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REVIEW ARTICLE

Conservation Agriculture – A Portuguese Case Study

M. Carvalho & E. Lourenço

Instituto de Ciências Agrárias e Ambientais Mediterrânicas (ICAAM), Universidade de Évora, Évora, Portugal

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Correspondence
M. Carvalho
Instituto de Ciências Agrárias e Ambientais Mediterrânicas (ICAAM)
Universidade de Évora
Apartado 94
7002-554 Évora, Portugal
Tel.: +351 266 760885
Fax: +351 266 760847
Email: mjc@uevora.pt

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Abstract

This paper gives a glance about the conservation agriculture concept and the worldwide increase in agricultural area where this technique has been adopted. The main constraints to agricultural production in the Mediterranean region are discussed, highlighting the importance of conservation agriculture to mitigate them. Results of long-term studies with this technique, in Portugal, showed an increase in organic matter, improvement of aggregates stability and continuity of biological porosity along the soil profile. These changes in soil properties are helping to overcome edaphic and climatic constrains under Mediterranean conditions. The saturated hydraulic conductivity is improved allowing a better drainage during wet winters, and together with higher soil cohesion, the transitability of the soil is enhanced, allowing a correct timing of field operations like nitrogen top dressing and herbicide application. Nitrogen-use efficiency is improved either by the timing of application and by the improvement of soil organic matter content. Soil productivity is also enhanced and the overall energy-use efficiency is double when soil organic matter content is raised from 1 to 2 % in the top 30 cm of the soil. Therefore, conservation agriculture is advantageous from the economic and environmental point of view contributing to the sustainability of rainfed agriculture.

The Concept of Conservation Agriculture

The focus of conservation agriculture is on the improvement of soil characteristics in order to get high and sustainable crop yields lowering the production costs while, at the same time, contributing for the conservation of natural resources (soil, water and air) and environmental protection. In order to meet these challenges, some principles should be taken into account when using the soils for agroforestry production (Dumanski et al. 2006).

The concept of conservation agriculture includes various components: (i) using a seedbed preparation with minimal soil disturbance, (ii) maintaining crop residues covering the soil in order to save water and regulate temperature regime, (iii) incorporating a cover crop in the rotation cycle and (iv) using integrated fertilization and pest managements strategies in order to maximize yields and securing soil fertility (Lal 2010). Other authors consider in addition to minimizing soil disturbance by mechanical tillage, and maintaining year-round organic matter cover on the soil (i) and (ii) as mentioned above, also diversification of crop rotations, mainly with nitrogen-fixing legumes in order to maintain biodiversity, increases soil nitrogen, and to avoid pest and disease incidences (Kassam et al. 2010). However, the use of cover crops is not possible in many regions of the world, particularly if water is the limiting factor.

The practice of zero-tillage (also referred as null-tillage, no-tillage or direct drilling) decreases the mineralization of organic matter and contributes to the sequestration of organic carbon in the soil. Higher amounts of organic matter in the soil improve soil structure and root growth, water infiltration and retention, and cation-exchange capacity. In addition, zero-tillage reduces soil compaction and crop production costs. Crop residue mulch or cover crops are important to reduce soil erosion and to improve soil moisture and temperature regimes.

The benefits the farmer can get by practising conservation agriculture are several. First of all, the soil potential increases due to the improvement of the physical, chemical, biological and hydrological characteristics, which means more water and nutrients available for the crops. These benefits are mainly due to the build-up of organic matter content in the soil and due to the reduction of soil erosion.

The residues on the surface of the soil reduce the impact of rain drops leading to greater water infiltration.

There are also benefits with respect to climate change by reduction of CO_2 emissions due to the decrease in number of farm machinery operations, and by increasing soil carbon sequestration (Fuentes et al. 2012). In a changing world where food security is an important issue, conservation agriculture enhances and sustains agricultural production while improving the environment. Higher sustainable yields with reduction of production costs, mainly in energy and fertilizers, lead to economic and social benefits, allowing farm families to have the opportunity to improve their livelihoods.

