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## CASE STUDY 5: THE ROLE OF NO-TILL AND CROP RESIDUES ON SUSTAINABLE ARABLE CROPS PRODUCTION IN SOUTHERN PORTUGAL

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**ABSTRACT**

The Mediterranean conditions prevailing in Portugal are imposing several constrains to sustainable arable farming production. In this presentation it is discussed the role of conservation agriculture, namely no-till and crop residues management, as means to overcome some of the main problems using field experiments carried out in the Southern regions of Portugal.

Long term field experiments are showing that conservation agriculture can control soil erosion and improve several soil properties like organic carbon, aggregates stability, continuous biological porosity and saturated hydraulic conductivity. As a consequence crop yields can be significantly increased and, at the same time, the amount of fertilizers can be reduced. Another important benefit is the better soil bearing capacity, that together with the drainage, improves soil trafficability under no-till. This allows a timely application of herbicides and fertilizers which offers the opportunity for further improvements of the efficient use of expensive production factors. The combine effect of all this benefits greatly enhances the sustainability of the arable cropping systems under Mediterranean conditions.

**Keywords:** no-till; residues management; soil proprieties, sustainable production.

**1. INTRODUCTION**

Under Mediterranean conditions the concentration of rainfall that prevails over winter results in waterlogging, erosion and the impairment of timeliness of field operations, while the scarcity of precipitation during the spring leads to water stress in crops. The general characteristics of Portuguese soils serve to aggravate the problems for crop production. Soil fertility is inherently poor (about 70% of the soils have an organic matter content that is less than 1% and only 4% have a cation exchange capacity that exceeds 20 meq/100 g of soil) and water infiltration and internal drainage are negatively affected by the instability of soil structure and the marked changes in clay content that occurs between soil horizons. Both climatic and soil constraints limit yield potential and the efficient use of the resources, such as fertilizer particularly nitrogen, whilst imposing agronomic limitations by preventing the correct timing of operations, which cannot be overcome by increasing labour input because of the need of farms to stay economically competitive. Any meaningful amelioration of the situation can only be achieved by a significant improvement in soil fertility and in soil-water relationships, which can only be acquired through increases in soil organic matter (Carvalho, 2006, Douglas et al., 1986).

The effect of no-till (NT) on soil organic carbon (SOC) seems to depend on the prevailing conditions of climate, soil and crop, with results in the literature varying from the absence of effect when the whole soil profile is considered (Dolan et al., 2006) to an increase over the depth of tillage (Martin-Rueda et al., 2007), and even to enhanced levels below the depth of tillage (Ordõnez-Fernandez et al., 2007). The positive impacts of NT on SOC have often been attributed to a reduction in the rate of organic matter mineralization in the absence of soil disturbance (Recolsky, 1997). There are also authors who state that the beneficial effects of no-till depend on the amount of the crop residues produced over the course of the crop rotation (Salinas-Garcia et al 2001; Halvorson et al 2002; Lopez-Bellido et al., 2010). However, it is generally recognized that beneficial effects of NT are derived from maintaining crop residues on the soil surface and the associated control of soil erosion (Towery, 1998). The relative importance of this aspect depends on the soil and on climatic conditions, but conventional tillage can result in soil loss through erosion that is more than 75 times greater than that from no till systems (Engel et al., 2009). Under such circumstances and over the long term, nutrient losses from the soil can be very large, being aggravated by the enrichment of organic matter, phosphorus and potassium on constituents of the soil sediments such as clay, (Sharpley 198,5). Consequently, whenever prevention of soil erosion is an important benefit derived from the adoption of no-till a significant increase in SOC would be expected.

