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Conservation Agriculture and Soil Fauna: Only Benefits or also Potential Threats? A review

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Abstract

Soils and their inhabitants are fundamental for life since they contribute to the terrestrial ecosystem's functionality and they provide different ecosystem services, in particular related to food provisioning. The intensification of agriculture and the traditional techniques based on extensive tillage have seriously affected soils, degrading their physical and chemical parameters and causing loss of biodiversity. Conservation agriculture (CA) and the related management practices have demonstrated in the last decades to be an efficient tool to combine food productivity with environmental protection around the world. The reduction or the absence of tillage, the permanent soil cover, and the crops' rotation have clear and demonstrated positive effects on soils, including the improvement of physical and chemical properties, the decrease of water run-off and wind erosion, and an increase of water retention. The use of cover crop and the organic residues on the surface enhance the stability of soils and regulate temperatures. Therefore, the biodiversity increases.

On the other hand, it seems that some negative effects could be relied on conservation practices. Mainly after the conversion from traditional agriculture, soil compaction could represent a negative parameter that emerges, especially in clayey soil, affecting porosity, water infiltration and edaphic organisms' ability to move into the soil. Moreover, without a mechanical way to uproot weeds, it is possible that a great amount of herbicides would be used with consequences on soil fauna not yet fully known. This paper considers the benefits deriving from the use of CA on soil microarthropods. Besides, it seeks to identify potential points of weakness, in particular related to a massive use of herbicides.

Keywords: *Conservation agriculture; Soil microarthropods; Soil parameters; Soil compaction; Herbicides*

Abbreviations:

CA: Conservation Agriculture

C : Carbon

CO_2: Carbon Dioxide

Introduction

Soil is a key habitat because not only it sustain the functionality of terrestrial ecosystems [1,2], but also for the ecosystem services that it provides [3]. Indeed, soil is a crucial regulatory centre to most of the ecosystem processes [4], and it provides them thanks to the rich and complex community of soil organisms [5,6]. Soil fauna are involved in several functions that are strictly related to the soil fertility and to the agricultural production [7,8,9], among the others, the decomposition of the organic matter and the nutrient cycling. Besides, edaphic fauna affect porosity and the aeration of soils, as far as water infiltration and the organic matter distribution within the soil horizons [2]. For these reasons, the biodiversity of soils, which has been often neglected and which is still only slightly known [10], is a great value to maintain and enhance. Unfortunately, the anthropogenic disturbances have severely affected biodiversity so far. Land use change, due in particular to agriculture intensification, has been recognised as a major driver for biodiversity loss [5,11 and 12]. The traditional agricultural practices, with ploughing, intensive crops and use of chemicals, have influenced abundances and diversity of edaphic communities [13-17]. Traditional ploughing (up to more than 30-40 cm deep) generally alters soil structure and buries crop residues resuming soils to the early stages of ecological succession [2,14 and 18]. Biodiversity decrease both within soil fauna taxonomic groups and among functional groups [19]. The communities under traditional agriculture are simplified with the reduction or the disappearance of some taxa, especially the most adapted to the soil and thus more sensitive to disturbances, and the predominance of these taxa that are more resistant. The population often needs decades to recover after tillage [20,21].The increasing awareness of the importance of soils and their inhabitants, and the necessity of saving natural resources facing global changes have been reflected in the purposes of maintaining the functionality of agro-ecosystems and protecting habitats integrity [22-24]. Finding new sustainable practices to provide food has become a priority and the conservation agriculture (CA) is nowadays widely recognised as a viable solution in this regard.

CA is defined as "a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment" [25]. It relies on three main principles [26-28]:

A. Minimal soil disturbance (minimum tillage with the aim to achieve no-tillage or zero tillage)
B. Permanent soil cover (with crops residues and cover crops)
C. Crop rotations.

CA recognizes the importance of the upper soil layer (from 0 to 20 cm) while it is the most active area for the organisms, but also the most vulnerable to erosion and degradation [26]. The benefits that CA provides are multiples and they rely on physical (stability of soils, erosion reduction, increase of water retention, temperature), chemical (organic carbon, nutrient availability, pH), and biological (diversity of organisms, soil quality) properties of soils that increase [29]. However, some negative aspects can be linked to CA. Especially in the conversion process from traditional to conservative practices; the porosity could be affected with different consequences on water infiltration and on soil fauna. Moreover, the control of weeds without mechanical actions could increase the use of herbicides with effects on environment that have been poorly investigated yet (Figure 1).

