of total national agricultural land;
- Swazi Nation Land (SNL), 74.2% of total national agricultural land.

There is in fact a fourth category of Concession Land, which is minor and not well defined.

Crown Land is land over which Government holds title.

The Title Deed Land (TDL) embraces both urban and rural areas. High profitable investments in the agro-industry sector have been occurring in TDL for decades, by foreign capital (mostly from South-Africa), turning to the net export of considerable amounts of sugarcane/sugar, fruit and timber.

Such vast areas of intensive monocropping do not represent, actually, a real economic advantage for the country, since the returns are for a large extent transferred off-shore. However, around the 3% of the rural population find part- or full-time job thanks to these activities.

The Swazi Nation Land (SNL) is held "in trust for the nation" by the King and it is granted in usufruct to the traditional Chiefdoms: the entire country is divided in 180 of these extensive land units, each governed by a traditional "Chief", supported by a council named "Libandla".

The Chief grants to each head of a family one or more land plots to sustain the household's needs (e.g. building a house and running agriculture activity) and the right to have access to the community natural resources, i.e. water springs and forest.

Within the rural community, the "homestead" tipically represents the basic human settlement (Figure 5). It is composed by a number of huts, built by stones, wood and dry mud as cement. Rough grass is used as roof material. The huts are distributed in circle around an ample yard. Usually, the homestead's border is demarcated with a fence made by tree thorny branches and twigs.

Figure 5. A Swazi homestead

In the homestead there is also one or more corrals (*kraal*), used to keep the cattle over night (usually free-ranging), thus representing the sole area where organic matter is accumulated (Figure 6).

Figure 6. A typical *kraal* where the cattle of the homestead are taken over night

As discussed above, the agricultural sector plays a vital role in the Swaziland economy. It accounts for as much as 50% of the country's export earnings and it is the principle source of livelihood for over 70% of the population. On SNL, agricultural production is dominated by monocropping of maize or cotton (around 35%), while pulses cover a much lower area, about 10% (Swaziland Environment Authority, 2002).

Maize was introduced in Swaziland one century ago, and it drastically modified the traditional cropping pattern and diet of the Swazis, by almost completely replacing the formerly cropped sorghum and millet, that are much more drought resistant, and reducing the cultivation of pulses.

3.1.5 Swaziland's critical threats to sustainable development

Several issues are therefore severely hampering the capacity of many rural households of Swaziland to produce sufficient livelihood on their own.

Evident factors are the inequality in wealth distribution; the sometimes partial access to land and natural resources; the fact that drought and periodic floods have become persistent problems in large parts of the country whereas widespread overgrazing has caused soil depletion (IFAD, 2001).

However, the HIV/AIDS pandemic is unanimously considered a foremost factor leading to further marginalisation and socio-economic failure of the concerned rural people.

As a strategic answer to this problem, a comprehensive and community-based approach has been devised over the last decade by the governmental and non-governmental organisations, and supported by the international donors. Such an approach takes into account prevention, treatment and impact mitigation by decentralising the activities through local interventions, to be organised and implemented at community level with full involvement of the community traditional and institutional leaders (NERCHA, 2006).

Within such an integrated approach, the action to insure food security and food diversification, for a healthy diet for the affected rural families, plays an important role.

As a consequence, endeavours to improve the efficiency of subsistence farming, based on a more sustainable exploitation of the natural resources under marginal environmental conditions, are ultimately encouraged by institutions and the numerous international development agencies operating in the country.

In particular , the Italian NGO COSPE, since 2003 has started to spread throughout the Lubombo Region the method of conservation agriculture (FAO, 2001; FAO, 2005; Knowler and Bradshaw, 2007; Hobbs et al., 2008) at community level, as introduced in Swaziland by the Food and Agriculture Organization of the United Nations (FAO).

This chapter reports the first year's results of the three-years on-farm experiment, conducted over the growing season 2009-2010 in the neighbouring farmers communities of Tsambokhulu and Mafucula, both with noticeable incidence of HIV, in the northern area of the Lubombo district.

