Minipaper

Conservation Agriculture: A promising approach to invert SOM decline in the Mediterranean region

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1. Introduction

Soil organic matter (SOM) decline has been identified by the Soil Thematic Strategy as one of the major threats to European soils (Van-Camp et al. 2004), particularly under Mediterranean climate (Zdruli et al. 2004). Low SOM content of agricultural and grassland soils in Mediterranean temperate and continental areas may indicate soil degradation as a result of intensive use of these soils (Romanya and Rovira, 2011). Furthermore, the way agriculture has been developed in Europe, particularly under previous CAP, took farmers to use more power and more energy for tilling soils with little consideration on the increasing risk of soil erosion and the degradation of biological, physical and chemical soil properties. The disruption of soil aggregates and the exposure of the physically protected intra-aggregate SOM to excessive aeration and microbial attack increases mineralisation and reduces SOM (Basch et al. 2012), increasing the emission of greenhouse gases into the atmosphere (Cid et al. 2013). Additionally, low biomass production under rainfed conditions, straw removal and stubble grazing, as well as soil erosion, are also in part responsible for the extremely low organic matter contents in Mediterranean soils, which often do not exceed 1%.

In this context, the adoption of **Conservation Agriculture (CA)** appears as a promising approach for interrupting this cycle of driving conditions to SOM decline. Conservation Agriculture is a set of agricultural practices aimed at protecting the soil and enhancing its natural properties, such as soil structure stability, soil biota and SOM content among others (Brouder and Gómez-Macpherson, 2014). Its origins are in the responses to the "Dust Ball" period in USA. The present mini-paper aims at presenting CA principles and the opportunities their adoption offers for SOM improvement in Mediterranean conditions. The complexity for developing a successful CA system is also discussed.

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2. Solutions/possibilities/opportunities

Conservation Agriculture is based on three major principles (FAO, 2008):

- no inversion tillage and an overall reduction of soil disturbance, with preference for no-tillage;
- permanent maintenance of soil cover with crop residues or cover crops;
- plant species diversity or diversified crop rotations, viable in term of overall performance (agronomic, economic and environmental) of the farming system.

Operations for crop establishment are concentrated in one sole operation and one machine (Carvalho, 2010a).

The respect of all 3 principles concomitantly provides the potential benefits of CA, however, this is often difficult and farmers may only adopt partial elements of CA with variable impact on root growth and residues production, and in the long term on SOM. In Mediterranean conditions, on-station experiments have shown that no-tillage increases soil organic carbon in irrigated systems (Muñoz et al. 2007; Cid et al. 2014) and rainfed systems (Murillo et al, 2004) though not always (López-Bellido et al. 1996). These contrasting results are due to the complexity of interacting factors that are influenced by CA (Fig. 1). When adopting no-tillage, a major concern is facing the impossibility to decompact the plough layer. Compacted soil will reduce plant and root growth (Raper et al., 2000), whereas compacted superficial soil will result in lower water infiltration and soil water content; waterlogging and killing of seedlings or plants may then occur. Controlled traffic or sporadic or precision tillage may reduce compaction limitations (Cid et al. 2014). Likewise, if no-tilled soils are not protected from rainfall or irrigation, soils may crust before or at sowing (Acharya and Sharma, 1994), leading to poor stand establishment. Another major concern when adopting no-tillage is the potential increase of weeds, diseases and pests incidence. Adopting no-tillage requires attentive weed control and increase use of herbicides.

Most of these negative impacts can be counteracted by maintaining residues on the soil surface after harvest (Figure 1). The mulch protects the soil from wind and raindrops thereby reducing risk of surface crusting. Surface residues reduce soil water evaporation and reduce runoff and increase water infiltration (Boulal et al., 2011b); consequently, residue retention with no-tillage may increase water availability to the crop (Lampurlanés et al., 2001) and irrigation use efficiency (Grassini et al., 2011). Generally, a minimum amount of residue is needed to achieve these positive effects (Erenstein, 2002) although specific amounts required for local conditions are not clear.

