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LONG TERM EFFECT OF TILLAGE SYSTEM AND CROP RESIDUE MANAGEMENT ON SOIL CARBON CONTENT OF A LUVISOL UNDER RAINFED MEDITERRANEAN CONDITIONS

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Abstract

Under Mediterranean conditions, soils under conventional tillage farming usually have very low contents of organic matter. This situation is due to intensive soil tillage, low biomass production under rainfed conditions, and removal of cereal straw for alternative use off the field. In order to study strategies to improve soil organic matter content (SOM), a long term experiment (11 years) was established in 1995 to evaluate the effect of four different tillage systems (conventional tillage (CT) based on moldboard plough (25 cm) + disc harrow with removal of cereal straw; reduced tillage (RT) based on non-inversion tine cultivation with removal of cereal straw; no-till (NT) with removal of cereal straw; and no-till with cereal straw retained (NT+S). The crop rotation was lupine – wheat – forage oat – barley. Soil organic carbon (SOC) (0-30 cm) and crop yields (grain and straw) were measured every year. In addition, yield response of the wheat crop to nitrogen fertilization was studied, in order to evaluate the interactions with SOC accumulation.

Under CT and RT, SOC remained almost unchanged over the experimental period. NT improved SOC by 18% in relation to CT and NT+S increased SOC by 62%. There were no significant differences between CT and NT in the amount of residues left in the field over the experimental period, but NT+S significantly increased the amount of residues retained in relation to the other treatments. The results indicate that NT reduced SOM mineralization, but that maximum increase of SOC can only be achieved if crop residues are retained on the field. Nitrogen use efficiency was significantly improved with greater SOC contents, i.e. from 19.1 kg of wheat per kg of applied N at 0.58% SOC to 104 kg of wheat per kg of applied N at 1.74% SOC.

Keywords: Soil tillage, Residue management, soil organic matter, Nitrogen use efficiency

Introduction

Under Mediterranean conditions, soils under conventional tillage farming usually have very low contents of organic matter. This situation is due to intensive soil tillage, low biomass production under rainfed conditions, and removal of cereal straw for alternative use off the field.

The effect of no-till (NT) on the soil organic carbon (SOC) seems to be depended on the conditions and results can be found in the literature that can vary from an absence of effect when the whole soil profile is considered (1) or an increase over the depth of tillage (2), or even below the depth of tillage (3). In general, the positive effect of NT on SOC is referred by authors working in regions, like the Mediterranean, were the organic content of the soil under the conventional tillage system (CT) is low (usually below 7 g C/kg of soil), whereas the absence of effect is referred from authors developing the work in wetter and cooler regions, where values of SOC under the traditional tillage systems are higher (usually above 1.2 g C/kg of soil). The positive results of NT on SOC are usually attributed to a reduction of the mineralization rate (4). There are also same authors referring that the beneficial effect of no-till will depend on the amount of the crop residues produced by the crop rotation (5; 6; 7). However, it is generally recognise the beneficial effects of NT and superficial placement of crop residues in controlling soil erosion (8). Naturally the importance of this aspect is depending on the soil and climatic conditions, but CT can present soil losses more than 75 times higher than NT systems (9). Under such circumstances and on a long term, nutrient losses from the soil can be very high, being aggravated by the enrichment of the soil sediments on constituents like clay, organic matter, phosphorus or potassium (10). Therefore, whenever prevention of soil erosion is an important benefit of NT it will be expected a significant benefit in terms of SOC increase.

The effect of nitrogen fertilization on SOC is well documented with the results varying with conditions. Although nitrogen is increasing the amount of residues produced, there are some authors referring an absence of its effect on SOC (11), and others finding a positive effect (12; 13). Naturally the crop residues management will influence the result, and (14) are reporting that nitrogen fertilization is only increasing SOC when crop residues were retained. However the information of long term effects of tillage and crop residues management on the crop response to nitrogen fertilization is missing.
The objectives of this paper are to analyse long term effects of tillage systems and crop residue management on SOC under Mediterranean conditions and its effect on wheat response to nitrogen.

