

POSTER PAPER

**Dynamics of Aggregate Stability Influenced
by Soil Management and Crop Residues**

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Abstract: The type of tillage and crop systems used can either degrade or cause a recovery of the structure of agricultural soils. The objective of this study was to determine the structural stability of the soil using mean weight diameter (MWD) of soil aggregates in three different periods of a succession of crops consisting of beans/cover plants/maize under no tillage (NT) and conventional tillage (CT) management systems. Soils were sampled at 0- to 5-cm and 5- to 15-cm depths in three periods (P1, P2, P3): 1) November 2002 (spring/summer), 2) April 2003 (beginning of autumn), and 3) December 2003 (end of spring/beginning of summer). Aggregate stability was determined by wet sieving. The effects of the tillage systems, vegetal residues, and sampling depths on the structural stability of the aggregates were assessed and then related to organic matter (OM) contents. Aggregate stability showed temporal variation as a function of OM contents and sampling period. No tillage led to high MWD values in all study periods. The lowest MWD values and OM contents were observed 4 months after the management of the residues of cover plants. This finding is consistent with the fact that at the time

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of the samplings, most of the OM had already mineralized. The residues of sunn-hemp, millet, and spontaneous vegetation showed similar effects on soil aggregate stability.

Keywords: Aggregate stability, cover plants, sampling period, tillage systems

INTRODUCTION

Knowledge and quantification of the impact soil management and use can have on the physical quality of the soil are fundamental for the development of sustainable agricultural systems (Dexter and Youngs 1992). According to Sánchez (1981), the changes produced in the soil as a result of tillage and type of crop used should be evaluated by subjecting a soil under natural vegetation to agricultural practices and then analyzing its properties periodically. However, for different reasons, it is difficult to carry this out under these conditions. In Brazil, studies have been conducted on what changes occur in the properties of soils using natural soil as a reference (Silva and Ribeiro 1992; Sanches et al. 1999; Borges, Kiehl, and Souza 1999).

Different management practices can directly affect the properties of a soil, including aggregation processes. The factor having the most negative effects is the tillage system used, which can lead to intense soil removal and addition of low levels of organic residues (remains of crops, roots, etc.), affecting the organic matter (OM) content of the soil, one of the principal agents in the formation and stabilization of aggregates (Tisdall and Oades 1982). Hence, the agricultural systems adopting more conservative practices, such as minimum tillage and no tillage, which also accompany high rates of vegetal residue addition, can halt the decline of structural stability of agricultural soils, as well as promote the recovery of soils that have already undergone degradation.

For the most part, soil aggregate stability results from the mechanical union of cells and hyphae of organisms, the cementing effects of products derived from microbial synthesis or the stabilizing action of the breakdown products that act individually or in combination (Baver, Gardner, and Gardner 1973). The soil aggregation can undergo permanent or temporal alterations, showing cyclical variation brought on by factors related to the climate, soil type, soil management practices, and the amount and quality of the organic residues incorporated into the soil (Campos et al. 1999; Castro Filho et al. 2002; Plante and McGill 2002; Wohlenberg et al. 2004). Working with gramineous and leguminous plants as recovering agents in the aggregation process, Reinert (1993) found a important temporal variation in the aggregation of the soil and concluded that experiments involving few evaluations can lead to erroneous interpretations.

The influence of OM in soil aggregation is a dynamic process, a continuous supply of organic residue being necessary to maintain the adequate soil structure for plant growth. The management systems of soils and crops,

when adequate, provide a supply of OM through vegetal residues, in addition to the beneficent action of plant roots and the protection given to the soil surface (Campos et al. 1995). In South America, generally, crop residues are not removed from the land but rather they are left on the surface or incorporated into the soil by conventional tillage. Presently, the technique commonly used is a succession of crops with cover plants, to supply elevated levels of OM to the soil. If the amounts of vegetal residues are large, these will persist on the soil surface for a greater period of time (Stroo et al. 1989; Bertol et al. 1998; Gilmour et al. 1998), especially with residues that are resistant to decomposition, as in the case of gramineous residues. The breakdown of crop residues will depend on the nature and quality of the vegetal material, the soil fertility, the management of the cover, and the degree of residue fractionation. The climatic conditions must also be considered, mainly rainfall and temperature, which influence the microbial activity in the soil.

The objective of this work was to evaluate the stability of aggregates in a succession of crops, under two soil management systems, consisting of beans/cover plants/maize, in three periods: 1) November 2002 (spring/summer), 2) April 2003 (beginning of autumn), and 3) December 2003 (end of spring/beginning of summer).