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After CA adoption, SOM and soil aggregates improve with time (Carvalho et al, 2010; Boulal and Gómez-Macpherson, 2010) and soil erosion is reduced thereby enhancing soil fertility (Boulal et al., 2011a; Boulal et al., 2012), improving soil structure, water infiltration, retention in the root zone and water productivity (Verhulst et al., 2010; Cantero-Martínez et al., 2007; Rockstrom et al., 2012). On the other hand, maintaining residues may also have negative short term effects (Figure 1). In the initial phase of adopting no-tillage and mulching, high amounts of residues may result in N immobilisation (Alvarez and Steinbach, 2009). Higher amount of fertilizer will then be required to compensate the immobilisation until soil fertility is increased and the system is balanced. Additionally, manure or non-mobile soil nutrients, e.g. phosphorus, cannot be incorporated into the soil in detriment of growth unless the drill or farmer locates them next to seeds. Residues also reduce radiation interception by the soil and soil warming during early establishment of spring crops when temperatures are low (Griffith et al., 1977). Leaving residues on the ground also require specific drills to sow through them, and makes difficult flood or furrow irrigation or herbicides application.

In conservation agriculture, crop rotation has a major role facilitating weed control and reducing the risk of pest and diseases incidence (Figure 1), particularly in the soil (Kirkegaard et al., 2008). Having legumes in the rotation may improve the nutrient cycle also (Carvalho, 2010a). Additionally, the rotation would also help to maintain a manageable amount of residues in the system by combining high and low producing crops (Boulal et al., 2012). As other models of sustainable agriculture, CA should be considered in the long term to be fully implemented and to allow expressing all its benefits (Mazzoncini et al., 2012).

Conservation Agriculture in Europe and the Mediterranean & the way to go

Current global estimates of adoption of CA are 124 million hectares (Friedrich et al., 2011), 87 % of which is concentrated in five countries: the United States, Brazil, Argentina, Australia, and Canada. In Europe CA is below 2% of all agricultural land and only Africa has a lower adoption. Socio-economic issues (Lahmar 2010; Soane et al. 2012) and the CAP have been identified as a major factors for this low adoption of CA. The plan model of farm business in EU is strictly dependent on subventions and this model deters farmers from innovation or from any consideration of soil erosion threatening farming sustainability. It is still to be seen if the new CAP will change farmers' modus operandi. Education and awareness on risks related to SOM depletion and fertility losses, and short- and long-term effects on SOM and productivity should contribute to this change. In this context, active national and regional associations promoting CA among farmers, researchers, decision makers and stakeholders can play an essential role in CA development. Similarly, in most of the Mediterranean countries, there are farmers successfully

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practicing CA either because they were curious and innovative enough to try new and apparently promising approaches, or because they received support and advice from others. For example, Figure 2 presents four successful farm plots in Portugal. Other farmers can learn from their experience to minimize risks.

An additional limitation is the lack of a single recipe for successful full adoption of CA. Many Mediterranean farmers adopt 1 or 2 CA principles only. For example, no-till is more common for single crops only, e.g. winter or spring cereals (De Vita et al., 2007). Besides the basic research carried out on-station, practices need be tailored for adaptation to local conditions (Knowler and Bradshaw, 2007). More specifically, there is a need to better understand SOM dynamics under different agro-ecological conditions within the Mediterranean region and how it is influenced by different crops and cropping systems. Additionally, to avoid conflicts such as competition for residues in mixed farming systems present in the Mediterranean, R&D work is needed to improve crop livestock integration in CA systems. Weed control can be considered as a major concern in CA and the dependence on a single or a few herbicides is a weakness point in terms of sustainability. Targeted research is needed to improve weed control and similar topics (e.g. slugs control, corn and cereals mycotoxin incidence), reducing chemical treatments and working towards compatibility with organic farming. In all cases, multidisciplinary research and the involvement of all actors (from machinery to seed of alternative crops availability) are required. Unfortunately, the CA research carried out in Europe is set up around on-station trials that often do not represent the conditions faced by farmers, and with the aggravating fact of practically inexistent extension services. Furthermore, the specific economic or legislative conditions in Europe may make some options not feasible.