The entire experiment intends to compare the effect on yield and other productivity-related parameters of two alternative packages of farming practices. One, highly widespread in Swaziland and pricipally based on monocropping of maize; the other, more focused on endogenous resources, conservative soil cultivation, crop diversity and enhanced management of (soil) organic matter.

Two field extension officers of the Swazi Ministry of Agriculture and Cooperatives joint the trial, as institutional partners of the EU-financed project mentioned below, and participated to the monitoring and evaluation meetings with the farmers.

3.2 Materials and Methods

3.2.1 The farmers, partners in research

The research was conducted in 3 and 2 small subsistence farms of the Tsambokhulu and Mafucula communities, respectively. The farmers group was duly assisted by the technical staff of the EU-financed project "Community-based response to HIV/AIDS in rural areas of Lubombo region – Swaziland, Food Security component", that is being implemented by the Italian NGO, COSPE.

One Italian and one Swazi agronomist monitored the trial operations and took several measurements. I designed the research protocol and I have been the responsible of the research. I carried out two field missions: one at the beginning of the trial, to instruct the farmers and the technical staff, and a second one at almost the end, to carry out fresh and dry weight measurements.

The area of the selected farms reflects the average size of the farms of the region, i.e. 1 ha.

The project area lies in the rainfed north-eastern Lowveld (Figure 3), on the fringe of the escarpment of the Lubombo Mountains (Figure 7). Climatic characteristics of the area are shown in Table 1.

The five farmers participating to the trial are: Tsabile Nyoni (Mafucula), Edison Maseko (Mafucula), Ntombemhlophe Mahlalela (Tsambokhulu), Richard Mahlalela (Tsambokhulu) and Khanyisile Nkomo (Tsambokhulu).

These farmers were selected because of their relatively good skills in field management and because of the motivation in actively joining the experimental initiative.

During the trial and after the conclusion of the first crop cycle meetings with the farmers group were carried out to assess the field feasibility of the farming practices combinations under test (e.g. labour demand, productivity, soil improvement, etc.) and discuss the outcomes.

Results of soil analyses, carried out at the beginning of the trial in the five farms, are shown in Table 4.

Table 4. Soil parameters as measured at the beginning of the trial

Param.	**Unit**	**E. Maseko**	**T. Tsabile**	**R. Mahlalela**	**N. Mahlalela**	**N. Khanysile**
pH (KCl)		6.00	6.25	6.00	5.50	6.15
Ntot	mg/kg	11	9	14	10	11
Ca	mg/kg	2,116	1,556	2,016	2,089	3,035
Mg	mg/kg	249	200	342	415	498
K	mg/kg	412	359	494	336	174
Na	mg/kg	11	12	20	19	25
P	mg/kg	10	15	18	11	10
C_{org}	%	1.58	1.13	1.31	1.42	1.39
Texture		silty clay	silty clay loam	clay loam	clay	clay

Figure 7. On-farm research area in the Tsambokhulu and Mafucula communities (red square), north Lubombo Region. The rainfed fields are placed at the extreme edge of the Lubombo Mountains escarpment, dominating the vast sugarcane irrigated plantations (on the left section of the picture).

3.2.2 Treatments

The treatments consisted in two different combinations of cropping practices, as described in Table 5. Each farm applied both treatments in separated but bordering fields.

<u>- Treatment SA</u> (sustainable agriculture) presents an intercropping combination of one cereal (open pollinated varieties (OPV) of sorghum or maize, made available by the Government) with one pulse, chosen by the farmer among the following: *Vigna unguiculata*

(cowpea); *V. subterranea* (bambara groundnut); *V. radiata* (mung bean); and *Arachis hypogaea* (groundnut). All the leguminous seeds belong to local ecotypes, and are produced by the farmers themselves. Soil tillage is minimized. One farmer however decided to apply a crop rotation, alternating cereal with pulses, instead of intercropping them (Table 6). A leguminous cover crop is sown during the very last rains, and grown over the dry and cold season (May to September), when normally the soil remains bare.

