Physical properties of an alfisol and no-till soybean yield

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PHYSICAL PROPERTIES OF AN ALFISOL AND NO-TILL SOYBEAN YIELD[(1)]

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SUMMARY

It is known that any kind of soil management causes changes in the soil physical characteristics and can affect agricultural yield. The purpose of this study was to evaluate soil properties of an Alfisol and soybean yield under different management systems for no-tillage annual crops, no-tillage with chiseling and no-tillage crop rotation. The 11-year experiment was initiated in the 1998/99 growing season, on 100 x 30 m plots (11 % slope). Soil samples (5 per management system) were systematically collected (0–25 cm layer) in the summer growing season, to quantify soil organic matter, bulk density, macroporosity and flocculation, as well as soybean yield. The highest values for soil bulk density and organic matter content and the lowest for macroporosity were observed in the no-till system alone, whereas in the no-till system with quarterly chiseling the values for organic matter content were lowest, and no-tillage crop rotation resulted in the highest values for organic matter and macroporosity, and the lowest for soil bulk density. The average soybean yield was highest under no-till and trimestrial chiseling or crop rotation, and lowest for no-tillage annual crops no-tillage annual crops alone.

Index terms: No tillage, soil physical properties, organic matter, crop rotation.

(1) Received for publication in January 13, 2011 and approved in November 11, 2011.

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RESUMO: *ATRIBUTOS FÍSICOS E PRODUÇÃO DE SOJA EM NITOSSOLO SOB SEMEADURA DIRETA*

Sabe-se que o manejo do solo, qualquer que seja ele, provoca modificações nos seus atributos físicos, as quais podem alterar a produção agrícola. O objetivo deste trabalho foi avaliar, após 11 anos de experimento, os atributos de solo (matéria orgânica, grau de floculação, densidade e macroporosidade) e a produção de soja em um Nitossolo Vermelho sob diferentes manejos com cultura anual e semeadura direta com escarificação e rotação de cultura. No ano agrícola de 98/99, iniciou-se o estudo em áreas de 100 x 30 m de comprimento e de largura respectivamente, e declive de 11 %; nas safras de verão, sistematicamente, foram feitas coletas de amostras de solo (cinco por manejo considerado) entre 0 e 25 cm, para quantificar matéria orgânica, densidade, macroporosidade e grau de floculação do solo, além da produção de soja. O manejo semeadura direta apresentou o maior valor de densidade do solo e matéria orgânica e os menores valores de macroporosidade, ao passo que o manejo semeadura direta e escarificação quadrianual apresentou o menor valor de matéria orgânica, e o manejo semeadura direta e rotação de culturas, os maiores valores de matéria orgânica e macroporosidade e o menor valor de densidade do solo. A maior produção média de soja ocorreu nos manejos semeadura direta com escarificação quadrianual e semeadura direta e rotação de cultura, enquanto a menor produção média de soja ocorreu para o manejo cultura anual com semeadura direta.

Termos de indexação: semeadura direta, propriedades físicas, matéria orgânica, rotação

INTRODUCTION

Agriculture in the northern region of the State of Paraná, Brazil, began around 70 years ago, based mainly on cotton and coffee. As of 1975, the area of coffee plantations was reduced due to climatic problems and the land converted to grain production, mainly, for the domestic and export markets.

Initially, the soil was conventionally prepared with continuous, intense tillage. This was later replaced by no tillage (direct planting) in view of the better soil protection against erosion and the advantage of no-till as low-cost cropping system.

The objective of soil management is to make physical conditions more favorable for crop growth and development, but this inevitably changes the soil structure to varying degrees according to the tillage type. The so-called conventional systems are believed to affect the soil structure more (Costa et al., 2003), whereas conservation systems such as no tillage are presumed to disturb and affect the soil structure less. However, according to Collares et al. (2006), the absence of tillage associated with more intense land use exposes the soil to intense heavy machinery traffic, often on poorly drained soil, changing the soil structural properties and increasing compaction (Tavares Filho et al., 2001).

