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Effects of direct drilling on the fertilization of cereals

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SUMMARY – There are changes in the physical, chemical and biological properties of the soil, when direct drilling is adopted. This presentation reports experimental results for soil fertility and the response of crops to fertilizers under direct drilling in the south of Portugal. The increase of soil organic matter content, that usually occurs under no tillage, seems to be the only effective way to overcome the poor nitrogen-use efficiency of winter cereals under Mediterranean conditions. The normal organic matter content of the soil in the region is only about 1%. For this level of organic matter, the results indicate that the most economical nitrogen application would be 160 kg N/ha and the correspondent yield would be 3063 kg wheat/ha. However, for an organic matter content of 3% the most economical nitrogen level would be only 37 kg N/ha and the corresponding yield 3862 kg/ha. The application of fertilizers to the soil surface under direct drilling can increase soil acidity of the top-most layer. However, the experimental results show that this effect is temporary and the increase in soil organic matter offsets this effect on pH. The soils under direct drilling develop a very steep gradient in the concentration of nutrient, especially those less mobile in the soil, such as phosphorus. Experimental results suggest that this is one beneficial effect of direct drilling. Another significant interaction between tillage and fertilization is the importance of the timing of the first nitrogen topdressing application (at tillering stage) especially during wet winters. Under conventional tillage systems this can be delayed because of the inability to get onto the land with farm machinery under wet conditions. Experimental results will be presented that quantify this effect.

Keywords: Direct drilling, wheat, nitrogen, phosphorous.

RESUME – *"Effets du semis direct sur la fertilisation des céréales". Il y a des changements dans les propriétés physiques, chimiques et biologiques du sol lorsque le semis-direct est adopté. Cette communication présente des résultats expérimentaux sur la fertilité du sol et la réponse des cultures à la fertilisation en conditions de semis-direct dans le sud du Portugal. L'augmentation du taux de matière organique (MO) du sol, qui se produit habituellement en semis-direct, semble être le seul moyen efficace pour surmonter la faible efficience de la consommation d'azote des céréales d'hiver en conditions méditerranéennes. Le taux de matière organique (MO) moyen des sols dans la région est seulement de 1%. Les résultats montrent que, pour ce niveau de MO, l'apport d'azote le plus économique serait de 160 unités/ha et que le rendement correspondant serait de 3063 kg/ha de blé. Cependant, pour un taux de MO de 3% le niveau d'azote le plus économique serait de 37 unités/ha et le rendement serait alors de 3862 kg/ha de blé. En semis-direct, l'apport d'engrais en surface peut augmenter l'acidité de la couche superficielle du sol. Néanmoins, les résultats expérimentaux montrent que cet effet est temporaire, et que l'augmentation du taux de MO du sol compense cet effet sur le pH. Les sols en semis-direct développent un très fort gradient dans la concentration d'éléments nutritifs, particulièrement ceux qui sont moins mobiles dans le sol, tel que le phosphore. Les résultats expérimentaux suggèrent que c'est là un des effets bénéfiques du semis-direct. Une autre interaction significative entre labour et fertilisation est l'importance de la période du premier apport d'azote en surface (au stade tallage) notamment lors d'hivers humides. Dans les systèmes de travail du sol conventionnels, et en conditions trop humides, cet apport peut être retardé du fait de l'impossibilité d'entrer dans les parcelles avec le matériel agricole. Des résultats expérimentaux quantitatifs de cet effet seront présentés.*

Mots-clés : *Non labour (non travail du sol), blé, azote, phosphore.*

Introduction

There are changes in the physical, chemical and biological proprieties of the soil, that can affect crop response to fertilizer application when direct drilling is adopted.

Direct drilling increases the bulk density and the penetration resistance of the soil (Vyn and Raimbault, 1993). There is also a tendency to develop of a laminar structure close to the soil surface under direct drilling. Despite these apparent unfavourable characteristics, many authors describe an increase of the infiltration rate under direct drilling, which they explain by the increase in continuous bio-pores and a better aggregate stability (Basch et al., 1990; Lal e Van Doren, 1990; Carter and Steed, 1992; Mahboubi et al., 1993). The enhanced preferential flow through the bio-pores allows smaller nitrogen losses by leaching (Goss et al. 1993). At the same time the water retention capacity tends to be bigger and the total volume occupied by macro-pores smaller (Carter, 1991; Riley, 1983). This increases the opportunity for gaseous losses of nitrogen.

