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No-tillage, soil organic matter and soil structure: Relationships and implications

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SUMMARY – In Mediterranean semiarid agroecosystems, a low soil organic matter content and a weak soil structure are two main constraints to enhance crop yields and soil quality. A reduction in tillage intensity can be a viable strategy to improve these soil attributes and, therefore, soil quality and productivity. Thus, a better understanding of the interactions among tillage, organic matter and soil structure is a key issue in those environments. However, little information exists about these relationships in the Mediterranean semiarid region. Results from this study show the potential benefits of no-tillage on soil organic matter accumulation and soil structure improvement in rainfed agricultural soils of North-eastern Spain.

Keywords: Soil organic carbon, no-tillage, conventional tillage, aggregate stability.

RESUME – *"Non labour, matière organique du sol et structure du sol: relations et implications". Une faible teneur en carbone organique du sol et une faible structure sont deux limitations principales pour augmenter la production des cultures et la qualité du sol en agroécosystèmes méditerranéens semi-arides. Une réduction de l'intensité du labour peut être une stratégie viable pour améliorer ces attributs du sol et, ainsi, la qualité et productivité du sol. Une meilleure connaissance des interactions entre labour, matière organique et structure du sol est essentielle dans ces environnements. Cependant, il y a peu d'information sur ces interrelations dans la région semi-aride méditerranéenne. Les résultats obtenus dans cette étude montrent les profits potentiels du non-labour sur l'accumulation de la matière organique du sol et l'amélioration de la structure des sols cultivés en sec dans le NE de l'Espagne.*

Mots-clés : *Carbone organique du sol, non-labour, labour conventionnel, stabilité des agrégats.*

Introduction

Soil organic matter (SOM) can be used as an appropriated soil quality indicator due to the role that it plays in a wide range of soil properties and processes such as soil structure, water dynamics and cation exchange capacity. At the same time, SOM is a key property in soil productivity trough a direct plant nutrient supply. Thus, a better understanding of mechanisms controlling carbon storage is a crucial issue in agricultural soils.

Soil aggregation plays an important role in SOM stabilization. Soil aggregates protect SOM from microbial accessibility and, therefore, from subsequent decomposition. Protection of SOM within soil aggregates against microbial decomposition will be greatest with higher aggregate stability and lower aggregate turnover (Krull, *et al.*, 2003). Several studies have concluded that a reduction of tillage intensity, especially with no- tillage, provides a greater aggregation and consequently a greater SOM content (Franzluebbers and Arshad, 1996; Hernanz *et al.*, 2002).

Soils in the Mediterranean region have low soil organic carbon (SOC) content. Traditional soil management practices in these agroecosystems are long-fallowing and conventional tillage with mouldboard ploughing as the main tillage practice. Few studies have been carried out in order to determine the effects of traditional and alternative (no-tillage) soil management practices on SOC content under these semiarid Mediterranean conditions (Hernanz *et al.*, 2002). Likewise, little information exists about the influence of soil management practices on SOC that relate to soil structure in these semiarid areas.

The objective of this study was to compare the effect of no-tillage and conventional tillage under different cropping systems on SOC content and soil aggregate stability in dryland agroecosystems of the Ebro river valley (NE Spain).

Materials and methods

In July 2005, immediately after harvest, soil samples were collected at the soil surface (0-5 cm) from three different long-term tillage experiments located in semiarid Ebro river valley. Sites, ordered from higher to lower mean annual precipitation were: Selvanera, Sv (500 mm), Agramunt, Ag (430 mm) and Peñaflor, Pñ (390 mm). The first site was established in 1987 and the other two in 1990. In the three sites conventional tillage (CT) and no-tillage (NT) treatments were compared. In Sv, CT treatment consisted in a pass of a subsoil plough up to 50 cm and in Ag and Pñ consisted in a pass of a mouldboard plough up to 40 cm. In the NT treatment none tillage implementation was done, leaving crop residues above soil surface. In Sv, the cropping system was a continuous 4-year rotation of wheat-barley-barley-rapeseed with rapeseed as the crop grown during the season studied. In Ag, the cropping system was a continuous 2-year barley-wheat rotation with wheat during the season studied. In Pñ, samples were taken from two different cropping systems: a continuous barley (Pñ-cc) and a barley-fallow rotation (Pñ-bf) in the crop phase of the rotation. In the barley-fallow rotation, crop residues are returned to the field every two years whereas in the other cropping systems, crop residues are returned every season.