Therefore, due to the intense soil use for high-tech agriculture in the region, especially of Red Oxisols and clayey/very clayey Alfisols, the soil structure is dedisked (Neves et al., 2003; Domingos et al., 2009; Tavares Filho & Tessier, 2009, 2010). Since the soil physical properties are interrelated, soil structure variations caused by management methods can cause changes in bulk density, porosity, penetration resistance and root system growth, with knock-on effects on crop yield, in addition to erosion problems.

Given that any kind of soil use and management brings about changes in the soil physical properties, the purpose of this study was to evaluate some soil properties and soybean yields over a period of 11 years in Red Alfisol under different management systems, involving annual crops and no tillage.

MATERIAL AND METHODS

The evaluations were carried out in the state of Paraná (Brazil), in an agricultural area in São Luiz, in the municipality of Londrina (23º18” S, 51º25” W, 585 m asl), in a subtropical humid climate with no dry season, hot summers, and winters with rare frosts (Cfa according to the Köppen classification). A clayey, eutroferric Red Alfisol (Nitossolo Vermelho) was studied, with clay contents varying from 755 to 812 g kg^{-1} at depths from 0 to 1.00 m, originating from basalt (São Bento group, Serra Geral formation), with a gradient of 7–10 % and well-developed, deep horizons: horizon A (red (2.5 YR), clayey, granular) and nitic horizon B (red (2.5 YR), clayey, subangular, “waxiness” common in this horizon).

The study area was originally a plantation from which the coffee trees were removed in 1976 and the soil plowed, disked and cropped annually for 12 years (soybean/maize in summer and wheat in winter). From 1988 until 1994, no tillage was adopted for the summer crop (soybean). Then the entire area was chiseled to a depth of 25 cm, at a soil moisture content of 0.20 kg kg^{-1}, using a chisel with five shanks spaced 0.25 m apart and a soil harrowing roller. There was no secondary soil tillage (disking). From this point onwards, no tillage with trimestrial chiseling was used. In the 1998/99 growing season, a study was initiated to analyze three different crop management and planting systems (Table 1), on plots of 100 x 30 m (distance between two terraces), with equal elevation and gradient (11 %).

The seed/fertilizer drill used consisted of nine rows spaced 0.45 m apart, with 15" diameter smooth disks for cutting through the cover vegetation, chisel plow trenchers with fertilizer hoses, offset dual-disk (13" x 15" diameter) seed trencher, two press wheels and planting depth regulator with flexible rubber strip and two narrow V-shaped wheels to press the earth on the seeds. The fertilizer consisted of 0-30-10 NPK. Simple superphosphate was used to supply S (around 12 %). Soybean was sown on October 25, rows spaced 45 cm apart and 16 plants per meter (356,000 plants ha^{-1}) using a semi-early soybean cultivar and fungicide-treated seeds, inoculated with *Bradyrhizobium*, with vigor and emergence of at least 90 %.

Five undisturbed soil samples (0–25 cm layer) per management system were taken in every summer growing seasons were randomly sampled, to quantify soil organic matter, bulk density (50.26 cm^3 volumetric ring) and macroporosity (according to Embrapa, 1997). Soil flocculation was calculated using the expression: FL(%) = ((Total clay – Dispersed clay) / Total clay)*100, where total clay was determined according to Embrapa (1997), but with slow stirring and elimination of the organic matter, as described by Tavares Filho & Magalhães (2008). Soybean yield was also determined based on a subsample of the yield from four 2 m rows. When weighing soybean, the moisture content was determined and subsequently the mass adjusted to a moisture content of 13 %.

In the last year of the experiment (2008/2009 growing season), undisturbed soil blocks (300 cm^3) were collected from the center of each plot (5–20 cm layer, moisture content around 0.21 ± 0.02 kg kg^{-1}). The blocks were wrapped in laminated paper and placed in polystyrene boxes packed with sponge to avoid moisture loss and as protection on the transport to the INRA soil science laboratory in Rennes, France. Thin sections were prepared and examined under an optical microscope with UV light (Hartmann et al., 1992) to analyze the predominant solid phase (soil macroporosity) in the two blocks, according to the method proposed by Bullock et al. (1985) and Stoops (1986).