- Treatment CV (conventional agriculture), representing the typical widespread farming system in the region, is instead based on monocropping of OPV maize, and annual ploughing.

As shown in Table 6, two out of the five farmers applied cattle manure (≈ 6 t/ha). The manure was taken as such from the *kraal* of the farm, however its quality was not very good, being usually poor in plant fibers and diluted for some extent (Figure 8). Same amounts of lime were applied to all the fields (1 t/ha), to improve the pH.

Figure 8. Field distribution of *kraal* manure in one of the experimental fields, prior to land preparation. The photo also emphasises the poor soil cover made up of the easy-decomposable maize residues from previous season.

Table 5. Farming components of the two treatments, growing season 2009-2010

Code	Land preparation	Crop pattern	Crops	Winter cover crop*	Fertilisation
SA	minimum (shallow soil tillage by chisel plough)	intercropping legume+cereal	bambara groundnut, mung bean, cow pea, groundnut, sorghum, maize (OPV variety)	yes	lime** + no/organic fertiliser (cattle manure)
CV	ploughing (mould board ploughing, 30 cm deep)	monocropping	maize OPV	no	lime + no/organic fertiliser (cattle manure)

* The winter cover crop to be approximately intersown within 15th of February 2010.
** Finely crushed calcium carbonate (dolomitic lime), 1 t/ha.

The treatments details as applied in the five farms are described below (Table 6).

Table 6. Treatments as applied in the 5 farms, growing season 2009-2010

Farmer	Treat ment	Field size (ha)	Soil tillage	Crops	Winter cover crop	Fertilisation
T. Nyoni (Maf)	**SA**	0.10	chiseling	maize + groundnuts	yes	lime + org.manure
	CV	0.14	ploughing	maize	no	lime + org.manure
E. Maseko (Maf)	**SA**	0.30	chiseling	cow pea	yes	lime
	CV	0.22	ploughing	maize	no	lime
N. Mahlalela (Tsamb)	**SA**	0.12	chiseling	sorghum+ cowpea	yes	lime + org.manure
	CV	0.13	ploughing	maize	no	lime + org.manure
R. Mahlalela (Tsamb)	**SA**	0.15	chiseling	sorghum + mung bean	yes	lime
	CV	0.10	ploughing	maize	no	lime
K. Nkomo (Tsamb)	**SA**	0.20	chiseling	sorghum + groundnuts	yes	lime
	CV	0.12	ploughing	maize	no	lime

Crop residues management differed in the SA and CV treatment.

Maize and sorghum plants under SA treatment were left standing in the field all over the dry and cold season, until end of September 2010, with the aim to slacken decomposition and keep the residues as mulching for the next sowing time: the effect of this practice will be assessed on next growing season.

Maize plants under CV were slashed right after harvest (April 2010) according to the common practice, and the residues left on the soil.

In the SA fields, a winter cover crop (a creeping ecotype of *V. unguiculata* - cowpea) was intersown on February between the rows of cereal and legumes.

All the farmers were given of a jab-planter and trained on its use in order to facilitate the hand-sowing operations (Figure 9): such a tool will turn to be particularly useful in the next two years of the trial, when a tick and semi-permanent soil cover by crop residues is supposed to be established, so that direct sowing could be attempted.

Figure 9. Training farmer on use of jab-planter for direct sowing

3.2.3 Measurements

During the crop cycle and at the end of it, the following measurements were taken in all the fields:

- Evolution of weeds population: three measurements per field were randomly taken by a 1 m^2 frame at the end of the 5^{th}, 8^{th}, 11^{th}, 14^{th} and 17^{th} week. The farmer cleared the plots according to the need and his/her labour availability; the number of weedings per farm was recorded.