Material and Methods

The experiment was carried out at Revilheira Experimental farm in Alentejo region of Portugal (38°28´N 7°28´W). The climate of the region is Mediterranean, with a long term annual precipitation of 572 mm, and annual average temperature of 15.6 °C. The soil under study is a Luvisol with 31.1% and 46.8% clay in A and B horizons, pH in water (1:2) of 6.0 and 8.1 g of C, 6.1 mg of P and 57.2 mg of K per kg of soil in the 0-30 cm soil depth.
In order to study strategies to improve SOC, a long term experiment (11 years) was established in 1995 to evaluate the effect of four different tillage systems (conventional tillage (CT) based on moldboard plough (25 cm) + disc harrow with removal of cereal straw; reduced tillage (RT) based on non-inversion tine cultivation with removal of cereal straw; no-till (NT) with removal of cereal straw; and no-till with cereal straw retained (NT+S). The experimental design was a randomized block with three replicas. The size of the each plot was 405 m^2 (6x75 m), and all the elements of the crop rotation were present every year. The crop rotation was lupine – wheat – forage oat – barley. Crop yields were measured every year. Harvest index was measured from plants collected in three samples per plot (1 linear meter each sample) and total biomass per plot was calculated from grain yield of the plot and harvest index from the samples. Soil organic carbon (SOC) (0-30 cm) was measured by dry combustion according ISO 10694, and the carbon content calculated from the total carbon minus the quantity of this element which is present in the form of carbonate.
In order to investigate the effect of SOC developed under different tillage and crop residues management on the crop response to nitrogen, fertilizer trials were carried out between 2000/2001 and 2003/2004, within the tillage plots. These experiments were conducted on two areas with a different soil organic matter content. These levels were the result of the tillage system (conventional and direct drilling) and of the crop residues management (straw bailed or retained). The crop tested was wheat and the nitrogen levels used were 0, 6, 12 and 18 g N.m^{-2}. The nitrogen was applied as ammonium nitrate, at a rate of 2 g N.m-2 at seeding time (except on zero treatment) and the rest was split on two top dressings (one at tillering and the second at begging of shooting). The smallest SOC content was 6.0 g C.kg^{-1} of soil (site under conventional tillage and straw bailed) and the greatest was 1.2 g C.kg^{-1} of soil (direct drilling and residues of crops kept on the soil surface), both in the 0-30 cm soil depth. Multivariable regression analysis was carried out using Microsoft Excel program. The model presented is the one that most closely fitted the full data set

Results and Discussion

The annualized above ground production for each one of the tillage treatments were very similar on the duration of the experiment (Fig. 1). Therefore the estimated amount of crop residues left on the ground surface where also similar for all the treatments where the straw was bailed (1 ton.ha^{-1}.year^{-1}), but the amount of crop residues retained in NT+S was much higher (almost 3.5 ton.ha^{-1}.year^{-1}) (Fig. 2).
The soil organic carbon for the first 30 cm of the soil remained almost constant for the eleven years of the experiment in CT (Fig. 3). However there was a significant increase of SOC on the treatments RT and NT. Considering that the amount of above ground residues retained on the soil for these three treatments, it seems that the mineralization rate of the soil organic matter (SOM) was reduced on the RT and especially on NT tillage treatments relative to CT, which is in accordance with others authors (4). Unfortunately there was no evaluation of the effect of the different tillage treatments on soil erosion, and therefore it is not possible to discriminate between the loss of SOC by the two mechanisms (mineralization and erosion). This increase of SOC under NT in comparison with CT has been reported for several authors working

under Mediterranean conditions (2) and is in line with the generally reported tendency of a positive effect of NT on SOC, whenever the organic content of the soil under the conventional tillage system is low. When the residues of the grain crops were retained (NT+S) SOC doubled in the eleven years of the study, confirming that the effect of NT on SOC will depend on the amount of crop residues produced and kept on the soil surface (6; 7; 12).