MATERIALS AND METHODS

This study was carried out in Estado de Mato Grosso do Sul, in Brazil, in an area whose geographic coordinates are 51°22' longitude west of Greenwich and 20°22' latitude south, with an altitude of 335 m. In this area, the mean annual precipitation level is 1370 mm, and temperatures 23.5°C. The type of climate according to Köppen is AW (Camargo et al. 1974), characterized as humid tropical with rainy summers and dry winters. The soil was classified as Latossolo Vermelho (EMBRAPA 1999) or as Oxisol (Soil Survey Staff 1999). This area, whose original vegetation was savanna, was transformed into agricultural land in 1978. Starting in 1997, the area was studied for 6 years (1997–2003) to evaluate the effects of conventional tillage (CT) and no tillage (NT) in a succession of crops consisting of beans (*Phaseolus vulgaris*) in winter, cover plants in spring, and maize (*Zea mays* L.) in summer.

The experimental design included random blocks in a scheme of bands with subdivided plots with four repetitions. The treatments consisted of two soil management systems (NT and CT), two cover plants (leguminous/gramineous) + fallow, and two depths (0–5 cm, 5–15 cm). The cover plants used were sunn-hemp (*Crotalaria juncea* L.) and millet (*Pennisetum americanum*). As reference, two areas were considered: 1) a fallow area, having undergone the same agricultural practices as those of the cultivated area (NT and CT) but that was not seeded (this plot developed abundant

spontaneous vegetation (EV), which was incorporated into the soil in the same way as the residues of the crops/cover plants), and 2) natural soil (NS) with savanna vegetation.

For each of the three sampling dates studied, soil samples were collected at depths of 0–5 cm and 5–15 cm simultaneously for each subplot. Crop residues were managed after their collection, whereas cover plants were managed before floration. In both cases, the residues were broken up, and these remained on the surface in NT and were incorporated into the soil in CT. The first sampling (18 November 2002) was performed 2 months after the management of bean residues. The second sampling (9 April 2003) was carried out 4 months after the management of cover plants. The third (18 December 2003) took place 2 months after the management of bean residues; this area had spontaneous vegetation because this experimental plot had been abandoned.

Aggregate stability was determined by wet sieving, following the method proposed by Angers and Mehuys (1993), starting with aggregates of initial diameter between 4 and 6.35 mm. Six aggregate-size classes (>4 mm, 4–2 mm, 2–1 mm, 1–0.5 mm, 0.5–0.25 mm, and <0.25 mm) were considered.

From the percentage of aggregates for each size class, the mean weight diameter (MWD) was determined for the three study periods. The MWD and OM data were treated statistically by analysis of variance and Tukey test to compare the means at a significance level of 5%. The effect of the tillage systems and crop residues/cover plants residues on the structural stability of the aggregates were determined for the three study periods.

RESULTS AND DISCUSSION

The results of the effects of the interactions between the period and tillage systems on MWD and OM at two depths (0–5 cm and 5–15 cm) are presented in Table 1. The temporal variation of the structural stability is associated with the variation in the contents of OM of the soil and the type of tillage. Campos et al. (1999) showed that the aggregation of the soil could undergo permanent or temporal alterations, demonstrating cyclical variation provoked by soil and crop management practices.

In the NT system (5 cm being the mean depth at which crops and cover plants were planted), no significant differences were observed for MWD for the three sampling dates, whereas under CT the MWD values differed significantly at each sampling, at a depth of 0–5 cm. At the depth of 5–15 cm, a tendency toward lower values was observed, although not significant in all cases, with respect to those obtained more superficially. In this horizon, in the NT system, a gradual increase in MWD was observed throughout the study period; this increase was significantly greater during the third sampling date.

When comparing the two soil management systems, seeding crops with NT had a positive effect on soil stability. This indicates that not tilling the soil and maintaining the crop residues on the surface under direct seeding

Table 1. Effect of the interactions between sampling date and tillage systems on mean weight diameter (MWD) of soils aggregates and soil organic matter (OM) at two depths (0–5 cm and 5–15 cm)

Sampling date	MWD (mm)		OM (g dm ³)	
	NT ^a	CT ^a	NT	CT
0–5 cm				
18 Nov. 2002	3.68 aA	3.89 aA	38 aA	39 aA
9 Apr. 2003	3.53 aA	2.71 cB	32 bB	34 bA
18 Dec. 2003	3.69 aA	3.53 bA	38 aA	33 bB
5–15 cm				
18 Nov. 2002	3.10 bB	3.78 aA	26 bB	31 aA
9 Apr. 2003	3.28 bA	3.21 bB	24 cB	27 bA
18 Dec. 2003	3.65 aA	3.42 bA	31 aA	26 bB

^aNT: no tillage; CT: conventional tillage.