A composite soil sample was taken from each plot and stored in crush-resistant containers. Samples were air dried and stored at room temperature. From each sample a subsample was taken for soil organic carbon (SOC) analyses by the wet oxidation method of Walkley and Black (Nelson and Sommers, 1982).

Soil for aggregate analyses was previously passed through an 8-mm sieve. Dry soil aggregate size distributions (DAD) were determined on a vertical electromagnetic sieve apparatus (FRITSCH *Analysette 3* PRO) with the next sieve sizes: 2000; 250 and 50 μm. Wet aggregate size distribution (WAD) was determined by a wet sieving method adapted from Elliot (1986) using the same sieve sizes (2000; 250 and 50 μm). Before sieving, a slaking pre-treatment was applied to the soil. During slaking, a high level of disruption occurs because of the rapid build up of air pressure as capillarity pulls water into the aggregate (Kemper and Rosenau, 1986). Finally, for both DAD and WAD four aggregate size fractions were obtained: (i) >2000 μm (large macroaggregates); (ii) 250 to 2000 μm (small macroaggregates); (iii) 53 to 250 μm (microaggregates); and (iv) <53 μm (silt- plus clay-size particles).

Data were analysed using the SAS statistical package (SAS Institute, 1996). To compare the effects of tillage treatments per each site and aggregate fraction, an analysis of variance (ANOVA) for a randomized block design with three replicates was made.

Results and discussion

In all the sites, it was observed a greater SOC in NT than in CT. Differences between tillage treatments were significant except in Sv (Table 1). This greater SOC content in NT compared to CT was related with a greater decomposition rates under CT. Tillage, principally mouldboard ploughing, contributes to the mixing of new fresh residue with soil and modifies soil profile characteristics (e.g. aeration, moisture and temperature regimes) promoting soil microbial activity (Paustian *et al.*, 1998). Also, tillage continually exposes soil to wetting/drying and freeze/thaw cycles at the surface, making aggregates more susceptible to break down and to release protected SOM that becomes more available for decomposition (Paustian *et al.*, 1997). Differences in the SOC content among sites were related to differences in the quantity and quality of crop residues returned to the field every season. These differences are explained by the variability on crop biomass production due to differences among sites in annual rainfall and cropping systems. The lowest SOC content was observed in Pñ-bf where crop residues are returned every two years whereas in Sv, Ag and Pñ-cc crop residues are returned to the field every season. Other studies have shown that a reduction of the fallow period in the rotation results in an increase in the SOC content (Halvorson *et al.*, 2002).

Dry and wet aggregate distribution (DAD and WAD, respectively) presented a similar trend among sites and tillage systems. In the DAD, macroaggregates (>2000 and 250-2000 *μ*m size classes) accounted for more than 80% of the total soil and were the predominant size class in all the sites and tillage treatments (Table 2). In all the sites and cropping systems, large macroaggregates (>2000 *μ*m) were significantly greater in NT than in CT. However, for the small macroaggregates size class (250-2000 *μ*m) the opposite trend was observed with greater content in CT than in NT although no significant differences were found except for the Pñ-cc site. The microaggregate (53-250 *μ*m) content ranged from 9 to 16% of the total soil (Table 2). In all the sites and cropping systems, greater amount of microaggregates was found in CT than in NT although significant differences were only found in the Pñ site. The silt+clay fraction (<53 *μ*m) accounted for the smallest amount of soil with similar contents in all the sites and tillage treatments ranging from 1 to 2%.

Table 1. Soil organic carbon (SOC) in the soil surface (0-5 cm) under no-tillage (NT) and conventional tillage (CT) in the different sites and cropping systems

Sites and cropping systems	SOC[†] (g/m^2)	
	NT	CT
Sv	1088a	961a
Ag	920a	547b
Pñ-cc	851a	535b
Pñ-bf	675a	482b

[†] Within the same site, different letters indicate significant differences between tillage treatments (*P*<0.05).

