E C O M I T

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Edited by Zuzana Lehocka, Marta Klimekova and Wijnand Sukkel

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THE POTENTIAL OF NO-TILL AND RESIDUE MANAGEMENT TO SEQUESTER CARBON UNDER RAINFED MEDITERRANEAN CONDITIONS

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Abstract

Soil organic matter contents under Mediterranean climatic conditions frequently are low to very low, especially where extensive land use and thus low biomass production is predominant. Reducing tillage intensity and maintaining crop residues in the field are considered to be promising agricultural practices to counteract the decline in soil organic carbon. The objectives of this work were to study the combination of no-till and the use of different crops and amounts of residues and their management on the evolution of soil organic matter. In two trials, crops were established under no-till over 3 years using different levels of wheat straw and their management and one treatment with residues of chickpea. Initial and final soil organic matter contents were analysed. The results indicate that the higher the amount of residues returned to the field the higher the increase of soil organic matter. Maintenance of straw compared to *in situ* feeding enhances the build-up of soil organic matter. Chickpea as a low biomass producing crop with a low C/N ratio of its residues showed no positive effect in terms of soil organic matter improvement. The results suggest that the return of cereal residues instead of its removal or grazing in combination with no-till for crop establishment can contribute considerably to improve the low soil organic matter levels found in Mediterranean environments.

Introduction

Soils under Mediterranean climate are known to present low levels of organic carbon (Zdruli et al. 2004). Climatic effects inducing high mineralization rates of the organic matter, low biomass production under rainfed conditions, intensive soil tillage used for crop establishment, straw removal and grazing of the stubble and soil erosion can be pointed out as the main reasons for the soil organic carbon depletion of Mediterranean cropland. Average soil organic matter contents (SOM) in the top layer frequently are around 1%. These low soil organic carbon (SOC) contents affect crop and overall soil productivity in different ways; through a) reduced water infiltration and retention capacity, b) reduced cation exchange capacity and nutrient cycling efficiency, c) deficient soil structure and root growth. Furthermore, the frequent cycles of wetting and drying of the soil during the growing season not only favour decomposition of SOM and CO_2 emissions (Jarvis et al., 2007) but also silting and crust formation of the exposed soil layer leading to deficient gas exchange and plant emergence. In general, the extremely low SOM contents are responsible for the low resilience of Mediterranean soils to frequently occurring adverse conditions of scarce or excessive rainfall.

Thus the conditions for the build-up of SOM under the extensive rainfed Mediterranean cropping systems are very limited unless SOC mineralization rate is reduced and crop residues are left on the soil. Therefore, the aim of this work was to study both the effect of minimum soil disturbance and different type and management of crop residues on the build-up of soil organic matter under field conditions.

Materials and Methods

Site description

The experimental site is located near the town Reguengos de Monsaraz in the southeast of Portugal (38°28'N, 7°28'W) on a sandy clay loam (vertic Cambisol). The annual temperatures and precipitation averages are 16.1°C and 572mm, respectively. Table 1 shows the monthly values of temperature and precipitation both long-term and during the trial period. Before trial installation in 2004, the field had already been under not-till since 2001, and the crop rotation used was wheat-oats-fallow/sunflower. Until 2000, traditional soil tillage consisted in the use of a tine cultivator and a heavy disk harrow for primary soil tillage and a spring tine cultivator for seed bed preparation.

Table 1: Monthly mean temperature and precipitation both long term (Reguengos de Monsaraz) and during the trial period (on farm weather station).