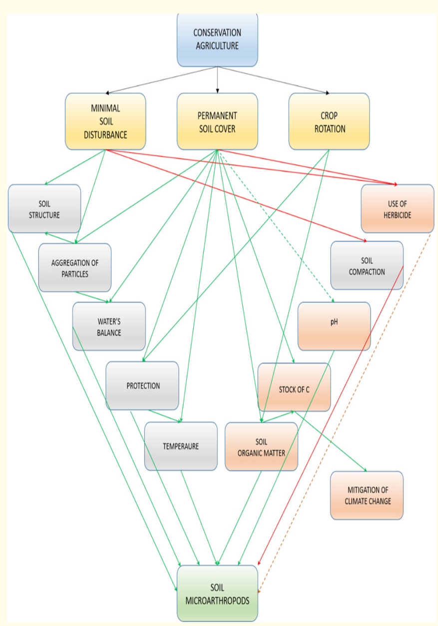

Figure 1: *The main principles of CA (yellow blocks), with positive (green arrows) and negative (red arrows) interactions that they have on physical (grey blocks), chemical (pink blocks), and biological (green block) soil properties. The dotted line indicates not clear or not known interactions.*

It is necessary to recognize that all physical, chemical and biological components interact in the soil and affect each other in different ways. This review aims, on the one hand, to evaluate the effects on soil microarthropods due to the improvement of soil properties (considering them one by one) and on the other hand, to indicate potential threats related to the absence of tillage. To achieve these purposes, an overview of the existing literature, dealing with conservation tillage and conservation agriculture and their effects on soils and on soil arthropods (derived from singular or combined searching on several databases), has been done and the articles involved have been evaluated using a critic point of view.

Physical Improvements

Soil structure is the arrangement of soil particles and aggregates of sand, silt and clay, and pores in soils [30-33] and it can be measured as the stability of aggregates [29]. Soil structure stability is the soil's ability to maintain the arrangement of particles and pores when exposed to environmental stresses [29,30]. CA avoids or minimizes stresses due to tillage (clod's overturning, oxidation, exposure to weather etc.), so the soil profile stays undisturbed [17,34 and 35], and aggregates, mycorrhiza and roots are not broken. The aggregates' formation process is not interrupted by tillage and the organic matter is not redistributed in the soil profile, affecting positively the stability of macro-aggregates [29].

Furthermore, the permanent soil cover, mainly with the action of the roots and fungal mycorrhizal hyphae, increases the aggregation of particles [36]. Thus, soils are more protected from abiotic factors [29,36]: combining soil stability and the soil cover, the soil surface is exposed to them only for a limited period of time or space. While intensive agriculture is one of the anthropogenic activities that stimulate erosion with the loss of nutrient-rich upper soil layers, CA reduces it even by an order of magnitude, thanks to the attenuation of the rain intensity and to the slowing down of run-off due to crop residues [29,36-42].

The latter likely influence soil water's balance, by an increase of the infiltration rate, the soil moisture and, thus, the water holding capacity, and a reduction of the evapotranspiration. The residues tend to capture rain, and they reduce the run-off and its speed, consequently water has more time to infiltrate [29,43]. The surface's moisture tend to be higher, and more water is available in the soil [36,44-45].This aspect it is very important, especially with prolonged drought periods [46]. The evapotranspiration, which depends on the amount of soil water and on the solar energy reaching the ground [47], decreases with different intensities based on the thickness of the residues [48-49].

The soil cover protects soils even from extreme temperatures, reducing the amplitude of daily and seasonal variations than traditional tillage systems [48,50]. On the one hand, it limits the amount of solar energy that reaches the surface, reducing high soil peak temperatures during the day in summer even by 2-8°C, and warming soils during the night by the insulation of the residues [48,50]. On the other hand, the residues cover screens off thermic radiations [37,38], maintaining a mild habitat even in the winter's coldest periods.