After analysis of variance, the averages obtained (5 samples per management system per summer growing season in 11 years of observation) for the soil properties analyzed (0–20 cm layer) were compared (Tukey test at 5 %) to obtain the minimum statistical differences between the treatments. The Pearson correlation coefficient and regression values for the different variables were also determined. The different soil management systems were compared using a procedure described by Costa et al. (2006) and the reference values (Table 2) to establish a

Table 1. Different management systems for eutroferric Red Alfisol with general characteristics (management system, clay content, particle density [Dp] and mineralogy to a depth of 60 cm) in the experim

Soil Use and Management[1]	General Characteristic	Clay	Dp	Mineralogy[2]
		g kg^{-1}	Mg m^{-3}	
NTAC	No-tillage annual crops (soybean, wheat) without crop rotation. This system is still in use. The area is terraced.	793	2.94	Vermiculite with Al-hydroxy in the interlayers, kaolinite, iron oxides (goethite & hematite), gibbsite, anatase
NTACC	No-tillage annual crops (soybean, wheat) with quarterly chiseling to a depth of 25-30 cm, and with a harrowing roller in 2000, 2004 and 2008. The area is terraced.	789	2.95	
NTACR	No-tillage crop rotation (soybean – wheat – soybean – second harvest maize – mixture of green manures (black oats (*Avena strigosa*) + hairy vetch (*Vicia villosa*) + white radish (*Raphanus sativus*) for incorporation into the soil). The area is terraced.	800	2.95	

(1) Anual crops management systems: no-tillage annual crops (NTAC); no-tillage annual crops with quarterly chiseling (NTACC) and no-tillage crop rotation (NTACR). (2)X-ray diffractograms of the deferrified clay fraction in the nitic B horizon saturated with magnesium; magnesium + ethylene glycol; saturated with potassium; with potassium heated to 350 ºC; with potassium and heated to 550 ºC at INRA (Institut National de la Recherche Agronomique), in Versailles, France.

Table 2. Soil properties of the surface layer in the different no-tillage systems and reference values

Property	Reference value
Soil bulk density[(1)]	1.45 Mg m^{-3}
Organic matter[(2)]	4.00 dag kg^{-1}
Macroporosity[(3)]	0.12 m^3 m^{-3}
Flocculation[(3)]	100 %
Soybean yield[(3)]	3000 kg ha^{-1}

(1) According to Reinert et al. (2001). (2) According to Costa et al. (2006). (3) Value used.

100 % index for the soil properties *organic* matter, flocculation, bulk density, and porosity, which are important to determine the soil physical, chemical and biological properties (fertility), as well as root development, soil aeration, and water infiltration, retention and drainage.

RESULTS AND DISCUSSION

Organic matter (OM) and flocculation (FL)

In terms of result accuracy, the CV obtained for OM was low (CV < 10 %) according to Pimentel-Gomes (1990), but for FL, the CV exceeded 20 % and was considered high, according to the same author. There seems to be a consensus among researchers on the use of CV as a measurement of experimental accuracy, to the effect that medium, high or very high experimental accuracy is no cause for concern (Cargnelutti Filho & Storck, 2007).

Organic matter content for NTACR was 11.5 % higher than NTACC, but did not differ from NTAC by the Tukey test at 5 %. However, the results for FL showed no difference between the management systems (Tukey test at 5 %) (Figure 1).

The results obtained for OM were in line with Lal & Greenland (1979) and Neves et al. (2007), and showed that in NTACR, where part or all of the vegetable residues are left on the soil surface, soil OM increased continuously, generating a pool from which nutrients were slowly released by the action of microorganisms, which also improved the soil structure. This is very important, since it increases the fertility of these acid soils with the pH-dependent charges associated with organic matter (Rheinheimer et al., 1998).

Another important point is that high OM contents play only a moderate role in increasing soil FL, whose relation is described by a power of x function, with a low coefficient of determination ($R^2 = 0.40$) (Figure 1), showing that soil OM explains only 40 % of the FL variation. The expected FL value is 57.7 when OM varies by unity, a value that tends to be a constant, whereas the OM increases only to 0.0092.

