Organic farming systems for adaptation to and mitigation of climate change: effects on soil fertility and resource use efficiency

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Keywords: diversification, cropping systems, agroecology, green manure, soil organic carbon

ABSTRACT. – Organic farming is pointed as one of the most sustainable farming practices in terms of environmental sustainability and climate change mitigation potential. At the core of organic farming practices there are practices aimed at improving soil fertility, increasing soil C content and enhancing system biodiversity. A long-term field experiment (LTE) (MASCOT) was started on 2001 in San Piero a Grado, Pisa (Italy) with the aim to compare two different cropping systems, one managed organically and one conventionally, in terms of agronomical, economic and environmental sustainability. In 2016, the MASCOT was redesigned as a full system trial and the organic system was reshaped according to up to date agroecological standards. Climate change adaptation capacity of the two systems is being assessed through agronomic and economic parameters, whilst greenhouse gas emission mitigation potential is mainly expressed in terms of soil C sequestration.

ORGANIC FARMING AND CLIMATE CHANGE. – Although agriculture is one of the human activities more affected by climate change, it is also claimed to contribute to it significantly. According to the most recent report from the IPCC (2019), it is estimated in 23% the contribution of agriculture, forestry and other land uses to total human greenhouse gas emissions (GHGs). Besides conversion of natural soils to agriculture, the most important agricultural GHG direct sources are ruminant fermentation and soil respiration. In addition, intensive agricultural practices have led to deforestation, overgrazing and soil fertility degradation. Sustainable farming methods are thus needed to enhance the capacity

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of agricultural systems to “adapt to unpredictable and extreme weather conditions such as droughts and floods, reduce greenhouse gas emissions in primary food production and halt or reverse carbon losses in soils” (Niggli *et al.* 2007).

Organic agriculture is widely considered as one of the most sustainable approaches in food production. According to its definition by the Codex Alimentarius Commission, “organic agriculture is a holistic production management system that avoids use of synthetic fertilizers, pesticides and genetically modified organisms, minimizes pollution of air, soil and water, and optimizes the health and productivity of interdependent communities of plants, animals and people” (Codex Alimentarius Commission 2001). Organic farming emphasizes the use of natural resources internal to the agroecosystems, the recycling of organic matter and practices supporting soil fertility and diversity at all levels. Soil fertility is at the core of organic farming since its first definitions and applications, and farming practices aimed at increasing soil organic matter content are of paramount importance to sustain the productivity of the land in the long term. Among these practices, the cultivation of green manures and cover crops, the application of organic amendments (*e.g*., animal manure, composts) to the soil, the diversification of cropping systems through crop rotations and mixed cropping (*e.g.,* intercropping, agroforestry systems, variety mixtures and polycultures) to increase and diversify the organic matter returning to the soil are the most impacting on soil carbon (Scialabba and Müller-Lindenlauf 2010).

Thanks to the intensive use of these practices, organic management has been shown to store, on average, 3.5 Mg ha^{-1} more C in the soil than conventional management, as reported in the metanalysis of Gattinger *et al.* (2012). This amount explains the great interest that organic farming is drawing as potential climate change mitigation strategy, given the very low share of land managed organically in the world, estimated in only 1.4% in 2017 (Willer and Lernoud 2019). The potential of organic agriculture to contribute to the mitigation of GHG emission could be even higher if also indirect GHG savings (*e.g.,* N_2O emissions reduced by avoiding the use of mineral fertilisers) are considered (Scialabba and Müller-Lindenlauf, 2010).

In terms of adaptation, compared to conventional systems, organic agriculture systems are expected to be more resistant and resilient against adverse climatic conditions and its implications (*e.g.,* increasing prices of fossil fuel-derived technical means). This is mostly due to the reduced use of external inputs and the normally higher diversity of crops and animals grown in organic farms than in conventional ones (Scialabba and Müller-Lindenlauf 2010).

MEASURING THE PERFORMANCES OF ORGANIC SYSTEMS: THE MASCOT LTE. – Long-term experiments (LTEs) are field trials where experimental factors are being applied repeatedly on the same piece of land for many years, with the aim to test scientific hypotheses dealing with phenomena unravelling only in the long run or producing significant information only on an extended time frame. Cropping systems are often tested in LTEs, due to their complexity and wide range of performance indicators included, for instance, in sustainability assessment framework (*i.e.*, economic, agronomical, environmental parameters). Studying organic cropping systems requires also a holistic approach as the contribution of single components of the cropping system is less important than the whole set of functions and interactions among all the elements.