All the improvements induced by CA on soil physical properties have numerous positive effects on soil arthropods. A higher amount of structure stability, without any mechanical stress that disrupt habitat, allows the presence of more microarthropods' groups, including these that spend all their life cycles into the soil, such as proturans, symphylans, pauropods for example. These latter have morphological adaptations (small dimensions, anophthalmia, winglessness, thin cuticles) to soil characteristics (e.g. small spaces, darkness) [51,52], and, for that reason, they are more sensitive and vulnerable to environmental changes [53] (Figure 2). Indeed, the residues represents a feeding source for soil arthropods, in particular for the litter transformers and ecosystem engineers, which are involved in their decomposition and transformation [55,56], with an increase of the numbers of organisms. Several authors have largely demonstrated that soil biological activity and diversity are higher under reduced tillage systems reusing crop residues [42,57-60]. Furthermore, the presence of the soil cover contributes to reduce the variations of temperatures and soil moisture during the day and seasons. This is fundamental for biodiversity conservation and for the provision of ecosystem services driven by soil fauna during prolonged dry periods.

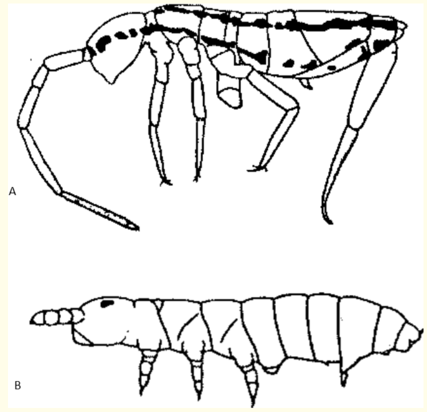

Figure 2: *The differences between an epigeic (a) and an emiedaphic (b) springtail (miniaturisation, reduction of the dimensions of the appendices -such as antennae, legs, furca-, depigmentation, reduction of visual apparatus). An example of the major adaptation to soil by the emiedaphic organism, which shows morphological adaptations to soil environment. (Adapted from [53]).*

Chemical Improvements

Soil organic matter is an integrator of several soil functions, it is a key component of soil quality and delivery of many ecosystem services, and it influences soil structure and soil stability [61,62]. CA proposes crop rotation, maintenance of residues, and cover crops in the intercropping periods to increase organic matter, and then C, inputs in agricultural soils.

In this way, firstly, there are more food resources for many edaphic organisms, leading more diverse soil communities [63]. Secondly, soil aggregation is enhanced as described before, promoting stable environments. Thirdly, the decomposition process is limited by increased particles aggregation, therefore C is accumulated and confined in the upper soil layer (up to 10 cm) [36,64]. Even though it was mainly introduced to regulate erosion [65], CA is now considered as a strong potential system to stock C in soils to slow CO2 emissions from agriculture practices [36,66 and 67].

The nutrient availability tends to increase near the soil surface due to the slower decomposition of residues and the limited leaching through the soil profile preventing by the action of the organic matter and soil aggregates [29]. The great amount of macro and micro nutrients near the surface facilitates their uptake by plant roots, whose density is usually higher in the topsoil under CA [29,68], reducing the necessity of chemical fertilizers.

The pH of soils in CA systems is, in general, lower. The acidity could be probably due to the accumulation of organic matter in the upper soil layers or to the fertilizers that are applied superficially. However, it is not possible to define a clear trend for pH values.

The higher biodiversity that can be found under CA is not only a great values in itself, but promote the functionality of the agro-ecosystems with the breakdown of the organic matter and the recycle of nutrients essential for plant growth and them for food production. The presence of different predators, which could choose between alternative preys, could control pests, reducing the use of pesticides [69]. The biomasses and the population densities of microarthropods reflect the resource availability [69,70]: a more diverse and abundant soil community seems to provide better to soil functions.

Potential Negative Consequences

Despite the benefits for environment and for biodiversity, some negative aspects could be caused by adoption of CA practices, such as compaction and use of herbicides.

It has been observed that problems of soil compaction can occur under CA [42,62,69 and 71]. The most important effects of soil compaction are the decrease of porosity, which involves the increase of bulk density [42, 72 and 73] (Figure 3). Many studies showed that bulk density increases slightly in the early stages after the conversion from conventional to CA and even after a long-term use of no-tillage systems [62,74-76]. The lack of tillage operation could reduce the numbers of macrospores, augmenting compaction and affecting the habitat of microarthropods, modifying the volume of air and water [77], and suppressing their population increase [18,69 and 78-80]. Among the microarthropods' taxa, Collembola seems to be the most affected group [18,78 and 80-82], but it can be supposed that other euedaphic taxa, such as Pauropoda and Symphyla, would be negatively influenced. Even though in most cases it represents a temporary problem seeing the presence of organic matter and the biological borrowing actions of earthworm and millipedes, the compaction of soils has to be cautiously consider during the conversion to minimize detrimental effects on soil microarthropods' community.