There was a highly significant interaction between SOC and wheat response to nitrogen (Fig. 4). The equation relating wheat grain yield (Y – kg/ha) the nitrogen applied (kg N/ha) and the soil carbon content for the top 30 cm (C -%) was:

$Y = 2105 + 35.4 N - 0.06 N^2 + 2718 \ln(C) - 14.9 N C$

($r=0.789$ $p<0.001$)

Considering the prices of wheat and nitrogen, the economical application of nitrogen fertilizer will be offset at a rate of 4 kg of wheat per kg of N applied. Using this ratio on the equation the most economical N fertilization would have been 160, 98 and 37 kg N/ha for a SOC content of 0.58, 1.16 and 1.74% respectively, and the resulting wheat yields would have been 3063, 3587 and 3862 kg/ha. These means an improvement of the efficiency of applied nitrogen, from 19.1 kg to 104 kg of wheat per kg of N of applied N, when the SOC increases from 0.58 to 1.74% in the top 30 cm of the soil. Under Mediterranean conditions nitrogen must be applied during the winter, because important stages of the wheat development, like tillering and spikelet differentiation occur during this period. Having in mind the excess of rain over evapotranspiration during the Mediterranean winter high losses of nitrogen, both by leaching and by volatilization can take place. As the soil organic matter increases, the ability of the soil to provide N to the crop increases, and there is a much less need to apply nitrogen during the winter.

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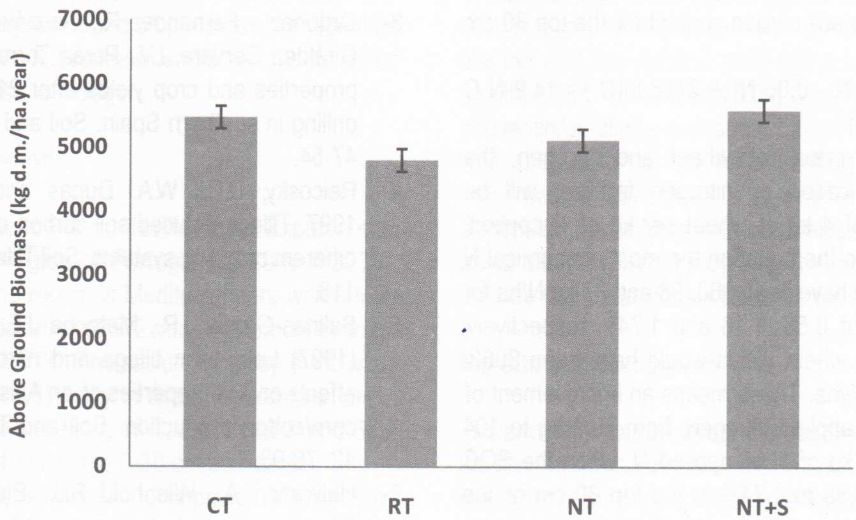

Figure 1: Annualized above ground production of the different tillage treatments over the experimental period (CT – Conventional Tillage; RT – Reduced Tillage; NT – No-Till; NT+S – No-Till plus straw retained).

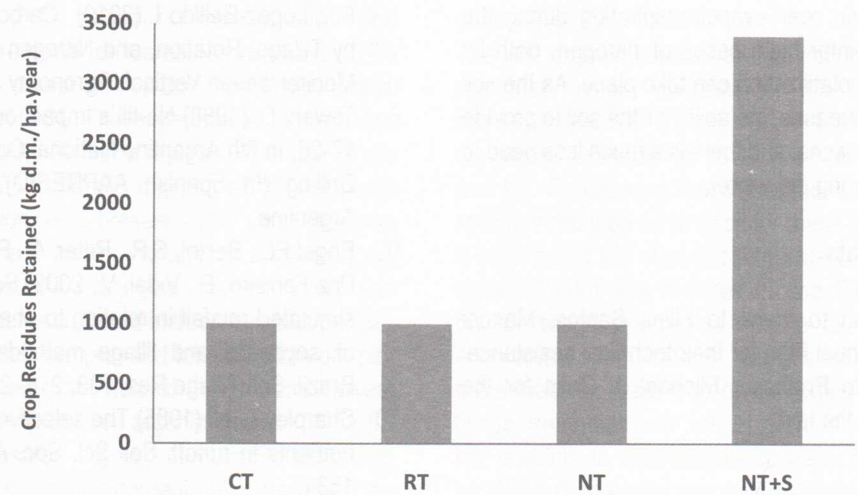

Figure 2: Annualized crop residues retained in the field for the different tillage treatments over the experimental period (CT – Conventional Tillage; RT – Reduced Tillage; NT – No-Till; NT+S – No-Till plus straw retained).