No-till can also affect soil water relationships. Under no-till, especially when an adequate amount of residues is left in the soil surface, there can be a reduction in water lost by runoff (Lal & Van Doren Jr., 1990) and a concomitant increase in infiltration. The residues on the soil surface will also reduce evaporation of water from the soil surface, and both increased infiltration and greater conservation will tend to increase soil water content, especially under Mediterranean conditions (Morell et al., 2011). Therefore, waterlogging can be accentuated during the initial year of no-till, under soils with a small saturated hydraulic conductivity or a perched water table. However, structural stability and the number of vertical continuous biopores also increase under no-till, which contribute to an increase in the saturated hydraulic conductivity over time (Ehlers & Claupein, 1994). Under these circumstances trafficability would be expected to improve (Gruber & Tebrugge, 1990) and allow more timely field operations, a very important agronomic benefit under Mediterranean conditions.

The aim of this paper is to discuss the role of no-till and crop residues as means of overcoming some of the main constrains to arable crop production in Portugal.

**2. MATERIAL AND METHODS**

Runoff and erosion studies (Fig. 1) were evaluated over two seasons, using runoff frames. The conventional tillage system (CT) consisted of a pass with a plough in the summer and then disk harrowing before seeding the wheat crop. No till (NT) was performed with a triple disc no till seeder, with weed control being achieved with a pre-seeding application of Paraquat. The slope of the land was uniform within each replicate of the treatments and varied between 6 to 8% between blocks. A detailed description of the experiment can be found in Basch et al. (1990).

Fig. 1: Effect of the tillage system on runoff and soil losses by erosion during a wheat crop in the south of Portugal. Values are verage of two years. NT – No Till; CT – Conventional Tillage (based on Basch et al., 1990).

Data collection on the Vertic Cambic soil (50% clay) took place 6 years after the tillage systems were put in place (1984/85 – 1989/90). The crop rotation was sunflower – wheat – barley. The tillage systems studied were no till (NT) for all crops of the rotation, and the conventional tillage system of the region, which is: summer plough (30 cm) + disk harrow (at least 2 passes) for the sunflower; tine sacrifier + disk harrow for wheat and barley. The experiment is described in Carvalho & Basch (1995).

Measurements on the Luvisol (31.1% and 46.8% clay in A and B horizons) were taken as part of a long term experiment comparing tillage system (1995/96 to 2007/08). The crop rotation was lupines – wheat – oat for forage – barley. The conventional tillage system consisted in one plough (25 cm) and disk harrows before seeding, and the straw of cereals was bailed. For the NT treatments weeds were controlled before seeding with glyphosate and crops were direct drilled. In one treatment the straw of cereals was kept on the soil surface (NTS), while for another treatment the straw of the cereals was bailed (NT).

**3. RESULTS AND DISCUSSION**

Under Mediterranean conditions the concentration of rainfall during late fall and winter, when soil cover by the crop is minimal, creates the opportunity for soil erosion under conventional tillage systems but no till can be very effective in reducing runoff and the consequent soil loss by erosion (Fig. 1). A reduction in erosion under no till was due to both a reduction in runoff and in the amount of soil sediment transported per unit of water volume (2.7 and 7.0 g of soil per litre of runoff water in NT and CT respectively), although the data was collected in the first year of imposing the treatments.

The results available in the south of Portugal indicate an increase of soil organic matter (SOM) under NT (Figs. 2 and 3), but the effect seems to be dependent on the soil and the amount of crop residues left on the soil surface. On the Vertic clay soil (Fig. 2), NT increased SOM over the depth of tillage, after 6 years under the same crop residue management. However, on the Luvisol, the effect of NT under the same residue management programme was much smaller and took longer in comparison to CT (Fig. 3). On this soil, NT could only improve SOM significantly when the straw of the grain crops was left on the field. The difference between the two soils could be explained by a greater effect of CT on the mineralization rate and the larger soil loss by erosion on the Vertic clay soil compared to effects on those values in the Luvisol.

Fig. 2: Effect after six years of different tillage system on soil organic matter over the depth of tillage, on a Vertic Cambic Soil in the south of Portugal. NT-No till; CT-Conventional Tillage (based on Carvalho & Basch, 1995).

Fig. 3: Effect of tillage system and crop residues management on the soil organic matter content (0-30 cm) on a Luvisol in the south of Portugal. CT – Conventional Tillage and  
straw bailed; NT – No Till and straw bailed; NT+S – No Till and straw kept on the field (unpublished data).