Key elements for increasing CA adoption and SOM in the Mediterranean

- **CA requires maintaining the residues on the ground**
- **Local-tailored solutions must be developed following a dynamic bottom-up approach: multidisciplinary researchers working in hand with multiactors e.g. farmers, machinery, seeds and chemist companies, agronomists, economists, pathologists,…**

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Examples of real projects

Commercial farm in collaboration with researcher (Portugal). In 1989 - first trials with direct seeding in maize when CA was not still a system. Results from trials were good. In, 1990 - large scale agriculture areas. Results were good but available drillers were not good to work with residues. During 1991-2000, as good drillers were not available in the market, minimum tillage was adopted with interesting results. In 2000, good drillers appeared to work in all conditions and the full CA system started. During 2000-2006, mostly maize monoculture with decreasing productivity year by year. During 2006 – 2009, crop rotation incorporated: ryegrass - maize - barley, with some problems in barley in wet years. During 2010 – 2014, crop rotation wheat - ryegrass+clover - wheat - lupines with lifestock integration with productivity increasing every year. CA gives an important contribution for farm economy:

- Cost reduction for reducing use of machinery. This reduction is valid for variable costs and for fix costs once with less machinery use we have also less investment.
- Soil structure and fertility improvement with crop rotations and maintaining crop residues on soil surface reduces soil erosion and improvement of SOM content.
- Water efficiency improvement for reducing evaporation and runoff.
- Environmental problems reduction due to erosion reduction. Less CO_2 emissions for using less machinery and for reducing organic matter mineralization once we do not till soil.

Irrigated maize-cotton rotation in commercial farm and on-station (Southern Spain). Commercial farm and on-station trial that started in 2007, no-till or conventional bed planting combined with controlled traffic. Residues were left on the ground after harvest. In the commercial farm, soil organic carbon (SOC), both in terms of concentration or storage, varied with landscape, mostly due to differences in rates of soil erosion and leaching which are much affected by slope, and to different soil textures. The difference in SOC stock after 4 years of the introduction of the new system compared to initial values was estimated 13 Mg C ha^{-1} (0-0.3m). In the trial established on-station, controlled traffic and residues placement –they tended to accumulate on furrows– resulted in spatial and temporal differences in soil compaction and SOC concentration in the no-till system (NT). In NT, SOC in the top 0.05-m layer increased faster and saturated at higher values in furrows than on beds (1.67 vs. 1.09%, respectively), the last being similar to SOC in the conventional system (CT). Stock of SOC was higher in NT than CT and the difference increased significantly with depth down to 50 cm (5.7 Mg/ha). In Spain, most studies on the potential of CA for C sequestration in cereal-based systems had been carried out in

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rainfed conditions and for shallower horizons than in the study presented here (Alvaro-Fuentes and Cantero- Martínez, 2010); on average, no-tilled systems stored 3.6 Mg/ha more carbon than the conventional systems (1.1 Mg/ha when compared with reduced tillage), for horizons up to 0.5 m. The lower values than that obtained for irrigated conditions could be related to experiments durations. Some local examples have resulted in similar or even higher levels of carbon sequestration after 11 years since adoption in rainfed conditions: 8.3 Mg ha^{-1} (López-Bellido et al., 2010; 0.9 m layer) and 10.4 Mg ha^{-1} (Ordóñez-Fernández et al., 2007; 0.52 m layer), but in vertisols soil type with clay content around 70%.

On-station rainfed annual-crops based system (Portugal). Trial to study the impact of the type and management of crop residues on SOM in rainfed conditions Basch et al. (2010). All crops were established under no-till. The treatments were the following:

- "Chickpea" as a legume, low residue producing crop with a low C/N ratio; the amount of residues left was approximately 750 kg of DM/ha;
- "Grazing" - wheat crop with removal of straw and stubble, and distribution of manure from sheep fed on wheat straw equivalent to 3000 kg/ha, in order to simulate the grazing of straw and stubble;
- "Stubble" - wheat crop with straw removal but stubble maintenance (cut at a height of 15 cm);
- "Straw" - wheat crop with stubble and uniform distribution of 2500 kg/ha of wheat straw (corresponding to an average production of wheat straw);
- "2 x Straw" - wheat crop with stubble and uniform distribution of 5000 kg/ha of wheat straw (corresponding to twice the amount of wheat straw produced).

After three years the differences in SOM concentration in the top 20 cm layer were +0.2% (2 x straw) > +0.18% (straw) > +0.08% (grazing) > +0.03% (stubble) > -0.02% (chickpea).

HelpSoil demonstration project (Italy). This project is funded by European Commission's DG ENV under Life+ programme, involves 5 regional Agriculture Ministries, with the scientific supervision by University of Piacenza, and the participation of Animal Production Research Centre (CRPA). The project started in 2013 and will be completed within four years. The objectives are:

- show CA is feasible and sustainable in 20 real farms, scattered in the northern regions of Italy;
- verify if CA is able to preserve soil fertility through C sequestration, soil biodiversity conservation, erosion control;

- identify environmental performance of CA, for instance considering energy and irrigation water consumption.