The organic matter content, especially of the surface soil, increases under direct drilling (Carter et al., 1990; Carter, 1991; Ellington and Reeves, 1990), and the same effect can be expected for total phosphorous (P) (Logan and Adams 1981) and available P (Guertal et al., 1991), whereas pH tends to decrease (Blevins et al.,1983).

The biological activity of the soil under direct drilling increases, in particular there is greater microbiological activity (Carter 1991) as well as a higher amount of overall biomass and a bigger number of earthworms.

In summary direct drilling can change the nutrients stored in the soil, their distribution in the profile, the rates of mineralization and immobilization and the opportunities for losses. It can also affect the soil water regime as well as the root growth and distribution. Therefore, there is a great potential for a differential crop response to fertilization under direct drilling, especially under the soil and climate conditions of the South of Portugal, where natural soil fertility is generally limited. Rainfall is also concentrated during fall and winter creating problems of runoff, water logging and water deficits.

In this paper we assess analysing the effect of different soil conditions promoted by different tillage treatments on the wheat response to nitrogen and phosphorus in the South of Portugal.

Materials and methods

The experimental data were obtained in experiments carried at Reguengos de Monsaraz (38º 26`N, 7º 33`W) at 210 m above sea level. The soil at the Revilheira Experimental Farm is a Luvisol, with an A horizon having 20% clay and a B horizon having 45% clay. The organic matter content of the A horizon, under conventional farming is approximately 1%. However, depending on the soil tillage and crop residues management, it is possible to find values for the organic matter content up to 2%.

Data from fertilizer trials, carried out between 2000/2001 and 2003/2004, were used to establish a model relating wheat yield, nitrogen fertilization and soil organic matter. Nitrogen fertility investigations were conducted on two areas with a different soil organic matter content. These levels were the result of the tillage system (conventional drilling, consisting in mouldboard plough plus disk harrow, and direct drilling) and of the crop residues management (straw baled or left on the soil). The nitrogen levels used were 0, 6, 12 and 18 g N/m^2. The smallest soil organic matter content was 1.04% (site under conventional tillage and straw baled) and the greatest was 2.04% (direct drilling and residues of crops kept on the soil surface). Multivariable regression analysis was carried out using Microsoft Excel program. The model presented is the one that most closely fitted the full data set.

The data relating nitrogen top dressing, rainfall and wheat yield were part of a project carried out from 1995 to 1998, at the same experimental farm. In this trial there were two independent variables: (i) the amount of nitrogen applied; and (ii) the N distribution along the crop cycle.

The data for the P distribution and the wheat response to P fertilization and the data relative to soil pH were obtained in on-going long term tillage experiment started in 1995.

Results and discussion

Soil organic matter content and wheat response to nitrogen

The nitrogen use efficiency for cereal production under Mediterranean conditions is usually quite low. The opportunity for deep percolation during fall and winter, the need of the crop for nitrogen during this period and the low organic matter content of the soil are the main reasons (Carvalho and Basch 1996). A possibility to improve the situation is to increase the organic matter content of the soil.

Previous attempt to improve this parameter in Portugal, under the conventional tillage system and using only endogenous crop residues, have failed (Alves, 1961). However, under direct drilling, significant increases of soil organic matter content have been achieved (Carvalho et al., 2002). The effect of these improvement, on the wheat response to nitrogen is presented in Equation 1, were Y is the wheat grain yield (kg/ha), N is the amount of nitrogen applied (kg N/ha), OM is the organic matter content of the 0-10 cm layer (%).

$$Y = 631 + 35\,N - 0.07\,N^2 + 2718\,\ln(OM) - 8.6\,N \times OM \quad (F_{[4,19]} = 7.84;\ p < 0.0007) \qquad \text{[Equation 1]}$$