- Percentage of soil cover: three measurements per field were randomly taken by a 1 m^2 frame at full crop development (March 16th);
- Total above-ground biomass production (fresh and dry weight): two measurements per field were randomly taken by a 1 m^2 frame at full crop development (March 16th); the dry weights were obtained and measured at the Malkerns Research Station of the Swazi Ministry of Agriculture and Cooperatives.
- Yield (total grain production per field, as sun dried according to the local practice).
- Percentage of soil cover at sowing time (by the residues from previous season) will be estimated on II and III year of the experiment.
- Total soil organic carbon, soil acidity and soil structure will be measured again at the end of the experiment.

3.3 Results and Discussion

The reported results refer to the period November 2009 - May 2010 (Ist year of the project), covering a full growing cycle of the concerned arable crops.

Weed cover and weed control activities by hoeing are reported in Table 7. Unanimously, the farmers group agreed on defining as 25% of soil cover the threshold over which weeds can irreversibly jeopardize crop development.

Table 7. Weed infestation as percentage of soil covered by weeds. Each value represents the mean of three measurements in the same field. WAP = weeks after plantation.

Farmer	**Field**	**5 WAP (17/12/2009)**	**8 WAP (08/01/2010)**	**11 WAP (28/01/2010)**	**14 WAP (23/02/2010)**	**17 WAP (16/03/2010)**	**No. of weedings over the season**
R. Mahlalela	**SA**	27%	15%	3%	5%	5%	3
	CV	10%	52%	8%	8%	13%	2
K. Nkomo	**SA**	5%	1%	4%	8%	8%	1
	CV	2%	4%	5%	9%	5%	1
N. Mahlalela	**SA**	1%	1%	3%	5%	5%	2
	CV	1%	3%	4%	8%	8%	2
T. Nyoni	**SA**	22%	5%	7%	10%	5%	3
	CV	25%	3%	23%	5%	5%	2
E. Maseko	**SA**	22%	9%	17%	33%	1%	2
	CV	2%	7%	23%	47%	62%	1

In the first phase of the growing season, the SA fields appeared to be more vulnerable to weeds, which required more interventions: this might have been caused by the lower intensity of land preparation of the SA treatment, that could not mitigate the aggressiveness of the first wave of weeds, during the early stages of crop growth coupled with the highest rainfall (Figure 10).

In the following phases however, the density of weed population - if properly controlled by the farmer in its early stages - seemed to become almost the same, in the two treatments, that could be partly explained by the soil cover established by the crops (Table 8).

Data in Table 7 show that three farmers carried out one intervention more in SA to keep the weeds at around 25%; however one of these three, Edison Maseko, who did not apply intercropping, could not actually keep his CV field under the target threshold by just one intervention (47% at 14 WAP and 62% at 17 WAP, respectively), which means he should have made another weeding in this field.

Table 8. Soil cover by crops per cent. Each value represents the mean of three measurements in the same field. WAP = weeks after plantation.

Farmer	**Field**	**17 WAP (16/03/2010) (full crop development)**
R. Mahlalela	**SA**	47%
	CV	47%
K. Nkomo	**SA**	25%
	CV	20%
N. Mahlalela	**SA**	30%
	CV	37%
T. Nyoni	**SA**	23%
	CV	15%
E. Maseko	**SA**	60%

Figure 10. Experimental plots in Tsambokhulu and Mafucula. Intercropping maize + cow pea (top left) and maize + groundnut (top right), both showing a good weed control. Bottom left, intercropping sorghum + groundnut: the weeds were not well managed which caused the leguminous crop to almost disappear; bottom right, cow pea pods under the sun to be dried.

Soil cover at full crop development presents a certain variability among the farms, however within the same farm the figures are rather similar, thus suggesting that the cropping pattern (intercropping vs. monocropping) did not influence soil protection in this phase.

In only one farm the above-ground dry biomass production was higher in SA than CV. In another farm the production was the same, whereas in the remaining three farms biomass production was higher in the CV fields (Table 9), so a specific effect due to the treatment cannot be emphasisedemphasised (Figure 11).

Table 9. Fresh and dry weight of the above-ground biomass. Each value represents the mean of three measurements in the same field.