Even though there are the unquestionable advantages of conservation agriculture, there is some farmer′s resistance to the technique. The main difficulties are concerned with the availability and cost of zero-tillage equipment. Moreover, at least at the beginning of its implementation, conservation agriculture relies more on the use of herbicides than traditional farming, with farmers worrying about a possible contamination of water by herbicides. The need will decrease over time, due to weed emergence prevention by crop residues. On the other hand, higher microbiological activity and organic matter in the soils might reduce leaching of different deleterious compounds to the environment and contribute to less pesticide utilization. Breakdown of diseases and pest cycles due to the use of crop rotations will also take place. Another constraint to conservation agriculture implementation is concerned with the need to convince farmers about the benefits of the technology which can be facilitated by initial government's support.

With respect to small farmers, besides the need of no-till implements, there are also difficulties related to seed stocks, availability of production factors, such as fertilizers, and technical assistance. Derpsch (2007) pointed out the lack of knowledge as being, most likely, one of the main constraints for the spreading of the technology in the world.

Conservation Agriculture in the World

The area where conservation agriculture is practised worldwide is estimated to be about 117 million ha. The area has increased from 2.8 million ha in 1973, mainly in South America (Argentina, Brazil, Paraguay and Uruguay), where the system is used on about 70 % of the cultivated area (Kassam et al. 2010). Worldwide, the same region accounts for about 48 % of the cultivated area. Other countries that use this technology in a large scale are the United States of America and Canada representing about 34 % of conservation agriculture area worldwide, and Australia and New Zealand with 15 %. Nevertheless, the total area in the world is still very small (about 8 %) as compared to the area under conventional farming.

The regions in the world with least expansion of conservation agriculture are Africa, Europe and Asia. In these continents, there is lack of agricultural development programmes to demonstrate the benefits. Also, suitable policies and institutional support have been missing. In developing countries, low adoption of conservation agriculture is attributed to poverty, imperfect capital markets and insecure land tenure, which discourage the adoption of sustainable soil management strategies (Barbier 1997).

In North Africa, several countries have been conducting research on conservation agriculture with good results. In sub-Saharan Africa, appropriate equipment for small holders is being developed as well as farmer field schools to facilitate farmers' understanding of the benefits of conservation agriculture. Some countries (about 14) are already using the technology, involving more than 100 000 small-scale farmers in the region (Kassam et al. 2010).

According to Basch et al. (2008), in Europe the area under no-till is only 2 % of the agricultural area. Since 1999, however, the area in some countries such as Spain, Finland, France, Germany and Ukraine has increased, partly as a result of the initiative of the European Conservation Agriculture Federation. One of the main constraints for the expansion is due to the policies in the European Union, with direct payments to the farmers and subsidies for certain commodities. This does not stimulate the farmer to reduce the production costs and to use crop rotations. In spite of that, the conditions might change due to environmental pressure on the European Union. The need to overcome the major constraints to annual crop production, such as water scarcity and soil erosion, mainly in the Mediterranean region, might also contribute to expand this technique (Karrou and El Mourid 2009). Conservation agriculture, with zero-tillage and the presence of residues on soil surface, has been suggested for controlling soil erosion and increase the soil organic matter.

Indeed, conservation agriculture in the Mediterranean region will improve farm economy due to savings in farm machinery, fuel and time for field operations and lead to greater flexibility concerning the time for sowing, fertilizing application and weed control (Centero-Martinez et al. 2007). Increases in yield and greater yield stability, soil protection against water and wind erosion, greater nutrient-use efficiency and better water economy in dryland areas will also be observed. In crops under irrigation, conservation agriculture can contribute to the optimization of irrigation system management leading to the conservation of water, energy and soil quality while increasing also fertilizer-use efficiency.