The low R^2 value shows how little FL is influenced by OM. According to Amaro Filho et al. (2008), the effect of organic matter on soil aggregation is greater in regions with a lower quantity of clay and oxides in the soil, as is the case in this study (Table 1). According to the authors, in oxidic soils (Oxisols), organic matter has less influence on aggregation, which is mainly due to Fe and Al oxides, the major factors in the formation of stable aggregates. Organic matter has a cementing effect, forming complexes between the quartz and clay surfaces (main components of an aggregate), and

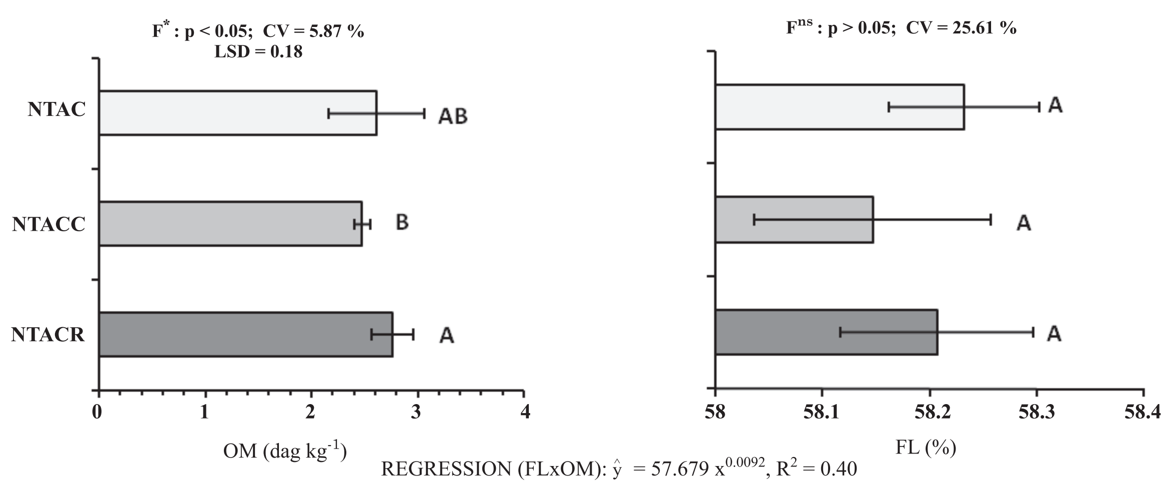

Figure 1. Average values (average of 55 samples per management system) for organic matter (OM), flocculation (FL), and standard error bars for soil samples collected at depths of 0–20 cm for annual crop management systems: no-tillage annual crops (NTAC), no-tillage annual crops with quarterly chiseling (NTACC) and no-tillage crop rotation (NTACR). (1)Means followed by the same capital letter did not differ by the Tukey test at 5 %.

strengthening this bond by forming organic-mineral complexes (organic matter and clay). Organic matter acts as a temporary aggregating agent, mainly for macroaggregates (Tisdall & Oades, 1982). Therefore, since the organic matter in the soil can promote the chemical adsorption of organic and inorganic compounds on its surface (Siqueira et al., 1990), one possible hypothesis is that increasing the organic matter in the soil probably generated excess negative charges, with little influence on flocculation (Paiva et al., 2000).

Soil bulk density (BD) and macroporosity (Ma)

In terms of result accuracy, the CV values obtained for BD were average (CV between 10 and 20 %), according to Pimentel-Gomes (1990), but the CV values for Ma were above 20 %, which this author considers high. However, as already mentioned when discussing OM and FL, medium, high or very high experimental accuracy is no cause for concern (Cargnelutti Filho & Storck, 2007).

The results for BD (Figure 2) show that system NTAC differed from NTACR (4.2 % higher bulk density), but did not differ from NTACC by the Tukey test at 5 %. These results are in line with Silva & Cabeda (2005), Costa et al. (2006), Domingos et al. (2009) and Tavares Filho & Tessier, (2009), who reported a BD increase in the surface layer under no tilllage, in contrast to the lower BD in the surface layer reported by Neves et al. (2003) and Benito et al. (2008) under no tillage in very clayey soils (Red Oxisol and Alfisol).