With time NT improved structure stability (Figs. 4 and 5) and further improvements in water infiltration (Lal & Van Doren Jr., 1990) and soil conservation would be expected. The improvement of structural stability under NT is more evident on the aggregates bigger than 0.5 mm. The effect of NT on improving structural stability appears to be more rapid than the effect on SOM (Figs. 3 and 5), suggesting that it is probably due to the enmeshment of soil aggregates by the fine roots of plants and the mycelium of associated fungi.

Fig. 4: Effect after six years of tillage system on aggregates stability (0-10 cm) on a Vertic Cambic Soil, S Portugal. NT – No till; CT – Conventional tillage.  
Δ MWD means change in average weight diameter of aggregates after wet sieving compared to dry sieving, and therefore higher values are found in CT.

Fig. 5: Effect after three years of tillage systems on aggregate stability (0-10 cm) on a Luvisol in S Portugal. CT – Conventional tillage; SD – No Til.  
The aggregate stability was evaluated by the final weight (as a percentage of initial weight) of the different classes of aggregates, after wet sieving, and therefore higher values correspond to a higher wet aggregate stability (unpublished data).

The development of a continuous network of biological porosity by NT due to the growth of roots and the burrowing of soil meso and macro fauna, such as earthworms, is well known (Goss et al., 1984), but under Mediterranean conditions the process of structure development can be quite rapid because of the rapid drying of the soil during the spring and summer. This drying can help to create vertical cracks that can be used by plant roots (weeds and crops) at the beginning of the next rain season (Fig. 6). This type of porosity together with enhanced aggregate stability are very effective in improving hydraulic conductivity, which is very important under the wet winter of Mediterranean climate (Fig. 7).



Fig. 6: Effect after six years of tillage system on biological porosity on a Vertic Cambic Soil in S Portugal. NT – No till; CT – Conventional tillag (based on Carvalho & Basch, 1995).

Fig. 7: Effect after six years of tillage system on saturated hydraulic conductivity on a Vertic Cambic Soil in the south of Portugal. NT – No till; CT – Conventional tillage (based on Carvalho & Basch, 1995).

The development of soil properties under NT as described above has important implications for arable crop production under Mediterranean conditions. The improved infiltration of water reduces the loss from runoff during the winter, which is particularly important during dry years, while the enhanced saturated hydraulic conductivity helps to alleviate waterlogging problems during wet winters. The better drainage associated with a higher soil cohesion under NT improves the trafficability of the soil, allowing a correct time for field operations, critical in the face of the variability of Mediterranean climate. The increase of SOM helps improve soil fertility. Consequently, an improvement in crops productivity should be expected together with an increase in the efficient use of soil resource, such as nitrogen.

Grain yield of wheat under NT, relative to CT, with and without the bailing of the straw, increased over time, and the average yield for the last four years of the experiment was 200 and 750 kg ha-1 greater under the two NT treatments (Fig. 8). These differences were consistent with the increments of SOM in soil under the two NT treatments (Fig. 3). The improvement of SOM was also related with an increase of the applied nitrogen use efficiency (NUE) (Fig. 9). According to the equation presented in Fig. 9, for 1% of SOM the most economical N fertilization (according current prices 4 kg of wheat per one kg of applied N) will be 160 kg N/ha and the yield obtained 3063 kg ha-1 (19.1 kg of grain per kg of applied N), which is a typical value for the region. However, for 2% of SOM the same variables will be 98 kg N/ha and 3587 kg ha-1 (36.6 kg of grain per kg of N). The explanation for this sharp effect of SOM on NUE can be the leaching losses of nitrogen during the winter. Under Mediterranean conditions critical crop development stages, such as tillering and spikelets differentiation take place during the winter, and any nitrogen deficiency will affect crop performance. Therefore nitrogen has to be available during the winter, and if the soil is poor in organic nitrogen, more mineral nitrogen must be applied as fertiliser.