The fit of the equation is highly significant. Based on the equation there is a negative interaction between nitrogen and organic matter content. The graphical representation of Equation 1, for three different levels of OM (Fig. 1) indicate that, the most profitable nitrogen application would have been 160 kg N/ha, when the OM level in the soil is 1% (assuming that four kilogram of wheat are required to pay for one nitrogen. The associated expected yield was 3063 kg/ha. For a OM of 2% the most profitable nitrogen level was 98 kg N/ha and the expected yield was 3587 kg/ha. Extrapolating the results to an OM of 3% (the maximum OM of the experimental site was 2.04%) a nitrogen application of 37 kg N/ha would be required for a expected yield of 3862 kg/ha. Therefore, the nitrogen use efficiency would have increased from 19.1 kg of wheat per kg of N for 1% organic matter content, 36.6 kg wheat/kg N for 2% of OM and to 104.3 kg wheat/kg N for 3% of OM. It seems possible to improve the nitrogen use efficiency for wheat production under Mediterranean conditions. For a 2% level of OM the NUE was similar to the values reported for temperate Atlantic regions and the extrapolation for 3% of OM is predicting very high nitrogen use efficiency. Naturally this is not a direct consequence of direct drilling. However, the available information is showing that, using only endogenous organic residues, it is impossible to increase soil organic matter content in the context of continuous arable farming under Mediterranean conditions, if tillage is used for installing the crops.

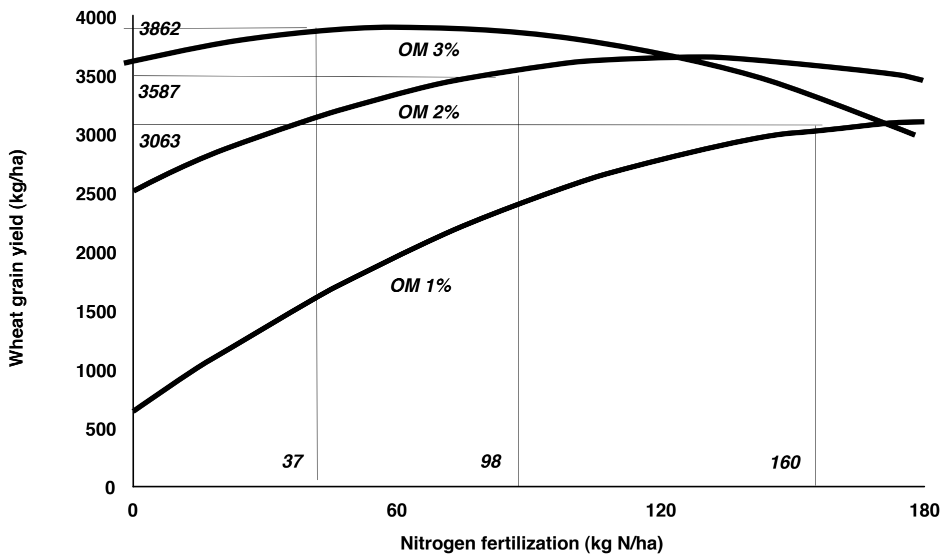

Fig. 1. Wheat response to nitrogen for different soil organic matter content (Carvalho *et al.*, 2005).

Timeliness of nitrogen first top dressing application and wheat yield

There is a strong relationship between wheat yield, nitrogen fertilization and winter rainfall under Mediterranean conditions (Carvalho and Basch 1996). The yield potential is increasing with winter rainfall, but a higher amount of nitrogen is needed. Beside the amount of nitrogen, the opportunities for modifying the date of nitrogen application takes on importance as winter rainfall increases (Carvalho *et al.*, 2005).

The wheat yield benefit associated with an application of 60 kg of N/ha by the 20th of January, when 120 kg of N/ha are applied on 28th of February increase linearly with rainfall (Fig. 2).