Values for BD, especially under the NTAC system, could be the result of soil particle accommodation after initiating the system, together with heavy machinery traffic (tractors, planters and harvesters) during planting and harvesting operations (Costa et al., 2003; Silva & Cabeda, 2005; Costa et al., 2006; Tavares Filho & Tessier, 2010). In the specific case of NTACC, the results obtained confirm Tavares Filho et al. (2006) and Domingos et al. (2009), who showed that chiseling reduces BD and increases Ma volume in clayey soils under different soil management systems, although this effect does not last long.

The results for Ma (Figure 2) show that macroporosity under NTACR was 40.8 % higher than under NTAC, but did not differ from NTACC by the Tukey test at 5 %. It is known that increasing BD reduces soil macroporosity (Ma), and a difference of around 0.01 $m^3 m^{-3}$ in pore volume results in 10 $m^3 Mg^{-1}$ fewer pores in the soil (Assouline et al., 1997; Tavares Filho & Tessier, 2010). Therefore, this difference between NTACR and NTAC indicates an increase of 53.1 $m^3 ha^{-1}$ in macroporosity in crop rotation.

It is important to bear in mind that to ensure gaseous exchange and root growth in most dryland crops, Ma must be higher than 0.10 $m^3 m^{-3}$. On the basis of figure 2 and the excellent R^2 obtained, soil BD cannot be higher than 1.54 Mg m^{-3}. None of the results obtained reached this value (Figure 2), although the value for NTAC is very close. This value is higher than the value proposed by Arshad et al. (1996) (BD = 1.40 kg dm^{-3}), Secco et al., (2004) (BD = 1.36 Mg m^{-3}) and Reinert et al. (2001) (BD of around 1.45 kg dm^{-3} in clayey soils) and is within the range proposed by Corsini & Ferraudo (1999) (1.27 < BD < 1.57 kg dm^{-3}). Based on the BD value at the beginning of the experiment (1.37 Mg m^{-3}), the maximum BD of 1.54 Mg m^{-3} and a constant soil mass (Ms) for all management systems, the soil was reduced in volume (compressed) by around

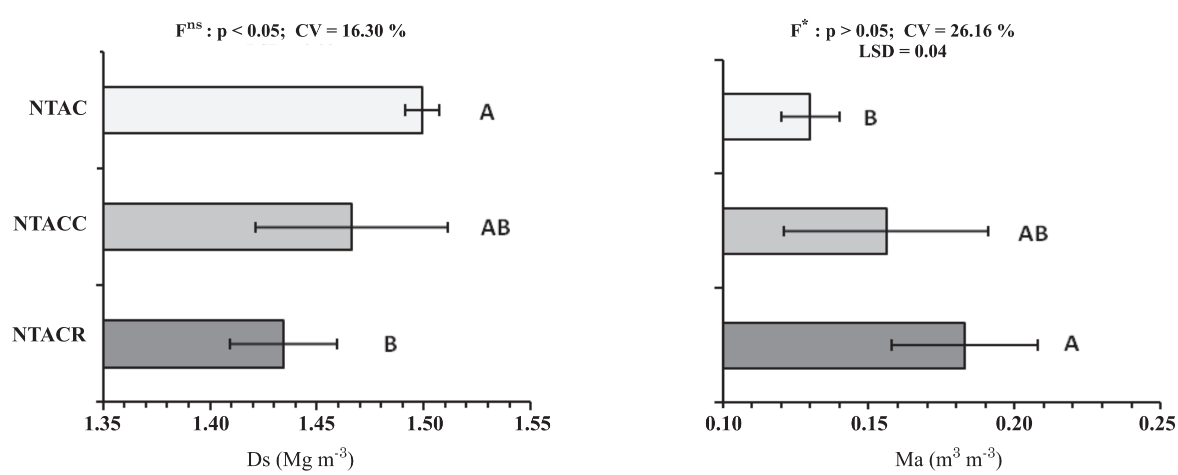

Figure 2. Average values (55 samples per management system) for soil bulk density (BD), macroporosity (Ma) and standard error bars for soil samples collected at depths of 0–20 cm for no-tillage annual crops (NTAC), no-tillage annual crops with quarterly chiseling (NTACC) and no-tillage crop rotation (NTACR). (1) Means followed by the same capital letter did not differ by the Tukey test at 5 %.