In Asia, countries such as China, India, Pakistan and Bangladesh have already started to introduce conservation agriculture in wheat, within the wheat-rice cropping systems to avoid delay in seeding time which affects the yield potential of the crop after rice. Also, some research has been reported by authors in Syria (Bashour 2007, Pala et al. 2007) and Turkey (Avvecci et al. 2007).

Conservation Agriculture in the Mediterranean Region

The Mediterranean region is predicted to suffer from increasingly severe droughts in future due to climate changes, in addition to increased problems with soil salinity and increased temperatures (Jacobsen et al. 2012). The Mediterranean region is characterized by an extremely variable climate (Ceccarelli et al. 2007), with hot, dry summers and cool, wet winters, being the transition between dry tropical and temperate climates. In addition, it is predicted that climate will change, with drier and hotter summer climate of the Mediterranean region including southern Europe and with hot drying spells all over Europe as a result of global warming (IPCC 2007).

The rainfed farming systems are the most important in the Mediterranean countries. It is suggested that improvements in crop production may arise from several strategies such as early sowing enabled by minimum tillage, increased use of organic manure and an efficient weed control. Further, crop rotations will play an important role in improving weed control, minimizing disease risk and increasing nitrogen availability (Jacobsen et al. 2012).

Climatic and edaphic constrains in Portugal

Rainfall prevailing during the winter causes waterlogging, and its scarcity during the spring induces drought stress. What is less referred is the dramatic variability that can occur in the region. The average annual rainfall during the 20th century, in the Évora region of Portugal, was 680 mm, although the values vary from 320 to 1080 mm.

Besides the variation of the annual precipitation, the amount of rainfall in the beginning of the cropping season is also variable. Considering that the amount of accumulated rainfall to impose germination of the weeds varies between 50 and 100 mm (from sandy to clay soils), germination can occur in the middle of September or beginning of November in sandy soils, or from the middle of October to the middle of November in clay soils.

On the other hand, an accumulated rainfall of 200 mm may create water logging on poorly drained soils, and this situation can happen already in the beginning of November. Therefore, the time available for weed control and sowing of the crops is variable and can be very short.

Concerning the edaphic constraints, in Table 1 are summarized some important characteristics of the Portuguese soils. Only 4.2 % of the soils present a high cation-exchange capacity (higher than 20 meq. per 100 g of soil). Most of the soils have low organic matter content and are acid. Associated with the climatic constraints, the predominance of soils with a low or very low fertility imposes limitations to the crop productivity.

Problems faced by the Portuguese agriculture

Considering the climatic and soil constraints described, Portuguese agriculture faces economic, environmental and agronomic difficulties. From the economical point of view, there is an urgent need to improve crop yields and reduce production costs. From an environmental perspective, the main challenge is soil improvement by controlling erosion, increasing organic matter content and improving soil structure in order to increase water infiltration and saturated hydraulic conductivity. From an agronomic perspective, the question is to develop a system that can achieve, at the same time, the economical and the environmental objectives, which can be summarized by the efficient use of the factors, the improvement of the working capacity of the different operations and the understanding of the interactions between climatic conditions, crop response to different factors (like nitrogen) and time of application.

Wheat is the most representative rainfed crop in the region. The production costs of the crop are mainly related to traction (42.5 %) and fertilizers.

Being tillage the major part of the traction costs and nitrogen the most significant input, any improvement of the economic situation can only be achieved if the efficiency of these two items can be considerably improved. Conservation agriculture can play an important role to achieve all these goals at the same time, on a long-term strategy based on no-till systems, the maintenance of the crop residues on the soil surface and a good design of crop rotations in order to keep diseases and weeds under

Table 1 Some soil characteristics of the Portuguese agricultural land (5.4 mill. ha). The first number represents the level of the parameter and the second the percentage of the area with the reported characteristic. C.E.C., cation exchange capacity; O.M., soil organic matter content (0–20 cm)

	C.E.C.		O.M.		pH	
Level	Meq per 100 g	% of the area	%	% of the area	Value (water)	% of the area
High	>20	4.2	>2	27.5	6.5	11.8
Medium	10–20	70.2	1–2	2.2	5.5–6.5	5.3
Low	<10	25.2	<1	70.4	<5.5	82.9

control. The first priority has to be the improvement of soil conditions in order to improve soil fertility, infiltration and saturated hydraulic conductivity. At the same time, knowledge has to be gained in order to understand the relationships between climatic conditions (especially rainfall), application of factors (mainly nitrogen), soil fertility (mostly soil organic matter (S.O.M.)), application opportunity and crop yield (Fig. 1).