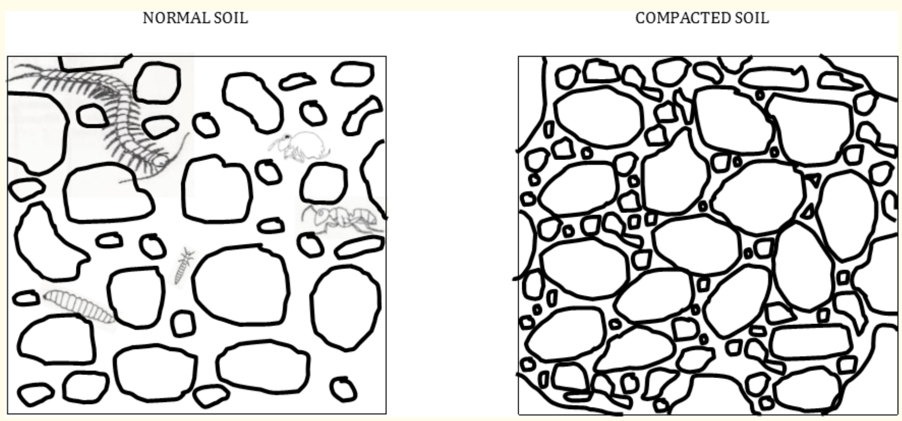

Figure 3: *The consequences of compaction on soil characteristics: decrease of spaces, reduction of air and water in the soil profile, thus a decline on the presence of soil microarthropods.*

Furthermore, the absence of tillage could affect the controls of weeds. Although the cover crops could provide a biological weed control by allelopathic substances and by promoting community diversity with the presence of beneficial insects, such as ants, that control weed seeds [83], CA systems have been held responsible for a significant increase in the use of chemicals, mainly herbicides [42]. Scopel., *et al*. [42] reported several weed infestations under reduced tillage in Europe that required a great numbers of herbicides applications. The herbicide Glyphosate is a very useful tool that farmers use to devitalised cover crop cultivated during the intercropping season [84], but it could implicate different risk for environmental and food safety. The intensive and repetitive use of Glyphosate selects the Glyphosate-resistant weeds and involves weed species shifts towards species Glyphosate tolerant. Afterward, the doses of the herbicide would increase to obtain some results. The Glyphosate is quite rapidly degraded in the soil, but its fate under CA has not been clearly understood: the organic matter in the upper layer of soil could fix the herbicides or its metabolites, slowing its degradation, so it could persist in the soil environment for long periods [42,84]. The effects that herbicides could have on non-target soil organisms have been partially studied so far, but the persistence in the soil is a key determinant of environmental impact [62]. The impacts that herbicides could have on soil biota are still not clear. Some recent studies deal with the toxicity of herbicides on springtails, which are well-studied organisms for eco toxicological bioassays and which are used as bioindicator of soil quality. Contrasting results emerged: herbicides have in some cases adverse effects on springtails [85-87], but even positive effects on densities and species richness [82]. Other studies are necessary to confirm the consequences on different soil components by herbicides and their metabolites accumulation in the upper soil layers, even to avoid the risk for environmental quality and food safety.

Conclusions

CA systems contribute to ameliorate and enhance many soil parameters that have been neglected in the past decades. The main drivers of agricultural soil degradation, like erosion, nutrients remove, management intensification, biodiversity loss, have been solved in most cases and the principle of limiting the use of natural resources could bring several economic benefits to farmers. Soil microarthropods' communities increase their abundances and diversity due to the higher amount of organic matter deriving from crop residues left on the soil surface. A great soil environment stability, with a major aggregation of particles carried by the organic matter, permits the presence of more sensitive microarthropods' group, which are more adapted to the soil and which can't leave it in case of disturb. A more diverse microarthropods community signs of increased soil quality and, thus, soil health. The improvements of temperatures and moisture establish an environment with less variability between day and night and among seasons, allowing a major protection facing drought or wet seasons.

The awareness that some threats could arise after the conversion of conventional to reduce tillage systems, such as soil compaction and use of herbicide, could stimulate to consider carefully case by case, due to climatic conditions or soil types, the more indicated management system to apply.

CA represents a great opportunity to enhance conservation policies to maintain soil functionality and to conserve biodiversity, if not as a value in itself, as a fundamental actor in providing ecosystem services and food production. It is now important that even the agriculture systems understand that the soil is a limited resource and only a healthy soil ecosystem could provide food for us and for future generations.

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