220.78 m^3 ha^{-1}, which represents a drop of around 3 cm from the initial depth of 20 cm.

The values for BD and Ma vary from one system to another (Figure 2). The macroporosity values were best in NTACR, and figure 3 shows the differences between the management systems in terms of solid phase organization (macroporosity) on a microscopic scale (Fitzpatrick, 1984; Bullock et al., 1985).

Larger clods were observed in NTAC and NTACC, some sized 20 to 50 mm, whereas for NTACR the clods were smaller but more widely spaced. The soils under NTAC and NTACC are therefore organized similarly, much more consistent and significantly different from the soil under NTACR. Another important detail is the presence of cracks under NTAC (fine and omnidirectional) and NTACC (larger and more horizontal), and the complete absence of soil cracks in NTACR. Whatever the management system, the most rounded pores are related to biological activity.

These thin sections show the different effects of the management systems on soil organization and confirm the BD and Ma data (Figure 2), showing that NTAC results in a more aggregated system, with aggregates grouped to form larger, less porous units than in the other two systems. NTAC and NTACC compact the soil and this effect is significantly less evident under NTACR. Porosity and cracking (between aggregates) was observed in NTAC and NTACC, whereas NTACR tends to a more intra-aggregate and biologically-induced porosity with greater pore continuity.

Soybean yield

Soybean yield was significantly effected by the treatments and NTACR and NTACC differed from NTAC ($p < 0,05$) (Figure 4), indicating that chiseling the soil a few times per year improves yields when no-till cropping is not combined with crop rotation, and in view of the cost of chiseling, crop rotation is preferable.

The soil characteristics BD and Ma influenced yield more strongly than OM and F1. About 98 % of the yield variation could be explained by BD and Ma, and less than 23 % by OM and F1, as shown by the following regression equations: regression (Yield x OM): $\hat{y} = 1348.1 + 574.22 x$; $R^2 = 0.20$; regression (Yield x FL): $\hat{y} = 134065 - 2254.9 x$; $R^2 = 0.23$; regression (Yield x BD): $\hat{y} = 10656 - 5352.8 x$; $R^2 = 0.98$; regression (yield x Ma): $\hat{y} = 1755.5 + 6755.6 x$; R2 = 0.98 (Figure 4).

Figure 5 shows a way of comparing the average soybean yield in the no tillage systems NTAC, NTACC and NTACR of 11 years and the values obtained in the 0–20 cm layer for organic matter content (OM), bulk density (BD), macroporosity (Ma) and flocculation (FL).

Taking the reference values (Table 2) as an index of 100 % the OM content and FL values were always below the reference values for all management systems studied. For NTACC and NTACR, the values of BD and average soybean yield

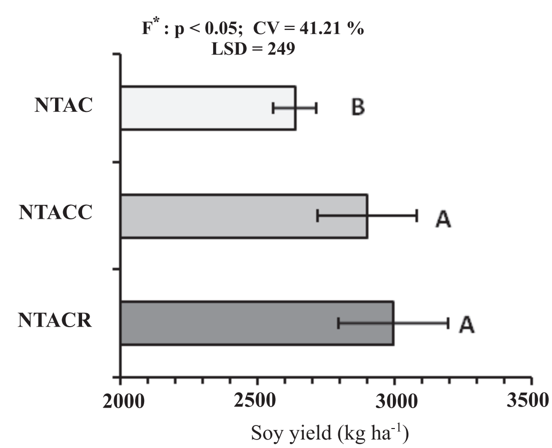

Figure 4. Average values over 11 years for soybean yield under no-tillage annual crops (NTAC), no-tillage annual crops with quarterly chiseling (NTACC) and no-tillage crop rotation (NTACR). (1) Means followed by the same capital letter did not differ by the Tukey test at 5 %.