The role of conservation agriculture

In order to improve soil quality, the most relevant indicator is the amount of organic matter of the soil. Therefore, the first step is to control soil erosion, and conservation agriculture, especially direct drilling, is a very efficient way to achieve this goal (Fig. 2). The ability of conservation agriculture to control soil erosion is either by reducing the runoff or the soil resistance to be transported because the runoff was reduced by a factor of three and soil loss by a factor of six.

Conventional tillage system gave an important contribution for the very low organic matter content of most of the Portuguese soils (Table 1); this was not only due to soil erosion, but also due to the increase in mineralization of the organic matter. Due to the relatively high temperature of the region, a major difficulty to improve soil organic matter is mineralization rate, which is enhanced by intensive and frequent soil tillage. Alves (1961) tried to improve soil organic carbon (S.O.C.) using green manure to increase the inputs of fresh organic matter to the soil (Table 2). In spite of the fact that half of the crop rotation was dedicated to green manure production, the combined effect of fresh organic matter and soil tillage had a tremendous effect on the mineralization rate, and the final result was a decrease in S.O.C. in the three treatments.

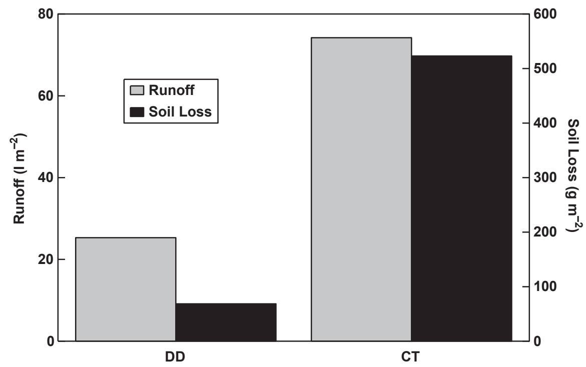

Fig. 2 Effect of soil tillage on the runoff and soil loss by erosion during a wheat crop in Évora, Portugal. Average of 2 years. DD, direct drilling; CT, conventional tillage based on the plough and disc arrows (adapted from Basch and Carvalho 2000). The values between the treatments, for both the variables, were significantly different ($P < 0.05$).

Direct drilling by itself has a positive effect on the soil organic matter by reducing the mineralization rate, and the combination of direct drilling and the maintenance of the crop residues on the surface of the soil is the solution to achieve significant increments of soil organic matter and at the same time produce a crop every year (Fig. 3).

The effect of direct drilling on the improvement of the structural soil stability is much faster than on the increase in soil organic matter (Fig. 4). Indeed, the effects on soil structure could be detected after 3 years, while no measurable differences on the soil organic matter were present. A possible explanation is the protection of the soil aggregates conferred by the network of the fine roots and the mycelium of the fungi associated. At the same time, under direct drilling, there was the development of a continuous network of biological porosity (Basch and Carvalho 2000) which also developed faster than the increase in S.O.C. As

