RELATIONSHIPS BETWEEN ORGANIC CARBON FRACTIONS AND PHYSICAL PROPERTIES OF AN ARGENTINE SOIL UNDER THREE TILLAGE SYSTEMS[1]

DIEGO COSENTINO[2], ALEJANDRO COSTANTINI[3], ANDREA SEGAT[2] and MATÍAS FERTIG[4]

ABSTRACT - A field trial was carried out on a Typic Argiudoll soil cropped to corn, located at Córdoba, Argentina. The effect of three tillage systems: direct drilling (DD), reduced tillage (RT) and conventional tillage (CT), on organic carbon (OC), microbial biomass carbon (MBC), structural stability, aggregates density and percentage of macroaggregates greater than 2 mm was studied. OC was significantly higher in DD plots. Also, DD was the only system that presented significant differences in depth. MBC showed a similar trend to OC, but the decrease of its contents in RT and CT were greater than DD. The highest soil structural stability was obtained in DD and the lowest in CT. The decrease in structural stability (in percentage) was greater than the decrease in OC and MBC. Aggregates density did not show differences between tillage systems for the surface samples. All the tillage systems presented the highest values of aggregates density at 5-15 cm. A greater percentage of macroaggregates was found in DD for both sampling depths. When MBC content was considered throughout the sampling depth, a high correlation with macroaggregates percentage was found.

Index terms: microbial biomass carbon, structural stability, macroaggregates, direct drilling, conventional tillage.

RELAÇÕES ENTRE FRAÇÕES DE CARBONO ORGÂNICO E PROPRIEDADES FÍSICAS DE UM SOLO DA ARGENTINA SOB TRÊS SISTEMAS DE CULTIVO

RESUMO - Um ensaio de campo foi feito com monocultura de milho em um solo Argiudoll típico em Córdoba, Argentina. Avaliaram-se os efeitos de três sistemas de cultivo: plantio direto (PD), cultivo reduzido (CR) e cultivo convencional com arado de aiveca (CC) sobre o carbono orgânico total (CO), carbono da biomassa microbiana (CBM), estabilidade estrutural, densidade de agregados e porcentagem de agregados maiores que 2 mm. O CO foi mais alto e significativamente diferente, nas parcelas sob PD. Foi também o único sistema que apresentou diferenças significativas com a profundidade. O CBM apresentou uma tendência similar ao CO, embora o decréscimo tenha sido maior em CR e CC que em PD. A maior estabilidade estrutural foi apresentada por PD, e a mais baixa por CC. O decréscimo em estabilidade estrutural (em porcentagem) foi maior que o decréscimo em CO e CBM. A densidade de agregados não apresentou diferenças entre os sistemas de cultivo nas amostras superficiais. Os valores mais altos foram achados sempre em profundidade. Uma maior porcentagem de macroagregados foi achada em PD nas duas profundidades. Quando o conteúdo de CBM foi considerado quanto ao total da profundidade de amostragem (0-15 cm), foi achada uma alta correlação com a porcentagem de macroagregados.

Termos para indexação: carbono da biomassa microbiana, estabilidade estrutural, macroagregados, plantio direto, cultivo convencional.

INTRODUCTION

Tillage, crop rotations and straw management have been identified as factors that control the organic matter level in soils (Parton et al., 1987). In general, when soil is cropped, the organic carbon content is adversely affected, because the organic matter input is reduced, and the decomposition of the present one is accelerated by tillage (Gupta & Germida, 1988; Havin et al., 1990; Richter et al., 1990).

Cropping practices have a marked effect on soil structure (Angers et al., 1992). The proportion of water stable aggregates changes, often rapidly, when tillage practices or cropping rotations are modified. Chan & Mead (1988) found a higher quantity of water stable aggregates under zero tillage than conven-

[1] Accepted for publication on February 4, 1998.