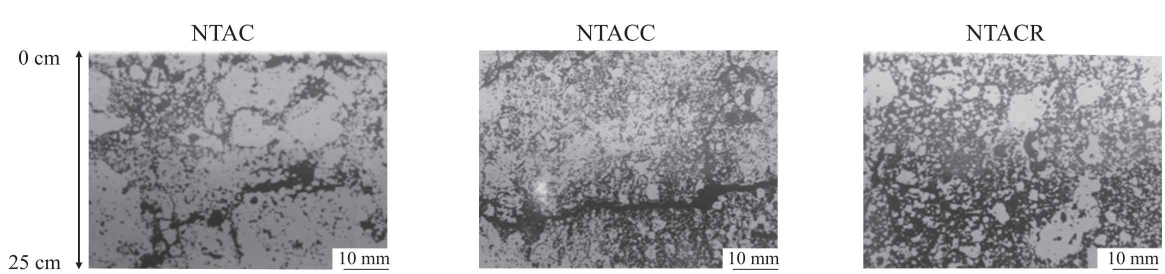

Figure 3. Thin section photos in reflected UV light under optical microscope showing macroporosity* in the 0–25 cm layer of soil under no-tillage annual crops (NTAC), no-tillage annual crops with chiseling (NTACC) and no-tillage with crop rotation (NTACR). *light areas = solids, dark areas = voids (pores).

were equal to the reference values, whereas Ma was always higher than the reference values, especially in NTACR. The lowest Ma and average soybean yield were observed in NTAC, i.e. variations in Ma influenced the average soybean yield.

These results show that in NTAC, heavy machinery traffic on the surface, especially when poorly drained, has a greater tendency to degrade the soil (lower values for OM, FL and Ma and a higher BD value) (Tavares Filho et al., 2001; Bertol et al., 2001; Beutler et al., 2001; Neves et al., 2007). Furthermore, the results reported by Tavares Filho et al. (2006) and Domingos et al. (2009) on clayey soils under different management systems show that chiseling significantly increases water infiltration under no tillage (increased macropore volume), although the authors state that this effect lasts no more than a year. On the other hand, no tillage (avoiding soil disturbance) with crop rotation (NTACR), as well as the plant residues left on the soil surface, helps maintain and improve the soil physical properties.

An important detail in the NTACR system is the possibility of higher microbial activity and greater aggregate stability and pore continuity (especially Ma) (Costa et al., 2006), facilitating water infiltration and preventing surface runoff (Schick et al., 2000) compared to systems without crop rotation. This could explain why soybean yields (Figure 4) were higher than in the other systems. Therefore, rotation of crop species with aggressive root systems and a high contribution of dry matter could improve the soil physical properties and therefore agricultural yield.

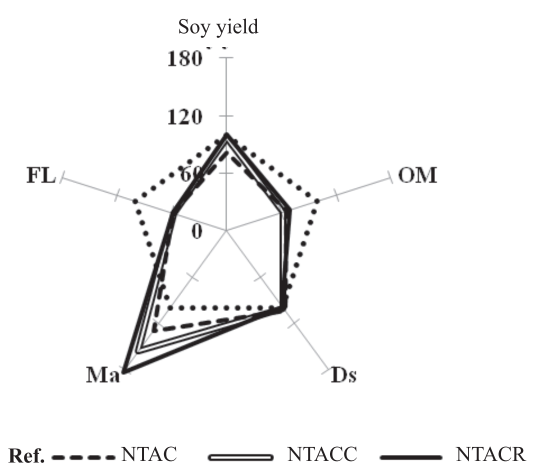

Figure 5. Comparative diagram of average soybean yield and its relation with soil organic matter content (OM), bulk density (BD), macroporosity (Ma), and flocculation (FL) in the 0–20 cm soil layer. after 11-years under three management systems: NTAC (no-tillage annual crops), NTACC (no-tillage annual crops with quarterly chiseling) and NTACR (no-tillage with crop rotation).

CONCLUSIONS

1. The highest values for soil bulk density and organic matter content and the lowest for macroporosity were obtained for the no-tillage annual crops (NTAC) system, whereas no-tillage crops with quarterly chiseling (NTACC) produced the lowest organic matter values and no-tillage crops with crop rotation (NTACR) produced the highest values for organic matter content and macroporosity, and the lowest soil density values.

2. The average soybean yield values were highest for no-tillage with quarterly chiseling and no-tillage crop rotation. The average yield values were lowest for no-tillage annual crops, with no chiseling or rotation.

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