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sum/Av
Mean temp. long-term (°C)	21,1	17,3	12,2	9,3	8,7	10,0	12,6	14,2	17,3	22,3	24,3	24,3	16,1
Precip. long-term (mm)	20,6	61,0	69,9	74,7	77,6	76,7	83,3	44,9	33,5	24,8	3,5	2,1	572,6
Mean temp. 2004/05 (°C)	22,2	17,2	11,6	8,3	6,9	7,4	12,5	14,9	18,7	24,2	24,8	25,8	16,2
Precip. 2004/05 (mm)	12,1	126,2	20,2	32,9	2,4	14,9	25,4	15,3	61,0	0,8	0,4	0,2	311,8
Mean temp. 2005/06 (°C)	21,9	17,7	10,7	8,5	6,9	8,2	11,7	14,9	19,2	22,3	25,8	25,8	16,1
Precip. 2005/06 (mm)	1,4	161,4	77,3	57,2	30,8	37,8	83,8	52,6	0,2	28,2	21,0	10,9	562,6
Mean temp. 2006/07 (°C)	22,7	18,5	14,3	8,3	7,7	10,8	11,4	13,4	17,0	20,6	24,5	23,6	16,1
Precip. 2006/07 (mm)	33,1	172,0	113,7	40,1	36,8	95,6	11,6	49,7	38,9	34,6	0,0	15,7	641,8

Treatments

The evaluation of the evolution of SOC was carried out in two field trials within a research project entitled "The potential of no-tillage for carbon sequestration on agricultural land". The first one designated as "crop and residue management trial" consisted in the following five treatments:

- "*Chickpea*" as a leguminous, low residue producing crop with a low C/N ratio; the amount of residues left was approximately 750 kg of DM ha^{-1};
- "*Grazing*" - Wheat crop with removal of straw and stubble, and distribution of manure from sheep fed on wheat straw equivalent to 3000 kg ha^{-1}, 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^{-1} 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^{-1} of wheat straw (corresponding to twice the amount of wheat straw produced).

The main objective of the second trial was to study the effect of different amounts of wheat straw (stubble, stubble plus 2500 kg ha^{-1} and stubble plus 5000 kg ha^{-1}) on the evolution of the population of earthworms ("residue trial"). However, this paper only reports on the effects of the residue levels on the changes in SOC.

The plot size of each treatment in the first trial on crop and residue management was 15x 3m, using a randomized complete block design as experimental layout. The second trial was a simple split of four strips (replications) into 3 treatments of different amounts of residues of 3x3m each. Both trials were realized with four replications. The crops were installed with a Semeato direct drill, equipped with staggered double disc openers and repeated over 3 years on the same area in order to accumulate the effect of the residues and their management.

Sampling and analysis
Before crop installation in October 2004 all plots were subject to an initial assessment of SOC. According a fixed scheme, composite samples of 14 points per plot (15x3m) were taken for the crop and residue management trial. Due to the reduced dimension of the residue trial, 12 points per replication (11x3m, with 1 m between residue levels) were considered sufficient for the initial assessment of SOC. Samples were taken using a core sampler with a diameter of 5 centimetres to a depth of 20 centimetres. This depth limit was chosen because no considerable soil disruption through soil tillage would take place and thus no relevant changes of SOC were expected below this depth. The cores were subdivided into three layers: 0-5cm, 5-10cm and 10-20cm. At the end of the project period, in November 2007, an identical sampling was performed in the case of the crop and residue management trial. In the residue trial, sampling was split up into the different residue levels using 8 points per plot of residues. Samples were air dried, grinded and then analysed in an automated combustion furnace working at 1350°C (Leco SC-144DR) using 3 replicates per sample. Bulk densities were determined for each replication of the two trials at the beginning of the project, but no significant differences between the locations were detected. Average bulk densities were 1.52 and 1.55 for the layers 0-10cm and 10-20cm, respectively.