[2] Agr. Eng., Facultad de Agronomía, Universidad de Buenos Aires, Cátedra de Edafología, Av. San Martín 4453, CP. 1417, Buenos Aires, Argentina. E-mail: cosenti@mail.retina.ar

[3] Agr. Eng., M.Sc., Facultad de Agronomía, Universidad de Buenos Aires, Cátedra de Edafología. E-mail: costanti@mail.retina.ar

[4] Student, Facultad de Agronomía. Universidad de Buenos Aires, Cátedra de Edafología.

tional tillage. Weill et al. (1989) found, for clay soils, an advantage in the stability of aggregates between 2 and 8 mm size for zero tillage and chisel tillage, with regard to conventional tillage. Carter (1992) found that chisel ploughing increased the aggregate stability 85% in relation to conventional tillage. Zero tillage or reduced tillage significantly increased surface soil stability.

Tillage systems affect soil structure in different ways, and reduce its organic matter content (Van Veen & Paul, 1981). Even though organic matter is an important aggregate binding agent, changes in water stable aggregates, produced under different managements, were not always related with total soil organic matter variations (Baldock et al., 1987). Elliott (1986) sustains that soil cropping produces a loss of labile organic matter, which joins microaggregates into macroaggregates. Sparling et al. (1992) conclude that a 6 to 14 years crop period provokes a sharply decrease in the water stable macroaggregates proportion, which is related with the decrease in the organic carbon and microbial biomass carbon contents. Hart et al. (1988) sustain that there is a strong loss in macroaggregates stability in silty loam soils afterwards continuous cereal crop, and they found that this decrease was more strongly related to microbial biomass carbon rather than to organic carbon. Microbial biomass carbon changes have been used to follow tillage-induced variations (Powlson & Jenkinson, 1981; Schnürer et al., 1985; Carter, 1986), but the role of microbial biomass carbon in the contribution of organic matter to aggregate stability is still not clear (Capriel et al., 1990). Soil microorganisms can participate in the aggregate formation and stability in many ways such as gums and mucilages production that bind soil particles, and through the effect of filamentous organisms (Tisdall & Oades, 1982). The loss of organic matter during a crop, and particularly the microbial component, can affect adversely soil physical and biological properties (Carter, 1986; Carter & White, 1986).

In the Argentine Pampa, some manifestations of physical and chemical degradation have begun to appear. The most notorious is a decrease in organic matter content and in structural stability, which provokes lesser yields and soil loss by erosion. To attenuate this degradation process, many farmers are beginning to implement more conservative tillage systems, such as direct drilling.

The object of this study was to determine the variations produced on organic carbon, microbial biomass carbon and some soil physical properties due to the use of different tillage systems, and to establish the contribution of some soil organic carbon forms to aggregate stability and size class distribution.

MATERIAL AND METHODS

Study locality

The present study was conducted at the Agricultural Experimental Station INTA, Marcos Juárez, Córdoba, Argentina, on a silty clay loam soil (Typic Argiudoll). The climate is temperate and subhumid, with an annual mean temperature of 17.2° C, and a mean temperature in July (month in which samples were collected) of 10.1°C. Annual mean rainfall is 924 mm, of which 72% occurs between October and March.

The trial was a completely randomized block design with three replications. In the plots, continuous maize (*Zea mays* L.) was cropped for the last six years under three different tillage systems: conventional tillage (CT), moldboard plow at 15 cm depth, two passes of tandem disk harrow at 10 cm depth, danish tines and spike-tooth harrow; reduced tillage (RT), chisel plow at 15 cm depth, one pass of tandem disk harrow at 10 cm depth, danish tines and spike-tooth harrow; and direct drilling (DD), using a no-till planter. The size of each plot was 15 m wide and 21 m long.

Sampling

Three samples of each plot at two depths were taken (0-5 and 5-15 cm). Taking into account that one of the objectives of the trial was to understand the relationship between biological and physical factors, the point of view of Jastrow & Miller (1991) was followed. Therefore, all the analyses were performed on the same sample.

Analytical procedures

Field moisture samples were carefully carried to laboratory in order to avoid alterations in physical properties. The following analytical determinations were performed: organic carbon (OC) (Page, 1983), microbial biomass carbon (MBC) (Vance et al., 1987; Tate et al., 1988), dry aggregates size class distribution, with mechanical sieving during 5 minutes, structural stability (De Leenheer & De Boodt, 1959), aggregates density (using aggregates between 2 and 3 cm) (Burke et al., 1986). All determinations were made by triplicate. An ANOVA was used to test for significant differences between treatments; when found, a Tukey's test was conducted.