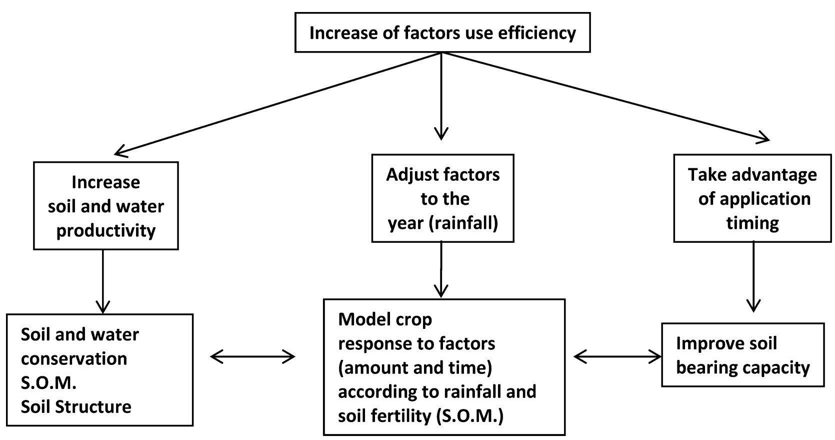

Fig. 1 Scheme of a global strategy to improve environmental and economic sustainability of crop production under Mediterranean rainfed production.

Table 2 The effect of faba bean and vicia green manure (g.m), and bare fallow on the variation of soil organic carbon (S.O.C.) under conventional tillage system in South of Portugal (Adapted from Alves, 1961)

	S.O.C (% of the value before each crop)		
Crop rotation	After preceding crop of the wheat	After wheat	Final result, after crop rotation
Bare fallow–wheat	−1.23	−0.83	−2.06
Faba bean (gm)–wheat	+1.47	−2.16	−0.69
Vicia (gm)–wheat	+1.35	−2.56	−1.21

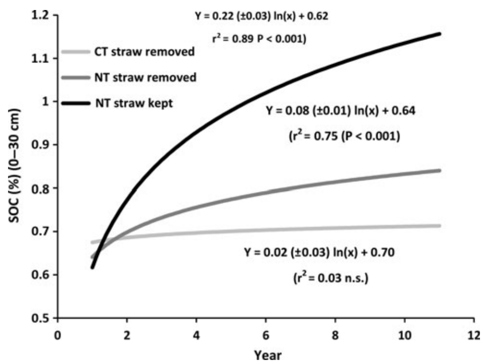

Fig. 3 Effect of the tillage system and crop residues management on the soil organic carbon (S.O.C.) in the 0–30 cm depth. DD, direct drilling; CT, conventional tillage (plough + disc arrows). Study conducted on a Luvisol in the south of Portugal. The crop rotation under study was wheat–oat for forage–barley–lupine (Carvalho et al. 2012).

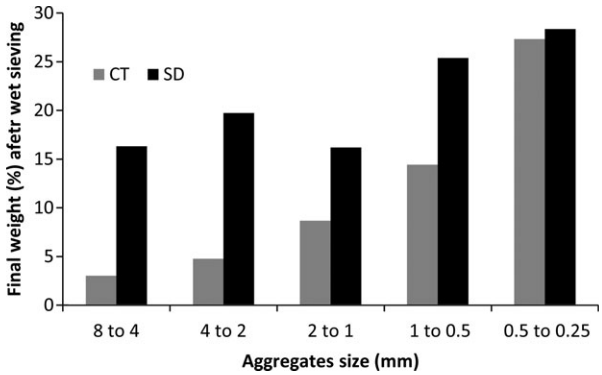

Fig. 4 Effect of the tillage system (wheat straw removed in both treatments) on the aggregate stability in a Luvisol in the south of Portugal. Results after 3 years. CT, conventional tillage (plough + disc arrows); DD, direct drilling (Carvalho 2003).