Farmer	Field	FW/m^2 (g)	DW/m^2 (g)	t DW/ha	Crop
R. Mahlalela	**SA**	400	112.00	1.1	sorghum+cowpea
	CV	1,325	291.50	2.9	mais
K. Nkomo	**SA**	2,200	506.00	5.1	sorghum+groundnut
	CV	1,575	378.00	3.8	mais
N. Mahlalela	**SA**	550	165.00	1.7	mais+cowpea
	CV	900	225.00	2.3	mais
T. Nyoni	**SA**	725	166.75	1.7	mais+groundnut
	CV	1,125	281.25	2.8	mais
E. Maseko	**SA**	1,100	330.00	3.3	cow pea
	CV	1,350	364.50	3.6	mais

Figure 11. Above-ground biomass measurements in the intercropping plot of Tsabile Nyoni (Mafucula)

Data of grains production (Table 10) show that the yields of maize, both intercropped with legumes and grown in pure stand, were approximately the same within the same farm.

Therefore, when the grain production per plant is considered, it might be observed that the intercropped maize was more efficient in utilising the available resources than the maize alone, suggesting a sort of "cooperation" with the intercropped leguminous crop rather than competition.

The same occurred for sorghum that presented good yields as well. The level of productivity of groundnut and cowpea did not vary among the farms (Figure 12).

Table 10. Sun dried grain production.

Farmer	**Field**	**Crop**	**t /ha**
R. Mahlalela	SA	sorghum	0.85
	SA	cowpea	0.61
	CV	mais	0.68
K. Nkomo	SA	sorghum	1.05
	SA	groundnut	0.49
	CV	mais	0.90
N. Mahlalela	SA	mais	0.82
	SA	cowpea	0.63
	CV	mais	1.03
T. Nyoni	SA	mais	0.93
	SA	groundnut	0.51
	CV	mais	0.77
E. Maseko	SA	cow pea	0.35
	CV	mais	0.00*

* crop failed due to improper weeds management

In the SA fields, the winter cover crop unfortunately failed due to the early occurrence of drought which prevented satisfactory germination.

Figure 12. Sun drying of groundnut in the farm of Khanyisile Nkomo (Tsambokhulu)

The peculiarity of the SA treatment lies on the functional exploitation of the crop residues with respect to the CV treatment, that is the ordinary farming method in the region, by which crop residues are neglected and, sometimes, burned at the end of the season. Furthermore, more biomass is expected to be produced through systematically growing a winter cover crop (usually indigenous cow pea, that presents a certain tolerance to drought): the crop is not meant to survive until the beginning of the next sowing season, nevertheless its remnants will join the residues of the main crops thus increasing the density of the mulching layer.

In the SA treatment, crop residues are in fact expected to accumulate in the soil to establish an efficient mulching layer to protect the soil itself, increase soil organic matter, reduce evaporation and partly control the weeds, thus helping the farmer in saving labour time and increasing farm productivity. Nevertheless, such a mulching layer can become really operational only after some years of continuous accumulation, and no disturbance by intense tillage.

As it has been observed, the SA treatment was not more efficient than CV in controlling the weeds over this first year: however it was not even worse than the CV treatment, despite the mainstream beliefs that less soil tillage equals to more weed infestation. To some extent, it has been shown that the key factor is rather represented by timely and proper weed management.

Intercropping however has shown its advantages on the first year of the experiment, confirming that a higher cultivation intensity by two simultaneous and complementary crops is likely to offer higher and more stable yields, due to the inclusion of drought-resistant species as sorghum instead of maize. In addition, a higher degree of diversity is created in the agro-ecosystem, that in turn makes the household's diet more varied and heatlhy.

3.4 Conclusions

The first year of the experiment proved to be successful in insuring good communication level between the researchers and the farmers, actual partners in the research and final users of the innovation under test.

At the end of the 2009-2010 growing season a meeting (Figure 13) was held to examine the preliminary pros and cons of the two farming methods under study (SA and

CV), and the possible changes that need to be done to the research protocol for the remaining two years of the experiment.