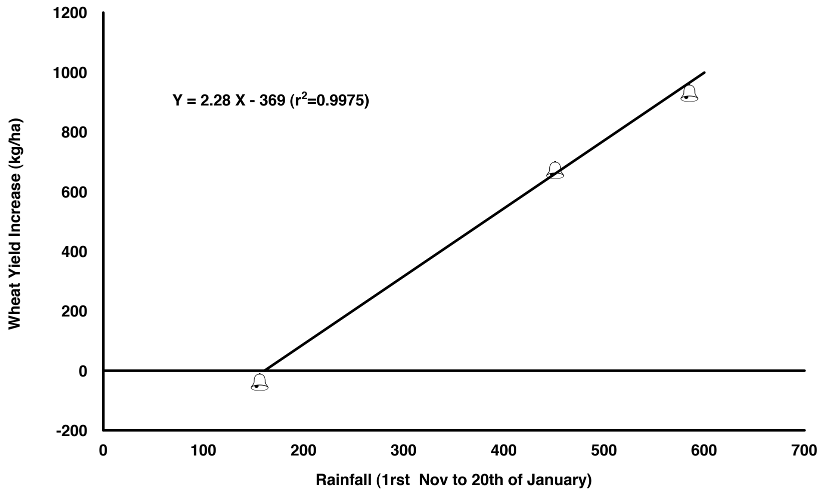

Fig. 2. Wheat yield benefit of an extra 60 kg N/ha applied at 20th of January (120 kg N/ha were applied in February) and the amount of rainfall from November the first and 20th of January (Carvalho *et al.*, 2005).

It is obvious that the need for an extra nitrogen top dressing, in January, is increasing with the amount of rainfall from the beginning of November. The reason is associated with an increase of nitrogen loss by leaching during wet winters. It is important to remember that tillering and spikelets differentiation of wheat are occurring during the winter under the Mediterranean environment. Therefore, a problem faced by farmers is the permeability of the soil under wet conditions. Under conventional tillage it is usually impossible to apply nitrogen in January and this is the main reason for the yield loss associated with wet winters under Mediterranean conditions. Direct drilling, by improving soil cohesion and the hydraulic conductivity of the soil, is enhancing the possibility of applying nitrogen when it is most needed.

Phosphorus distribution and wheat response to band application

It is generally accepted that phosphorus content of the soil is increasing under direct drilling, once soil erosion is the main cause for P losses from the soil. Beside this increment, there is an increase of phosphorus concentration in the top soil under direct drilling. The P distribution in the soil is quite different for the two tillage treatments after ten years (Fig. 3).

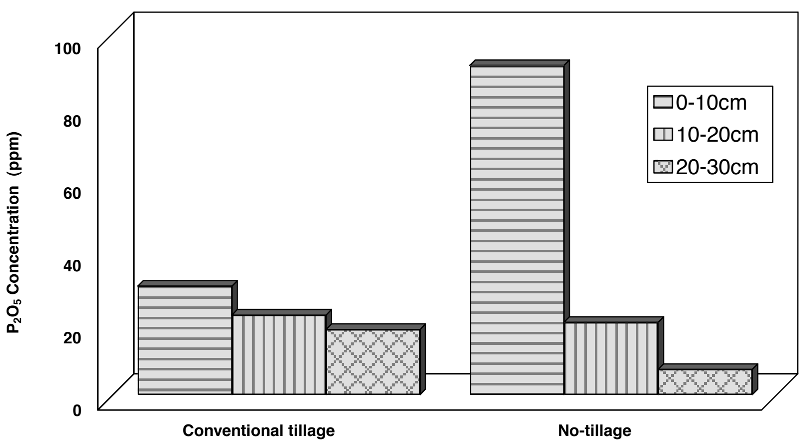

Fig. 3. Effect of tillage system on the distribution of P in the soil profile (unpublished data).

The elevated P concentration in the surface under direct drilling reduces the probability of crop response to a banded fertilizer application (Figure 4). Another possible interaction between tillage system and soil fertility results from tillage effects on the soil pH (Figure 5). Under direct drilling there is a tendency for the top soil to become acidified, due to fertilizer application. This effect was detected after only one year. However, with time, the value of soil pH was very similar in the first layer, for both tillage systems. One possible explanation is a greater buffering capacity of the top layer of the soil under direct drilling, associated with an increased organic matter content.