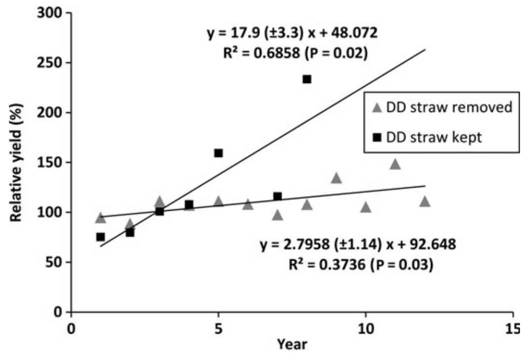

Fig. 5 Yield of the wheat crop under direct drilling (DD), with and without straw removal, in relation to the yield under conventional tillage system (100 %) in a Luvisol in the south of Portugal (Unpublished data).

expected, if the structural stability and the continuous biopores increased under direct drilling, there was a correspondent increase in the internal drainage of the soil, being the saturated hydraulic conductivity two and four times greater under direct drilling at 25 and 50 cm depth, respectively (Carvalho and Basch 1995). Leaving the straw over the soil surface is a highly beneficial practice. As shown in Figure 5, the relative yield increase was much higher, along the years, when the straw was kept on the soil.

In summary, conservation agriculture is a tool to improve soil fertility, in the first place by controlling soil erosion and, secondly, by improving soil organic matter content, especially if the crop residues are left on the soil surface. The soil physical conditions are also improved by conservation agriculture, namely the water stability of the aggregates and the amount of continuous biopores, which improve the saturated hydraulic conductivity of the soil. The reduction of the runoff and the improvement of drainage are very important benefits under the Mediterranean conditions, having in consideration the intra- and interannual variation of the rainfall. These benefits are improving crop yield and the soil bearing capacity, which makes possible to improve the number of working days and to have a correct timing for the operations, such as sowing and the application of fertilizers and herbicides (especially during the winter).

Crop response to nitrogen according to rainfall

The intra-annual variability of the rainfall affects both the yield potential of the crops and its response to nitrogen (Fig. 6).

The optimum amount of nitrogen depends on the precipitation, not only because of its effect on crop yield potential, but also due to nitrogen losses, either by leaching or by volatilization. Yield potential is higher when winter rainfall (from November to February), which is promoting nitrogen losses, is around 350 mm. The relationship between these three variables is presented in Figure 7.

Therefore, it is impossible to predict, in advance, the optimum nitrogen fertilization for a cereal crop under

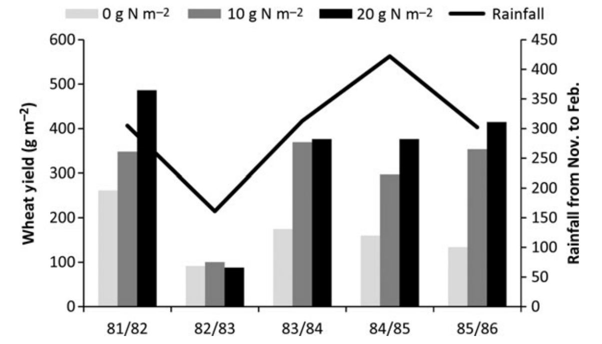

Fig. 6 Wheat response to three levels of nitrogen in 5 consecutive years and the amount of rainfall from November to February, on a vertic clay soil with 1 % of organic matter, in south of Portugal (adapted from Carvalho and Basch 1996).

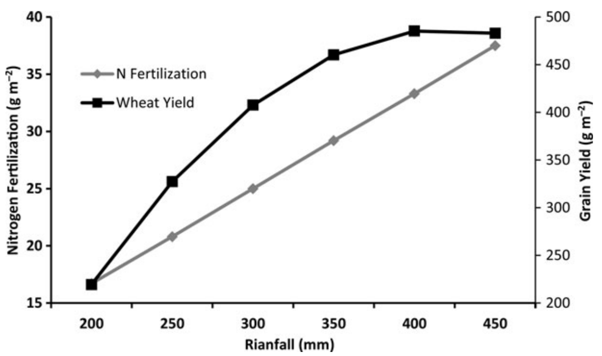

Fig. 7 Influence of winter rainfall on nitrogen fertilization for maximum yield and on achieved yield, according to the data presented in Figure 9 (Carvalho and Basch 1996).

Mediterranean conditions. During wet winters, when more nitrogen is needed, the nitrogen-use efficiency is low due to losses.