Note: Means followed by letters, lowercase letters in the column and uppercase letters on the line, do not differ at the 5% level of probability by Tukey test.

favors stability in the surface layers of the soil with respect to similar situations under CT with removal of soil (Carpenedo and Mielniczuk 1990; Campos et al. 1995). Hence, with direct seeding, there is no aggregate disruption and the contents of OM increase, due to less oxidation of organic carbon (Tisdall and Oades 1982).

Statistically, in the 0- to 5-cm layer, no significant differences were observed in MWD values between NT and CT at the first and third sampling dates. These results were expected because the two periods represent a similar situation; that is, at that moment the accumulative effects of summer/winter crops were being evaluated. Given that maize residues had been managed 6 months before, the effects on aggregation were minimal because a mineralization of these would have occurred and therefore aggregate stability would be due to the effects of the residues of the winter crops (beans). Analyzing MWD values, in absolute terms, the MWD values in NT were similar in both periods (3.68 mm and 3.69 mm on sampling dates 1 and 3, respectively). This result is related to the fact that the same amount of OM was present at both times (38 g dm³). In the conventional tillage, the highest OM value (39 g dm³) and the highest MWD (3.89 mm) were recorded on 18 November 2002. This OM value, higher than those obtained in NT, could be related to a greater supply of bean residues as a function of the variability in the number of plants in between plots. In the same experimental area, Silva (2003) found that the amount of green mass generated with CT (12723 kg ha⁻¹) was significantly higher than that obtained with NT (9583 kg ha⁻¹). The amount of dry matter was slightly higher in CT (2760 kg ha⁻¹) than in NT (2547 kg ha⁻¹), although these differences were not significant.

The strongest negative effects on the state of soil aggregation, for NT as well as for CT, during the succession of beans/cover plants/maize, were observed 4 months after the management of cover plants (9 April 2003). Under these conditions, the contents of OM decreased, with concomitant decrease in the MWD of the aggregates. In this phase in CT, MWD at a depth of 0–5 cm decreased by 1.18 mm with respect to MWD on 18 November 2002.

Guerif et al. (2001) observed that tillage systems have a direct influence on the OM content of the soil and aggregate stability. According to Hernanz et al. (2002), aggregate stability could be an indicator of soil quality, directly related to OM. Ismail, Belvins, and Frye (1994) showed, in a 20-year study using maize in Kentucky, that the higher content of OM is confined to the top 5 cm of soil.

Tisdall and Oades (1982) observed that the correlation between OM and MWD was not always significant. This work showed that some of the MWD values presented in Table 1 do not correspond with the OM contents found on some sampling dates. This suggests the existence of other factors responsible for the aggregate stability. Given that these Oxisols are characterized as having elevated levels of clay and the presence of iron and aluminum oxides, it would be expected that the stability of these soils would be greatly affected by the interaction of these factors. Russell (1973) stated that of the three classes of primary particles, clay is the most important factor for aggregate stability. Boix Fayos et al. (2001) observed that the clay fraction correlated positively with the indexes of soil aggregation. Demattê (1980), characterizing a soil profile from the area studied in the present work, observed that these soils presented 12.21% aluminum oxides and 23.99% iron oxides, giving stability to these soils.

Table 2 presents the results of the effects of the interactions between the sampling date and cover plants on MWD and OM at two depths (0–5 cm and 5–15 cm).

In the original soil, where the natural vegetation (NV) is savanna, samples were taken only on the first sampling date (18 December 2002). In the fallow land, showing the development of spontaneous vegetation (EV), samples were taken during the three sampling periods.

The effects of the residues of crops and cover plants on soil aggregation are dependent on the quality, quantity, and type of management used with this added material (degree of residue fractionation), apart from climatic factors and the specific characteristics of the soil (Gilmour et al. 1998; House and Stinner 1987).

Two months after the management of beans residues (18 November 2002 and 18 December 2003) a favorable environment was created in the soil due to the decomposition state of these residues. This improvement in the soil conditions affected aggregation, increasing MWD values. The dynamics of the OM in the soil induces temporal variations in the stability of the aggregates. Hence, on 9 April 2003, a notable decrease was observed in the amount of

Table 2. Effect of the interaction between sampling date and cover plants on mean weight diameter (MWD) of soil aggregates and soil organic matter (OM) at two depths (0–5 cm and 5–15 cm)