The main outcomes of the meeting emphasised the good yields obtained in the SA treatment, and the opportunity to have two different crops at the end of the season, to be consumed by the family but to be sold in the local market, too.

Figure 13. Final assessment meeting held with the farmers and technical staff to examine first year's outcomes from the trial

Both the treatments did not require external inputs, except the hired mechanical land preparation that however consisted of less tractor hours (and less costs) for SA: the entity of such a saving however was not ultimately calculated for the reason that the project paid the hired tractor, and not the farmers. But farmers could clearly realize the money saved associated to reducing tillage, and that it did not necessarily result into higher weed infestation (provided that weeds are properly and timely controlled).

All the farmers were still reluctant about planting a winter cover crop, especially after the last failure. Actually, for them it is very strange to grow a crop that will not yield any useful product; and they find it very difficult to look at their field in a long-term prospect.

This aspect indeed does represent a typical shortcoming of an on-farm research protocol, where the objectives of the researcher and the farmers may diverge to a certain extent, thus requiring particular attention by the researcher to not fail to keep the trust of the farmers.

Another problem that was lively discussed in the final meeting is given by the free-ranging livestock, that feed on crop residues over the dry season, being this material the sole fodder source for them in the absence of a community hay system. Community rules allow the animals to freely feed in any field. Therefore, fencing the fields seems today the only working measure to prevent the mulching layer to be completely removed: this issue however needs more discussion and in-depth evaluation. For instance, what kind of fences should be built? Highly costly barbed-wire fences, to be built in a short time? Or rather "living fences", based on (slow growing) thorny shrubs and trees, also useful as source of fodder for the animals, and organic matter?

Finally, it was agreed that, by the next growing season, some SA fields will not be tilled: direct sowing will be carried out by means of the jab-planters (Figure 9). Therefore, the effect of such technique on weed population and the mulching layer will be carefully studied.

Possibly, the soil analyses foreseen at the end of the experiment will provide indications on the effectiveness of the alternative organic matter managements under investigation.

4. GENERAL CONCLUSIONS

Efficient organic matter management definitely represents a pivotal aspect of those farming systems relying on low supply of external inputs. Especially when organic and biodynamic certification schemes have to be performed, the appropriate use and recycling within the farm of organic matter becomes crucial to optimize nutrients flows as well as maintain overall soil fertility at acceptable levels. Various techniques to enhance the use of farm organic matter have been tested during my research, both through on-farm investigations and short term laboratory experiments.

The so-called "biodynamic preparations" (BPs) are based on fermented animal manure with or without plant extracts; they show high organic carbon content and very high humification rate (humic and fulvic acid/total organic carbon) but they are used at very low doses in the fields. As a result, the observed effect of the BPs on the soil microbial activity, under controlled environmental conditions, highlights the importance of the qualitative aspects of the organic matter. However, the boosting effect on microbial basal respiration exerted by the "500 prepared" (BP), observed in our lab experiment, is not easy to be interpreted when the qCO_2 is also taken into account. The metabolic quotient seemed actually higher in the treatment with the BP with respect to the Control, which, according to several authors, might be the indication of a more stressful environment for the microflora.

Until now, no fully satisfactory natural science mechanistic principles explanation has been provided about the working mechanism of the BPs, however it is here hypothesized that the BP itself holds a prominent microbial concentration, as observed by other authors for similar preparations, thus exhibiting a character of "living" inoculation. However BPs turned out to be not able in short term field experiments to influence, even indirectly, important biochemical processes, that in turn are likely to drive the fate of the organic matter in the soil (i.e. decomposition and humification). Further research should be carried out in an intact agro-ecosystem, rather than under artificial conditions, to analyse more in depth the phenomenon, and its relationships with a more diverse environment.