Results and Discussion
Despite the relatively small area of implantation of the crop and residue management trial (40 x 45m), the initial sampling revealed considerable and even significant differences with regard to the levels of SOM. The spatial variability of soil properties and especially soil carbon on even small areas is well documented (Arnold and Wilding, 1991; Wilding et al., 2001). Sampling, handling and analysis were carried out with utmost care and individual values were checked for their consistency. Nonetheless, SOM levels in the monitored soil layer showed significant lower values in the straw and grazing treatments when compared to the chickpea treatment (table 2). In 2007, only the treatment with the highest amount of residues (2 x straw) revealed a significantly higher level of SOM. Regarding the changes obtained in SOM within the 3 years' trial period (table 2 and figure 1), both "straw" treatments showed a considerable increase in SOM of almost 0.2%, which was significantly different when compared to the other treatments. The chickpea crop with its low amount of fast degrading residues showed even a slight decrease in SOM. The distribution of dry sheep manure showed a higher increase in SOM than the stubble treatment, although not significantly different.

Table 2: Soil organic matter contents under two crops and different residue management systems of wheat straw in the top soil layer (0-20 cm) before and after 3 years of differentiated management.

	Crop and residue management treatments									
Sampling	Chickpea		Grazing		Stubble		Straw		2 x Straw	
2007	1.294	b	1.301	b	1.283	b	1.319	b	1.482	a
2004	1.318	a	1.221	bc	1.251	ab	1.140	c	1.285	ab
Diff. 2007-2004	-0.024	c	0.080	b	0.033	bc	0.179	a	0.196	a

Values followed by the same letter or letters are not significantly different at a 5 % level (Duncan Multiple Range Test)

Regarding the distribution in depth, all treatments showed an increase in SOM in the upper soil layer (0-5cm), which was highest in the two "straw" treatments, reaching an increase of around 0.35%. Astonishingly, the layer between 5 and 10 cm behaved worst with regard to the relative changes in SOM. In all five treatments the lower soil layer (10-20 cm) showed higher increases or lower decreases (chickpea), than the layer above. This result is hard to explain as sampling procedures were identical for both periods. Some authors refer to the changes of porosity and bulk density able to account for differences in the stratification of SOM over time (Kay and VandenBygaart, 2002), others refer to a lack of resolution regarding the changes of soil properties with depths Logsdon et al., 1999).

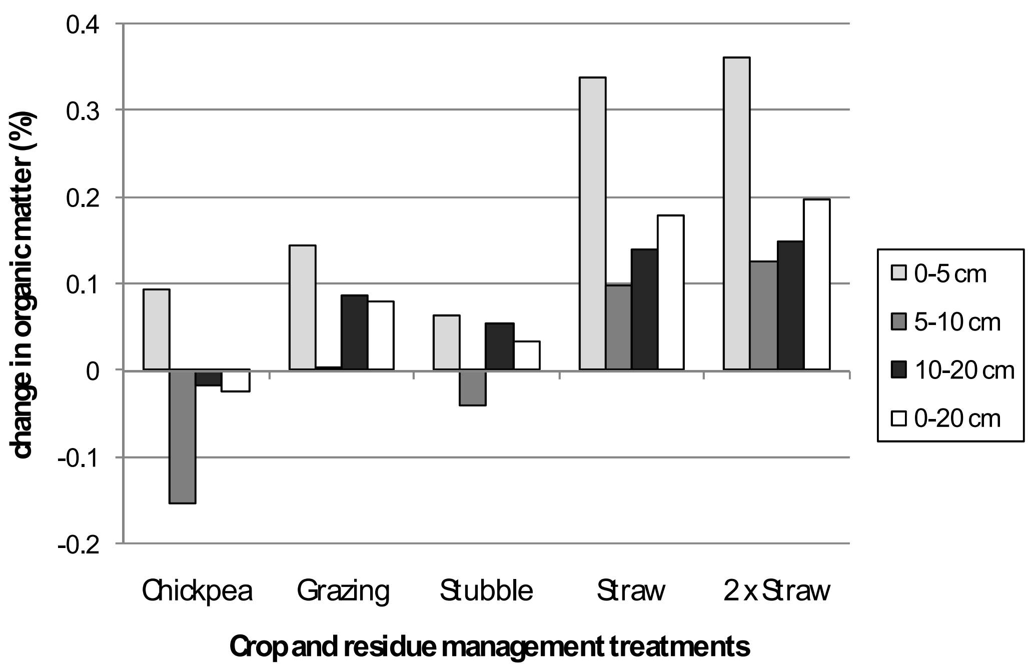

Figure 1: Relative changes in soil organic matter with depth under two crops and different residue management systems of wheat straw after 3 years.