Depth	Sampling date	Sunn-hemp	Millet	EV ^a	NS ^a
MWD (mm)					
0–5 cm	18 Nov. 2002	3.57 aB	3.44 aB	3.34 aB	4.79 aA
	9 Apr. 2003	2.65 bB	2.70 bB	2.34 bB	ND
	18 Dec. 2003	3.49 aB	3.04 abB	3.13 aB	ND
5–15 cm	18 Nov. 2002	3.05 aA	3.01 aA	2.96 aA	4.74 aA
	9 Apr. 2003	2.75 aA	2.92 aA	2.58 aA	ND
	18 Dec. 2003	3.17 aA	2.95 aA	3.29 aA	ND
OM (g dm ³)					
0–5 cm	18 Nov. 2002	30 aB	30 aB	30 aB	65 aA
	9 Apr. 2003	20 cC	24 abB	21 cBC	ND
	18 Dec. 2003	24 bB	26 bB	26 bB	ND
5–15 cm	18 Nov. 2002	27 aA	25 aA	25 aA	38 aA
	9 Apr. 2003	21 aA	20 aA	22 aA	ND
	18 Dec. 2003	26 aA	26 aA	25 aA	ND

^aEV: spontaneous vegetation; NS: natural soil; ND: not determined.

Note: Means followed by letters, lowercase letters in the column and uppercase letters on the line, do not differ at the 5% level of probability by Tukey test.

OM, justified by the time elapsed (4 months) after cover plant management. During this time (December 2002–April 2003), elevated temperatures (maximum mean temperature of 32 °C and minimum of 21 °C) and a total of 575 mm of precipitation were recorded. Under these local climatic conditions, the residue decomposed very quickly. Bertol et al. (1998) and Bertol, Leite, and Zoldan (2004), while studying the decomposition of dry residues of maize (Santa Catarina, Brazil), found differences in the rate of decomposition between both experiments and attributed these to the different seasons of the year. The influence of the climate on the decomposition of residues has been reported by several authors (Hunt 1997; Wieder and Lang 1982; Gilmour et al. 1998). As a consequence of the decrease in OM content in the soil, its capability in the formation and stabilization of the aggregates would decline, as manifested by a significant reduction in MWD during this period.

Aggregation is influenced by the chemical composition of organic residues added to soils. Organic residues that decompose quickly may produce a rapid but temporal increase in aggregation, whereas organic residues that decompose slowly may produce a smaller but long-lasting improvement in aggregation (Sun, Larney, and Bullock 1995). The cover plants were managed 52 days after being seeded and therefore before completing their vegetative cycle (180–240 days). Gilmour et al. (1998) showed that

the relation C/N is lower before plant maturation than after, because the accumulation of C-rich compounds, such as lignin, is avoided. The lower the C/N relation, the faster the decomposition of residues will be (Stroo et al. 1989; Bertol et al. 1998). This indicates that in the present study, during the second study period, it was not possible to evaluate this temporal and ephemeral increase in stability caused by the remains of the cover plants. Reinert (1993), working with gramineous and leguminous as aggregation recovering agents, found vast seasonal variation and concluded that experiments conducted with few analyses could lead to erroneous interpretations. To evaluate the transitory effects of the cover plants in our parcels, he would advise making a sampling in a shorter space of time and throughout several years.

When analyzing absolute values of MWD, sunn-hemp improved stability on 18 November 2002 (3.57 mm) and 18 December 2003 (3.49 mm). Spontaneous vegetation (gramineous and leguminous) had the same effect as millet on 18 November 2002 (3.44 mm); however, on 18 December 2003, spontaneous vegetation presented greater MWD values than did millet (3.13 mm and 3.04 mm, respectively). This could be due to the effect of rooting on the aggregation, because 6 months had elapsed since the last time the spontaneous vegetation (fallow) was managed. As expected, the natural soil (NS) presented extremely elevated OM values, with significantly elevated MWD values (4.79 mm). The tillage and cropping produced (after 6 years) a negative effect on the aggregation of the soil that originally was savanna.

The data on OM (Table 2) show significant differences among the three sampling dates for the horizon 0–5 cm, yet at 5–15 cm these differences were not significant. The lowest values were observed on 9 April 2003; the value obtained in the plot seeded with millet is the highest for this period. This value could be related to the fact that the production of dry material from the millet was elevated in that period. In this same study area, several authors found differences in the amount of dry material generated by the millet in different years. Carvalho (2000) obtained 10316 kg/ha in 1998, and Almeida (2001) obtained 10709 kg/ha. The production of dry material varies depending on the manure applied, the seeding density, the climate, and the phase of the vegetative cycle in which plant management was performed (Gilmour et al. 1998).

CONCLUSIONS

Three conclusions can be drawn from the results of this study: 1) NT gave the soil greater capacity to aggregate than CT, independent of the period evaluated; 2) aggregate stability showed temporal variation as a function of OM contents and sampling period; and 3) sunn-hemp, millet, and spontaneous vegetation had similar effects on soil aggregate stability.

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