In order to improve the nitrogen-use efficiency, two aspects are relevant. On the one hand, a model to manage the nitrogen fertilization according to rainfall is necessary, in order to reduce mistakes on the doses to be used by the farmers. On the other hand, it is indispensable to increase the capacity of the soil to provide nitrogen to the crop, by improving its organic matter content.

The model developed to manage nitrogen according to rainfall is the following one (Carvalho et al. 2005):

$$Y = 574 + 10.25\,N - 0.04\,N^2 - 1.76\,R_1 + 0.001\,R_1\,N + 19.6\,R_2 + 0.09\,R_2\,N$$

$$F_{[6,74]} = 106.81\ P < 2.15\,E - 34\ r^2 = 0.896$$

Y – grain yield (kg ha^{-1}).

N – nitrogen fertilization (total: seeding + 2 top dressing; kg N ha^{-1}).

R_1 – rainfall from 1st November to 20th of January (date of 1st top dressing).

R_2 – rainfall from 21st of January to 28th of February (date of the second top dressing).

The model assumes that 20 kg of N ha^{-1} is applied at the seeding time, the first top dressing during tillering (second half of January) and the second top dressing at the beginning of shooting (end of February).

The importance of both of the two nitrogen top dressings increases with the amount of rainfall during the respective period. The lack of nitrogen during the initial phases of the wheat crop, namely tillering, cannot be compensated by latter applications of nitrogen. Therefore, the practical use of such a model depends on the possibility of applying the nitrogen at the correct time, that is, on the soil bearing capacity. In relation to this issue, conservation agriculture also plays an important role, because soil cohesion and saturated hydraulic conductivity are much higher than under the conventional tillage system. Only modest amounts of nitrogen should be applied at sowing (around 20 kg N ha^{-1}). At tillering, a first top dressing must be applied according to the amount of rainfall from the beginning of November. At the beginning of shooting, a second nitrogen fertilization should be performed, depending on the rainfall since the previous application.

Although this nitrogen management model can help to improve nitrogen-use efficiency by avoiding mistakes, further improvements must be reached in order to improve environmental and economic performance of cereal production under the Mediterranean conditions, and this can only be achieved by increasing soil organic matter. The role of conservation agriculture on S.O.M. under the conditions prevailing in Portugal is well established as it is shown in Figure 3. If the level of S.O.M. is increased from 1 % (actual average level of the soils under cereal production in Portugal) to 2 %, and according to the equation presented in Figure 8, the nitrogen-use efficiency will increase from 19.1 to 36.6 kg of wheat per kg of applied nitrogen.

The difference in wheat yield potential due to S.O.M. will be reduced by increasing nitrogen fertilization, but that will be uneconomic and represents an environmental cost that is unacceptable.

Economic sustainability of cereal production under conservation agriculture in Portugal

Considering that conservation agriculture improves several soil properties, which affect soil fertility and water relationships like infiltration and drainage, this technique will affect the economic sustainability of crop production under Mediterranean conditions. The data presented in Figure 9 are relative to a long-term study carried out in south of Portugal and are the determined values in terms of either

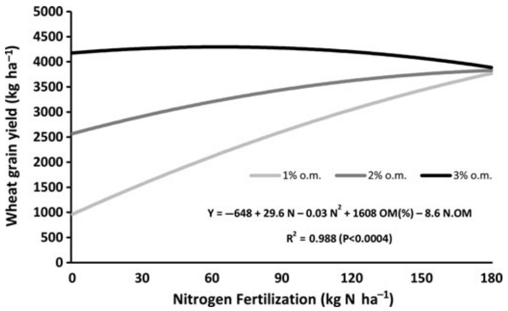

Fig. 8 Effect of the soil organic matter on the wheat response to nitrogen, on a Luvisol in the south of Portugal. $Y = -648 + 29.6 N - 0.03 N^2 + 1608 OM (\%) - 8.6 N.OM$ ($R_2 = 0.988$ ($P < 0.0004$)). Y – wheat grain yield (kg ha^{-1}), N – nitrogen fertilization (kg N ha^{-1}), OM – soil organic matter (0–30 cm; %; Carvalho et al. 2005).