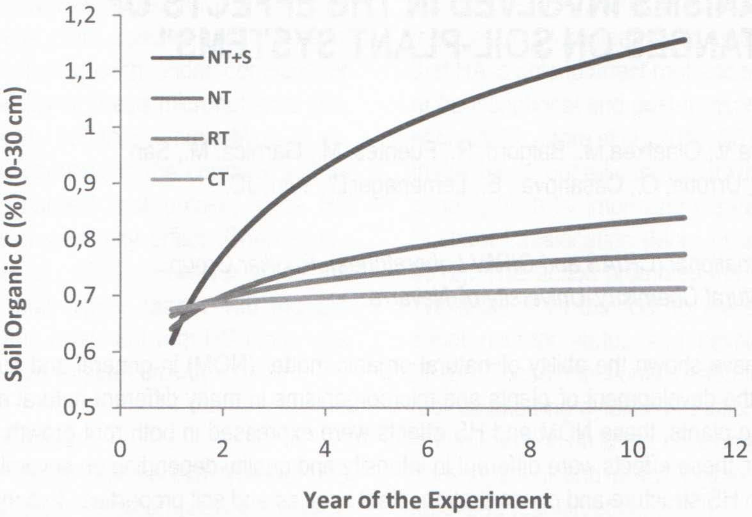

Figure 3: Evolution of soil organic carbon under different tillage systems over the experimental period (CT – Conventional Tillage Y = 0.67 + 0.02 ln(X) (r=0.17 n.s.); RT – Reduced Tillage Y = 0.66 + 0.05 ln(X) (r=0.598 p<0.05); NT – No-Till Y = 0.64 + 0.08 ln(X) (r=0.866 p<0.01); NT+S – No-Till plus straw retained Y = 0.62 + 0.22 ln(X) (r=0.941 p<0.001)).

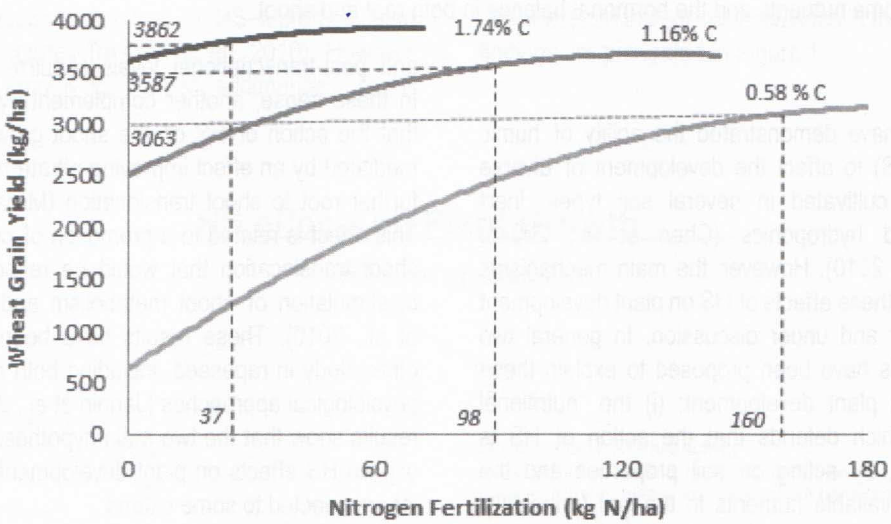

Figure 4: Effect of soil organic carbon (SOC) (0-30 cm depth) on the wheat response to nitrogen fertilization. The values of nitrogen level in italic (160, 98 and 37) are relative to the most economical N level for each one of the SOC values considered. The values of the wheat grain yield in italic (3063, 3587 and 3862) are relative to the respective predictable yield.