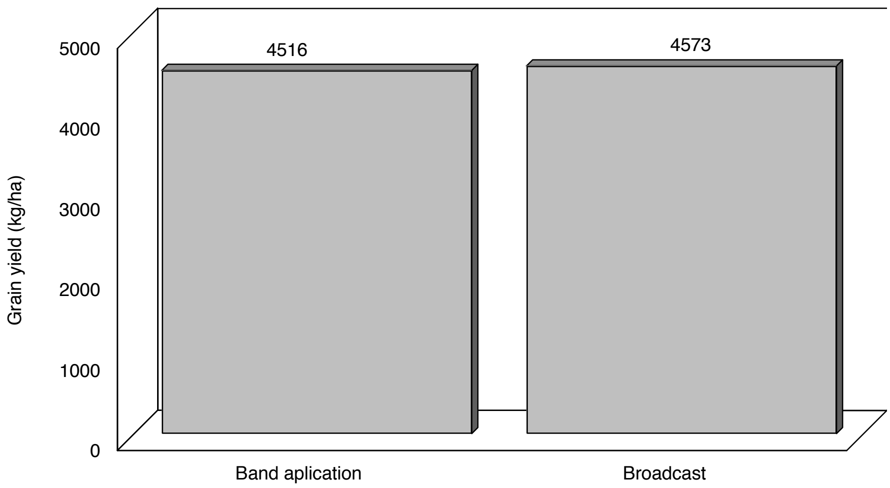

Fig. 4. Effect of phosphorus placement (80 kg of P_2O_5/ha) on the wheat yield under direct drilling (unpublished data).

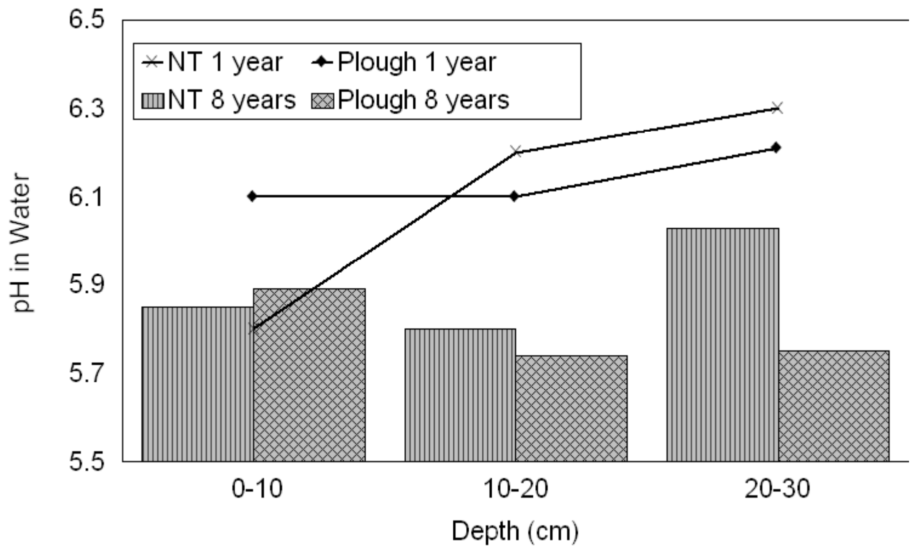

Fig. 5. Effect of the tillage system on the soil pH after one and eight years at the same site.

Conclusions

There are several changes on the soil conditions, when continuous direct drilling is performed, that affect the wheat response to fertilizers.

In relation to nitrogen, increases of soil organic matter content is increasing the nitrogen use efficiency under Mediterranean conditions, because less nitrogen has to be applied during the winter. Another interaction between direct drilling and nitrogen is the increase of the soil bearing capacity, which facilitates the nitrogen top dressing in January under wet conditions.

The soils under direct drilling are presenting a higher concentration of less mobile nutrients, as phosphorus, near the surface. This is reducing the probability of crop response to band application of the fertilizer.

Direct drilling is decreasing to pH of the top soil. However, it seems that this effect is off-set with time, probably because an increase of the organic matter content of the top soil.

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