Fig. 8: Effect of tillage system and crop residues management on the wheat grain yield (average of four years from 2005/06 to 2008/09) when the treatments were already in place from 1995/96, on a Luvisol in S Portugal. CT – Conventional Tillage and straw bailed; NT – No Till and straw bailed; NT+S – No Till and straw kept on the field (unpublished data).

Soil with 2% OM

Soil with 1% OM

Fig. 9: Effect of soil organic matter content (OM, 0-30 cm soil depth) on the response of wheat to nitrogen applied (N, kg/ha) on a Luvisol in S Portugal.  
Grey line for 1% OM and blak line for 2% OM, the different OM being developed under different treatments: Conventional Tillage and straw bailed; No Till and straw kept  
on the field, respectively (based on Carvalho, 2006)

The decrease of wheat yields during wet winters, which commonly occurs under conventional tillage systems, is due not only to waterlogging but also to the enforced delay in applying nitrogen top dressing and post-emergence herbicide. The pressure from weeds and the need for nitrogen increase with the amount of winter rainfall but often application has to be delayed until the beginning of March when the winter is wet, which is too late to benefit the crop. For nitrogen, the importance of an application in January (first top dressing at tillering for wheat) depends on the amount of rainfall from seeding to full tillering of the crop. If this period is dry, a later application of nitrogen (beginning of stem elongation – end of February/early March) is enough to achieved maximum yields. However, if the period is wet, an application of nitrogen in January is indispensable and cannot be fully offset by a later fertiliser application, even of 120 kg N/ha (Fig. 10). The negative consequences of a delay of post-emergence herbicide, either in terms of the dose of herbicide eventually required and the yield benefit to the crop, are also clear under Mediterranean conditions (Fig. 11). The better trafficability of the soil under NT is therefore key to maintaining cereal yields in wet years, by allowing applications of nitrogen and herbicides at the correct time. Experience in southern Portugal shows that, by adopting NT and using the correct equipment (light tractors and low pressure tyres) it is possible to apply fertilizer or herbicides without greatly damaging soil structure, irrespective of the amount of rainfall. Even if these benefits are nullified experimentally by hand application of nitrogen and herbicides to CT plots, the long-term commitment to NT and the maintenance of straw in the field have improved the economic benefits relative to CT (Fig.12). The improvement in the net margin of wheat production under NT is due to a reduction in costs associated with tillage (energy and labour) and nitrogen application, and the increase in SOM (Fig. 9) and its associated improvement in yields (Fig. 8).

Fig. 10: Crop yield increase (kg/ha) due to an extra nitrogen application at tillering stage (60 kg N/ha, on 20th January as first top dressing) when 120 kg N/h were applied at the beginning of the shooting ( 28th of February as second top dressing), as affected by the amount of rainfall from 1rst November to 20th January (Carvalho *et al.,* 2005).

Fig. 11: Interactions between the spraying time, the herbicide level and the wheat yield on a Luvisol in S Portugal.  
The herbicide tested was Dopler Plus ® (250g/l of diclofope-metil + 20g/l of fenoxaprope-p-etil + 40 g/l of mefenepir-dietil) (based on Barros et al., 2008).

Fig. 12: Effect of tillage system and crop residues management on the wheat net margin on a Luvisol in S Portugal. CT-Conventional Tillage and straw bailed; NT-No Till and straw bailed; NT+S- No Till and straw kept on the field (based on Marques, 2009).

**4. CONCLUSIONS**

Over the long term, NT is improving the sustainability of arable crop production under the conditions prevailing in the South of Portugal. A reduction of soil erosion and its associated improvement in the SOM content, particularly if the straw of grain crops is kept on the soil surface, has improved soil fertility, crop yields, nutrient use efficiency and annual net margin of the wheat crop. NT has also improved water infiltration, drainage and the trafficability of the soil. These are important benefits to stabilize yields over time under Mediterranean conditions. A reduction of runoff is important to increase soil water storage in dry years, while an improvement in the timeliness of field operations associated with better internal drainage is crucial for improving crop yields during wet winters.

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