production costs or yields. For instance, for the system where the straw was removed from the field, the loss of the annual net margin value was considerable after taking into account the extra income of selling the straw. The potential benefit of direct drilling systems in terms of the correct time of factors application, namely nitrogen, was not considered, because all the operations were carried out at the same time for the three systems, and the first nitrogen top dressing under the conventional tillage system (C.T.) was carried out manually. Otherwise, it would be expected to observe even greater advantage of the direct drilling system.

Direct drilling the crops but removing the straw improved the net margin of the wheat not only by reducing soil tillage costs but also by causing a slight increase in crop yields, as already pointed out in Figure 5. However, when straw was kept on the soil surface, the increase in soil organic matter allowed simultaneously an increase in crop yield (Fig. 5) and a decrease in nitrogen application (Fig. 8). These benefits are overcompensated by the loss of the straw value.

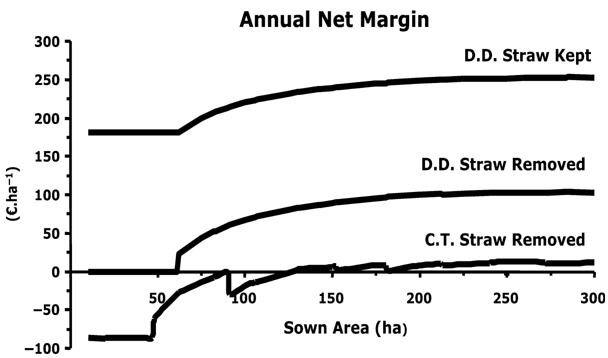

Fig. 9 Effect of the tillage system and crop residues management on the annual net margin of the wheat crop depending on the annual sown area. DD, direct drilling; CT, conventional tillage (plough + disc arrows). Study conducted on a Luvisol in the south of Portugal during 12 years. The crop rotation under the study was wheat–oat for forage–barley–lupine (Marques 2009). The economic value of the straw was considered in the calculations.

Environmental sustainability of cereal production under conservation agriculture in Portugal

Several environmental benefits can be obtained using conservation agriculture for crop production under rainfed conditions. The control of soil erosion is a major aspect, not only by preserving the soil but also by improving the quality of surface water, once soil sediments are by far the most important contaminants of surface water (ECAF 1999). The increase in soil organic matter improves nitrogen-use efficiency, which in turn contributes for ground water protection. Besides the benefits in terms of water quality, direct drilling systems also reduce water losses by runoff (Fig. 2), improving therefore water storage in the soil. Another important benefit, especially when the straw of the cereals is kept on the soil surface, is the carbon sequestration in the soil and the consequent reduction of CO_2 emissions. Considering the equations presented in Figure 3, and for a period of 10 years, direct drilling can reduce the emissions by two tons of CO_2 ha^{-1} $year^{-1}$ and by 4.7 tons of CO_2 ha^{-1} $year^{-1}$ if the straw is kept on the field. These figures are equivalent to the burning of 660 and 1518 l of fossil fuel, respectively.

Final Remarks

Conservation agriculture, especially if the straw of the grain crops is left on the soil surface, can have a major contribution to increase economic and environmental sustainability of rainfed agriculture under Mediterranean conditions. The improvement of soil proprieties such as soil organic matter, water infiltration and drainage enhance crop productivity and the efficient use of production costs with respect to traction and fertilizers. The improvement of soil bearing capacity (more cohesion and better drainage) allows a correct timing for field operations being this an extra benefit.

From an environmental point of view, soil and water conservation as well as CO_2 sequestration in the soil are the major benefits. From an economical point of view creates the opportunity to make cereal production profitable under the prevailing conditions in the south of Portugal and probably in the Mediterranean region in general.

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