RESULTS AND DISCUSSION

Organic carbon

The analysis of variance of the two depths as a whole showed significant differences between tillage systems (TS) ($P<0.001$) and in the interaction tillage system x depth ($P<0.02$). When sampling depths were analyzed separately, DD presented the highest significant OC contents at both depths (Table 1). OC was 27% and 32% lower in RT and CT, respectively, related to DD in the first 5 cm, while these percentages were 14% and 21% lower, for the 5-15 cm layer. Analyzing the tillage systems separately, DD is the only one that presented significant differences with the sampling depth ($P<0.02$), and is responsible for the significant interaction. Therefore, DD promoted a greater organic carbon surface accumulation, because mineralization conditions in this system were not as favorable as in the others.

Microbial biomass carbon

As organic carbon, when both sampling depths were analyzed as one, the MBC content showed significant differences between TS ($P<0.001$). No differences were found with sampling depth, but there was a significative interaction among tillage system x sampling depth ($P<0.05$). DD was the only tillage system that presented differences in depth (Table 1).

Considering the two sampling depths separately, it was found, for the surface sample, that DD presented higher contents of MBC than the other tillage systems. Over the 0-5 cm soil layer, RT and CT resulted in a decline of 29% and 48%, respectively, compared with the levels under DD. For the 5-15 cm layer, no differences between DD and RT were found, but both values were greater than CT (Table 1). For DD, the MBC content at 5-15 cm was 27% lower than the 0-5 cm layer.

In general, MBC distribution follows OC, being in line with Angers et al. (1992). Many studies have found a close relationship between OC and MBC (Adams & Laughlin, 1981; Carter & Rennie, 1982; Carter, 1986; Carter, 1991; Costantini & Segat, 1994), which in this study was greater for 0-5 cm depth ($P<0.001$) than 5-15 cm depth.

Even though statistical analysis showed similar trends for OC and MBC for tillage systems, percentage differences in MBC were greater than in OC, showing a higher sensitivity to detect changes in soil organic matter, produced as a consequence of soil management in accord with Powlson et al. (1987) and Sparling et al. (1992).

Aggregate stability

Aggregate stability, expressed as the variation in the mean weight diameter (ΔMWD), showed significant differences between TS ($P<0.001$). Analyzing each sampling depth separately, both layers showed the lower values of ΔMWD in DD, what

TABLE 1. Mean values of organic carbon (OC), microbial biomass carbon (MBC), aggregate stability (expressed by the ΔMWD), aggregate density and percentage of macroaggregates, for direct drilling (DD), reduced tillage (RT) and conventional tillage (CT), at the two sampling depths[1].

Tillage system	OC (%)		MBC ($\mu g\ C\ g^{-1}$ soil)		Aggregate stability (ΔMWD)		Aggregate density ($Mg\ m^{-3}$)		Macroaggregates (%)	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
DD	2.37 aA	2.04 aB	216.25 aA	156.88 aB	32.15 aA	40.57 aA	1.33 aA	1.48 aB	43.97 aA	62.22 aB
RT	1.73 bA	1.76 bA	154.41 bA	177.92 aA	74.84 bA	54.63 abA	1.30 aA	1.41 bB	35.69 bA	53.52 bB
CT	1.60 bA	1.61 bA	111.76 bA	86.59 bA	128.22 cA	84.31 bA	1.28 aA	1.38 bB	32.65 bA	52.76 bB

[1] Values followed by the same letter do not present significant differences (Tukey test, $P<0.05$); small letters indicate comparisons in a same depth (vertical way in the table); capital letters indicate comparisons between sampling depths of a same tillage treatment (horizontal way in the table).

implies a higher structural stability. Conventional tillage presented the highest ΔMWD and RT intermediate values. No significant differences with depth were found in each different TS (Table 1).

Although no differences were found with depth, CT and RT showed a trend to present higher aggregate stability at 5-15 cm. These TS provoke a greater soil disturbance, placing more stable surface aggregates in the deeper layer. Similar results were found by Angers et al. (1992), comparing cropped soil and grasslands. Due to the greater disturbance produced in CT with regard to RT, these trends were more emphasized in CT.

Considering DD as the most conservative TS, changes in structural stability in RT and CT compared with DD were greater than changes in OC and MBC, in accord with Sparling et al. (1992). There was a decrease in stability for the first 5 cm of 133% and 300%, in RT and CT respectively, in the ΔMWD.