However, the same phenomenon of a decrease of SOM between sampling periods in the 5-10 cm layer occurred in the residue trial, and the overall change of the SOM levels in the monitored soil layer was very similar to the one obtained in the crop and residue management trial (figure 2). Straw removal and the maintenance of stubble slightly increased the SOM content in the 20 cm top layer, whereas straw return and additional amounts of straw, which could occur under improved soil fertility conditions or irrigation, increased SOM up to 0.2% in the topsoil layer within a period of 3 years.

Both trials reveal the potential of the combination of no-till as non soil disruptive form of crop establishment and the return or maintenance of slowly degradable crop residues such as wheat straw for the increase of SOM on the highly organic carbon depleted Mediterranean soils. These findings are in accordance with results published by other authors (Dick et al., 1998; Clapp et al., 2000; Layese et al., 2002; West and Post, 2002) that report an increase of carbon incorporated into SOM when changing from intensive tillage to no-till, but only if harvestable carbon residues like straw or cornstalks were left in the field. However, contradictory results can be found in the review performed by Wilhelm et al. (2004), indicating that residue return may lead or not to an accumulation of SOM. Sanchéz et al. (2002), measuring the CO_2 flux from conventional and reduced tilled fields, found a reduction of 6660 kg CO_2 ha^{-1} $year^{-1}$ under reduced tillage. This amount of carbon dioxide corresponds to around 3000 kg SOM ha^{-1}, which is approximately the yearly SOM increase found in the most favourable treatments in the trials, assuming a bulk density of 1.5.

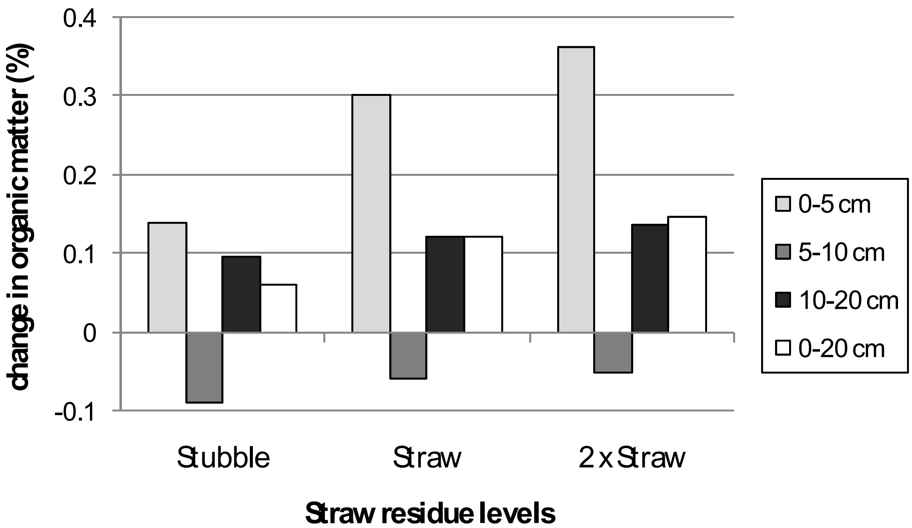

Figure 2: Relative changes in soil organic matter with depth under three levels of wheat straw residues after 3 years.

The evaluation of the total amount of SOC sequestered after only three years of differentiated treatments is certainly questionable. Nonetheless, the differences between crop type and residue levels and their management are considerable and give evidence of the potential contribution of the combined effect of no till and crop residue return to the build-up of SOM even under conditions of relatively low biomass production of Mediterranean rainfed agriculture. They also confirm that high C/N ratios of the residues are essential for the incorporation of crop carbon into SOM.

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