The MASCOT (Mediterranean Arable System COmparison Trial) is a LTE started in 2001 at the Centre for Agri-environmental Research "Enrico-Avanzi" (CiRAA) of the University of Pisa, San Piero a Grado, Pisa, Italy, and managed by CiRAA and Scuola Superiore Sant'Anna (SSSA), Pisa, Italy (Bàrberi and Mazzoncini, 2006). In the MASCOT, two arable cropping systems, one organic (OS) and one conventional (CS) have been compared on a loam soil until 2016, based on the same crop rotation (5-yr sequence with cereals and industrial crops), without any forage crop nor animal manure application ("stockless") and in rainfed conditions. Besides crop rotation, other elements of the cropping systems were constant between OS and CS, namely crop variety and soil tillage.

The first fifteen years of crop rotation practiced in these experimental conditions allowed for highlighting important general trends. Compared to CS, OS was shown to significantly improve soil fertility, in particular soil organic matter, microbial activity and soil biodiversity (Mazzoncini *et al.* 2010). From the energy efficiency point of view, OS was demonstrated to use less inputs per unit of land area respect to CS (Mazzoncini *et al.* 2011). CS conditions increased the yield of all the cereals in crop rotation, whilst less N-demanding crops yielded similar in the two systems. Crop produce quality was also investigated (Mazzoncini *et al.* 2015).

The redesign of the MASCOT LTE. – The layout of the MASCOT allowed anyway for a critical revision of the systems at the end of each cycle of the crop rotation, in order to readjust the management for embedding innovative practices or fine-tuning problematic components of the systems. This opportunity was exploited to replace crops which became out of business for farmers due to policy decisions (*e.g.,* sugarbeet in 2006), or to adjust the technique for cover crop management. In the meanwhile, the global context of the organic farming completely changed, thus making outdated the initial research questions. In the age of "organic agriculture 3.0" (Rahmann *et al.* 2016), it makes still not sense to investigate whether organic management of arable crops could perform similarly or not to conventional. The organic farming movement has been rewarded of full trust also in the science community, but at the same time is now challenged also in terms of contribution to big societal challenges as climate change mitigation.

That is why in 2016 it was decided to shift towards a full systemic approach and to redesign the two systems, taking into account also the agroecological principles establishing the new sustainability paradigms behind both organic and "conventional" systems (Antichi *et al.* 2018). In the OS, the crop sequence was enlarged to 8-yr rotation including emmer wheat (*Triticum turgidum* subsp. *dicoccum*), a 3-yr alfalfa (*Medicago sativa* L.) meadow, common wheat (*Triticum aestivum* L.), grain sorghum (*Sorghum bicolor* (L.) Moench.), grain millet (*Panicum miliaceum* L.), a grain legume (chickpea - *Cicer arietinum* L.) and two legume cover crops (pigeon bean - *Vicia faba* var. *minor* Beck., hairy vetch - *Vicia villosa* Roth.). Fertilization strategy includes the use of organic fertilisers to supply C to the soil (simulating availability of animal manure produced by a number of animals sustainable for the considered acreage and crop rotation), and tillage was differentiated respect to the crops in order to achieve a good weed suppression and a good soil structure. In the CS, the crop rotation was reduced to 4 years, and sod-seeding of winter wheat was introduced, aiming at improving soil fertility and reducing cultivation costs. The new market-oriented crop rotation includes common wheat, chickpea, durum wheat (*Triticum turgidum* subsp. *durum* (Desf.) Husn.) and grain sorghum.

Expected future results. – This shift in the methodological approach is expected to increase the impact of the MASCOT on local farmer community and to provide more robust scientific results in the mainstream of agroecological transition of current agricultural systems towards the target of climate change mitigation and adaptation. The redesigned OS is more likely to become a reference for organic farmers in the region as it was designed embedding also the standard practices suggested by some of them.

The experimental protocol of the MASCOT includes periodical sampling of soil cores to assess the effect of the two cropping systems on soil fertility, with a special focus on organic carbon, its fractions (*i.e.*, labile and stabile fractions) and interactions with soil physics and microbial activity. Recording also the amount of C outcoming or incoming the systems each year, it will be possible to estimate the C sequestration rate (*i.e.*, the amount of C that is stocked into the soil each year per area unit) and the C budget. Both indicators will provide a clear picture on the GHG emission mitigation potential of the two systems.

Monitoring crop performances across years respect to specific weather conditions, it will be possible also to determine the capacity of the two systems to adapt to current climatic conditions and see whether this ability would change at different ages of the systems.

Finally, as the elementary plots of the MASCOT have a real field size (0.35-1 ha), it will be possible to compute also energetic and economic efficiency of the two systems, allowing to estimate also the cost of the implementation of climate smart practices.

POSSIBLE COLLABORATIONS. – The MASCOT is an open-air laboratory available for scientists from other disciplines. We foresee the potential for fruitful collaborations with colleagues studying direct GHG emissions, water balance, biodiversity (*e.g.,* insects, microorganisms), microclimatic modifications, plant pathology, agricultural economy and social sciences.

ACKNOWLEDGEMENTS. – The authors acknowledge the staff of CiRAA for their precious support and enormous efforts in conducting the LTE.

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