The practice of highly diversified green manuring showed to be successful to enrich the soil, with relevant amount of easily decomposable organic matter, and to enhance above- and below-ground biodiversity in the farming system, although for a temporary period. The nitrogen-fixing species, identified and measured in the green manure mixture at the peak of the growing season, were likely to raise the nitrogen soil content thereby increasing the crop available quota of this important nutrient, as it has been shown by the higher above-ground biomass and cereal grain production in the rotation, only under the treatment with green manure. However, plant growth was not affected by green manure in the young olive orchard.

It has to be stressed that under the biodynamic and organic agriculture fertilisation standards, the organic form of nitrogen is the only permitted. Therefore, a well organized organic farming system, with sound nitrogen biological fixation and effective organic matter recycling, may play a positive role in reducing the net release of reactive nitrogen (N_2O). In fact, in such a system the nitrogen use efficiency in the farm is increased, with respect to a conventional farming system, based on the use of synthetic mineral nitrogen, since each newly-fixed nitrogen molecule is likely to be used several times as fertilizer before it undergoes denitrification (Ceotto and Di Candilo, 2010).

In addition to this, such low-inputs systems are capable to prevent the potential greenhouse gases emissions that are precedent to field application, as consequence of the fossil energy used for the industrial manufacture of nitrogen fertilizers, including worldwide transportation (Ceotto and Di Candilo, 2010). Therefore, on a global average, well designed low-inputs farming systems may play a significant role in mitigating the impact of agricultural activity on global warming.

The sudden increase of the below-ground biodiversity, due to the high variety of species used for green manuring, presumably boosted the microflora activity and established high functional diversity of the microbial population, that in turn might have been started mechanisms of suppressiveness, as stated by Postma et al. (2007) who observed that one year of organic grass-clover effectively stimulated *Rhizoctonia solani* suppression. Above-ground green manure biodiversity effectively improved the bees activity, as asserted by the farmer.

However, some hindrances were experienced by the farmer when implementing green manuring in the rainfed arable crop rotation, due to the necessity to match the right weather conditions, especially when dealing with timely soil tillage, and not to compromise the following spring crop by sowing too late, thus risking to meet the summer drought during crucial phases of crop development. On the other hand, a too early green manure incorporation led to low biomass production, so making the whole operation fruitless. Due to the above reasons, eventually the farmer rejected this practice in his farm, although the observed agronomic advantages.

In the young olive orchard, placed on a steep slope prone to severe erosion, the green manure management was much easier, due to the absence of time constraints, but the farmer found this practice anyway hard to be implemented, still because of the weather limitations. In such a farming system, a plant soil cover might be easily established during the very first years, made up with locally-adapted, diversified and self-reseeding species. In the following years, the permanent mixed plant cover could be easily managed through periodical mowing, however still providing high degree of biodiversity and soil protection.

Keeping the soil covered as long as possible by organic matter resulted to be the most important requirement for the group of subsistence farmers of Swaziland, who are participating to the on-farm community-based trial. The proper management of high quality plant and animal organic matter, combined with crop diversification and minimum soil disturbace, seem to be the key factors to sustain low input farming in that rainfed (and prone to drought) area, to ensure food security: nevertheless, some issues pertaining to the socio-cultural context and local tradition still need to be properly addressed, to make the proposed technical package more appropriate and suitable.

The on-farm approach to research showed positive aspects, in both the experiences in Italy and Swaziland, since it allowed (i) a clear formulation of the key research objectives within a system vision, (ii) an unproblematic monitoring of the activities, and (iii) an evaluation of the efficacy and feasibility of the investigated techniques, together with the farmers, in a collaborative, and sometimes creative, environment.

However, in both the trials the constraints to set up a reliable experimental layout together with appropriate statistical analysis came out evidently, as explained in the previous chapters, which biased the quality of the results and weakened the conclusions drawn from the experiments. The difficulties in laying out the field experiments, that is implicit in such kind of trials with a very deep farmers involvement, is definitely the cost to pay for the above described advantages. As stated by Drinkwater (2002), the most correct approach to agricultural research should in fact combine, for a given set of research objectives, appropriately designed factorial experiments with on-farm trials. Such an integrated methodology might avoid the highlighted shortcomings although it would imply a great effort for its execution.

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