Aggregate density

The aggregate density for the whole samples showed significant differences with sampling depth ($P<0.001$). There were no differences among TS but there was a significative interaction between both sources of variation ($P<0.001$). When both depths were studied separately, no differences were shown between TS for the surface depth, while DD showed a higher density for the 5-15 cm layer (Table 1). This can be explained by the fact that DD only disturbs soil in the first 5 cm, while the other TS affect the whole soil layer studied. All the tillage systems presented an increase in aggregate density for the 5-15 cm layer (11%, 8% and 8% for DD, RT, and CT, respectively).

Since the aggregate density did not follow the same trend in depth that organic carbon forms did, the 5-15 cm layer increase in this parameter is probably due to a mechanical compaction effect.

Percentage of macroaggregates (> 2 mm)

For the two studied depths, DD resulted in a higher percentage of macroaggregates compared with the other TS (Table 1). The lower percentage of macroaggregates in CT and RT can be explained, as mentioned by Tisdall & Oades (1980), by the decrease in aggregate stability in these TS. A significant difference was found between both depths ($P<0.001$) for the three TS, being in all cases highest at 5-15 cm depth. In DD there is no disturbance of the 5-15 cm layer, which results in a higher proportion of macroaggregates. On the other hand, there is an increase of structural stability in RT and CT for the same depth, which could have as consequence a greater proportion of macroaggregates. This increase can also be explained by the increase in the aggregates density.

Comparing different TS for each depth, the proportion of macroaggregates was related with OC and MBC for the 0-5 cm depth layer. The correlation with MBC was $r = 0.48$ ($n = 27$; $P<0.02$) and with OC, $r = 0.697$ ($n = 27$; $P<0.001$). For the 5-15 cm layer, a significative correlation was found with OC, but no correlation was found with MBC. Sparling et al. (1992) found no significative correlations between percentage of macroaggregates with OC nor with MBC.

Considering both depths as a whole, and transforming the quantities of MBC from μg C g^{-1} soil, to kg ha^{-1} (taking into account the thickness of each layer and its bulk density), a close correlation ($r = 0.647$; $n = 54$; $P<0.001$) was obtained between MBC and macroaggregate percentage (Fig. 1).

When direct drilling is practiced, depth distribution of carbon fractions and physical soil properties change. A higher OC and MBC content is preserved, becoming more stratified than in the other TS, and turning aggregates more stable. Less DD planter soil aggression, derived from the disruption of only the top 5 cm layer, results in a greater quantity of macroaggregates, and a lower organic matter decomposition thus increasing aggregates stability, making the three variables change concurrently. Although 2-3 cm clods used to determine aggregate density have a more favorable physical and organic condition in DD, aggregate density tends to be higher in DD at 0-5 cm layer and in all TS at 5-15 cm layer. This may be due to the simultaneous effect of higher quantity of macroaggregates with small interaggregate porosity, and the greatest compaction of superficial layer with regard to the deeper one under the three TS.

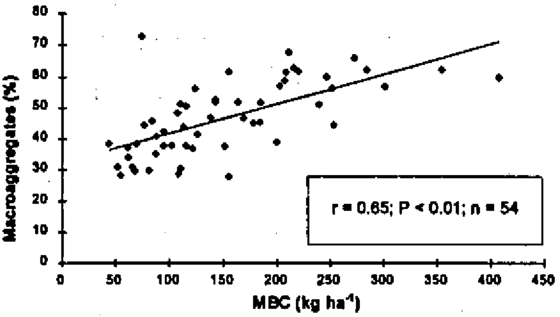

FIG. 1. Correlation of microbial biomass carbon (MBC) (0-15 cm depth) with percentage of macroaggregates.

CONCLUSIONS

1. Direct drilling is the tillage system that promotes less degradation of organic fractions and physical properties than other tillage systems commonly used.

2. Physical parameters are clearly related to the carbon fraction in surface; in the deeper layer, the effect of carbon components is not so clear.

ACKNOWLEDGEMENTS

To Prof. M. Conti for her useful comments and Dr. H. Marelli for his collaboration. This work was partially supported by "CULTIVOS SIN LABRANZA" project, INTA - FAUBA.

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