Some new techniques (as referred to irrigation, to organic fertilizers' use and innovative actions regarding plant health) will be tested to investigate the results achieved in the demonstration farms, where CA is adopted.

The project will promote an intensive demonstration and dissemination activity, based at the demonstration farms. At the end of the project will be available a manual of guidelines to implement CA in different farming situations of Italy. This deliverable will be focused on practical solutions, adopted through the interaction between researchers and farmers, sharing the objective to spread more sustainable agricultural systems.

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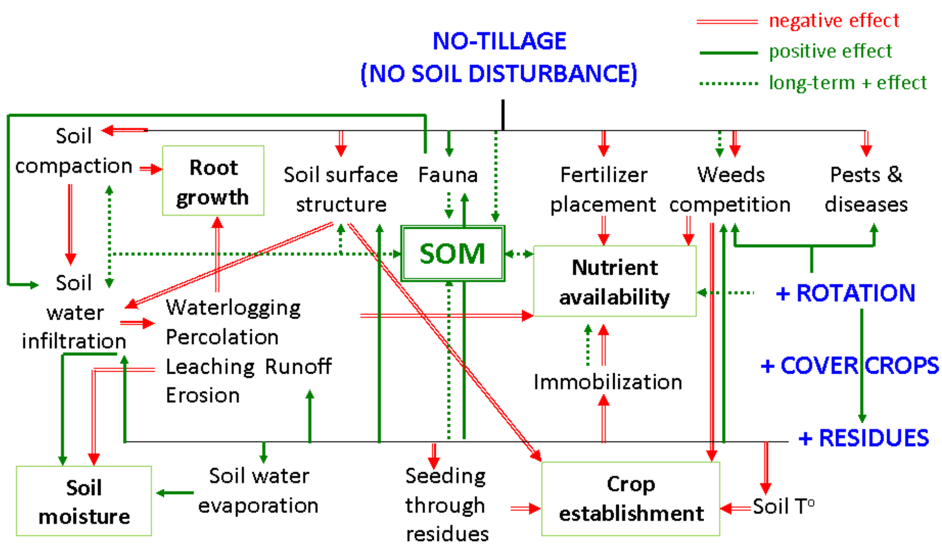

Figure 1. Main pathways through which a change in management from conventional to no-tillage first, followed by maintenance of residues and finally by crop rotation or cover crops, may impact key drivers (in green boxes) of crop performance and SOM (adapted from Brouder and Gómez-Macpherson, 2014). A single dark green arrow and a double red arrow indicate beneficial and constraining effects. A dotted line indicates a beneficial effect expected in the long term.

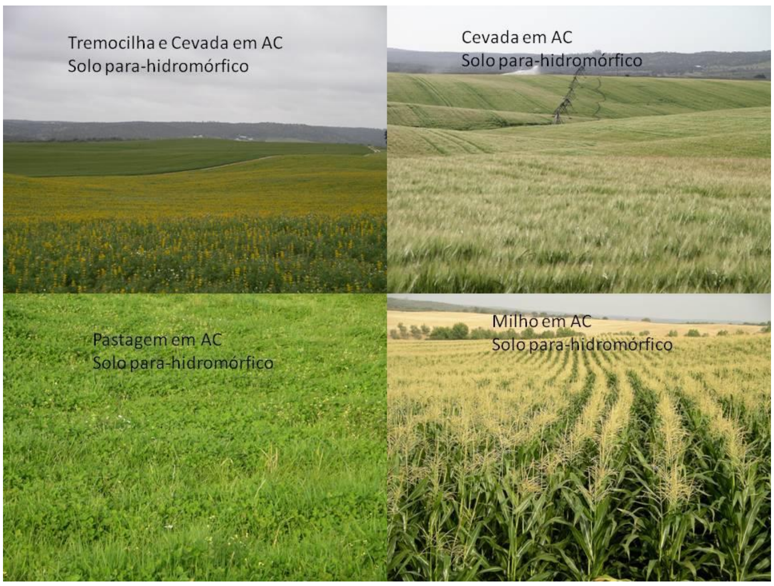

Figure 2. Different crops cultivated under CA in a commercial farm in Portugal.

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