Table 2. Dry aggregate distribution (DAD, g aggregate/g soil), wet aggregate distribution (WAD, g aggregate/g soil) and difference between DAD and WAD from the no-tillage (NT) and conventional tillage (CT) treatments in the different sites and cropping systems

Site	Class aggregate (*μ*m)	DAD[†]		WAD[†]		DAD-WAD (%)	
		NT	CT	NT	CT	NT	CT
Sv	>2000	0.41a	0.38b	0.27a	0.10b	-14	-28
	250-2000	0.46a	0.47a	0.37a	0.32a	-9	-15
	53-250	0.11a	0.14a	0.28b	0.46a	+17	+32
	<53	0.02a	0.02a	0.08b	0.12a	+6	+10
Ag	>2000	0.41a	0.34b	0.15a	0.02b	-26	-32
	250-2000	0.44a	0.48a	0.31a	0.13b	-13	-35
	53-250	0.12a	0.16a	0.40b	0.63a	+28	+47
	<53	0.02a	0.02a	0.14b	0.22a	+12	+20
Pñ-cc	>2000	0.50a	0.36b	0.17a	0.05b	-33	-31
	250-2000	0.40b	0.47a	0.25a	0.20b	-15	-27
	53-250	0.09b	0.16a	0.47b	0.65a	+38	+49
	<53	0.01a	0.02a	0.11a	0.10a	+10	+9
Pñ-bf	>2000	0.48a	0.31b	0.13a	0.10a	-35	-21
	250-2000	0.42a	0.47a	0.36a	0.19b	-6	-28
	53-250	0.09b	0.20a	0.42b	0.60a	+33	+40
	<53	0.01a	0.02a	0.09a	0.11a	+8	+9

[†] Within the same site and class aggregate, different letter indicate significant differences between tillage treatments (*P*<0.05).

Greater amount of large macroaggregates (>2000 *μ*m) in NT than in CT has been observed by other authors. For example, Mrabet *et al.* (2001) in semiarid Morocco observed a greater dry mean weigh diameter in NT as compared to CT probably caused by a greater amount of large macroaggregates.

Whereas small macroaggregates (250-2000 μm) were the predominant class in the DAD, microaggregates (53-250 μm) were the largest size class in the WAD (Table 2). Therefore, a reduction in macroaggregate content as compared with DAD was observed in both CT and NT. Slaking process occurs when dry soil aggregates are wetted quickly at atmospheric pressure causing rupture and disintegration of the aggregate (Kemper and Rosenau, 1986). This effect was especially significant in CT where in some sites nearly the 70% of the macroaggregates (>250 μm) broke down whereas in NT was less than 50%. Thus, tillage caused a decrease in macroaggregate stability as compared to NT as it was observed by other authors (Franzluebbers and Arshad, 1996).

The rupture of macroaggregates observed after WAD was accompanied by an increase in the microaggregate (53-250 μm) proportion. Likewise, Cambardella and Elliot (1993) concluded that the higher proportion of microaggregates (53-250 μm) particularly observed in CT may be explained by the breakage of macroaggregates into smaller aggregates due to the slaking process.

The lack of differences in the silt and clay size class (<53 μm) among the three tillage treatments implied that after slaking, microaggregates (53-250 μm) were not reduced to silt and clay (<53 μm) particles. Therefore, this suggests that microaggregates (53-250 μm) are more stable than macroaggregates (>250 μm) as reported by other authors (Elliot, 1986). Soil organic matter within soil aggregates increases the binding of primary-sized particles and decreasing aggregate wettability resulting in greater stability (Chenu *et al.* 2000). Therefore, differences in the SOC content among sites influenced the amount of macroaggregates broken down due to slaking. Macroaggregates of NT at Sv resulted in the lowest rupture after slaking compared with NT macroaggregates from other sites and cropping systems (Table 2). However, although the lowest SOC content was found in the CT treatment of Pñ-bf, the greatest macroaggregate rupture was found in the CT treatment of Ag. Chaney and Swift (1984) suggested that, in some cases, total SOC may not be sufficient to explain differences in aggregate stability and that certain SOM fractions may play a more important role.

Conclusions

Greater aggregate stability and SOC under NT as compared to CT has been showed in this study carried out in semiarid agroecosystems of the Ebro river Valley. Greater aggregate stability in NT implied a greater aggregate resistance to breakage and therefore a reduced SOC decomposition by soil biomass. Differences in SOC and aggregate distributions among sites were explained by differences in rainfall, crop biomass production and therefore in the amount of crop residues produced and returned to the field annually.

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