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Soil and water loss in Ultisol of the Cerrado-Pantanal Ecotone under different management systems

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Soil and water losses were evaluated in dystrophic ultisol of the Cerrado-Pantanal Ecotone cropped with common bean, *Phaseolus vulgaris* L, under different tillage systems. The treatments studied were conventional tillage with primary and double secondary disking (CT), minimum tillage with chisel plow (MT) and no-tillage (NT) systems, the last associated to 4 crop densities: 0, 3, 6 and 9 Mg ha^{-1}. In order to characterize the experimental area, analyzes of water-dispersible clay, flocculation degree, aggregate stability, soil bulk density, soil porosity, soil moisture and surface roughness was carried out. Using the portable rainfall simulator, the plots received application of rainfall of 60 mm h^{-1} to evaluate soil and water loss. The treatments were arranged in a randomized block design with four replications. The soil losses ranging from 11.38 to 380.56 × 10^{-3} kg m^{-2}, while water losses ranging from 4.15 to 31.57 × 10^{-3} m^{3} m^{-2}. The highest soil losses occur in CT and the lowest water losses in MT. In NT, the highest level of crop residue deposition on soil surface reduces soil and water loss. Compared to water loss, soil loss is more susceptible to variations in the type of tillage system and levels of plant residues.

Key words: Water erosion, soil conservation, simulated rainfall.

INTRODUCTION

The agriculture and livestock activities in Brazil are still based basically on systems of non-conservative soil management practices. In recent years, the increase in extensive beef cattle husbandry has been linked to deforestation of native areas for the purpose of establishing new pasture areas, which do not receive adequate soil management. The bigger production of the Brazilian agricultural commodities likes grains, fiber and energy source. Sometimes it is planted under conventional soil tillage, increasing soil degradation by water erosion.Areas with higher rainfall and intense land use are more susceptive for water and soil losses (Valipour, 2014). The intensive soil tillage can pulverize the soil aggregates and cause compaction at different positions of the soil profile. This compaction reduces the water infiltration into the soil and promotes runoff which increases the loss of soil, water and nutrients.

Conventional tillage is characterized by complete soil

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turnover before cropping. This practice promotes incorporation of crop residues, but also disaggregates soil (Meijer et al., 2013), decreasing porosity and reducing water infiltration. Other studies report that conventional tillage is not as efficient as conservation tillage in avoiding nutrient, soil and water loss by water erosion (Mello et al., 2003; Carvalho Filho et al., 2007).

Conservation tillage, with low soil disturbance and maintenance of previous crop residues on the soil surface, reduces water and sediment loss (Schick et al., 2000; García-Orenes et al., 2009). Soil cover reduces the possibility of soil surface sealing because it dissipates the kinetic energy from rain and decreases disaggregation of soil particles, in addition to reducing the velocity and erosion capacity of runoff.

The present study evaluated soil and water losses under simulated rainfall in dystrophic ultisol subjected to different soil tillage systems in a bean crop.

MATERIALS AND METHODS

Study area

The experiment was carried out in Aquidauana, MS (20°28'S; 55°40'W; 191 m altitude). The area is part of the Cerrado-Pantanal Ecotone, characterized by hot sub-humid tropical climate with average annual rainfall of 1400 mm and average annual temperature of 24°C. Its soil is classified as dystrophic Ultisol with a sandy texture in Horizon A (750 g kg^{-1} sand, 130 g kg^{-1} silt and 120 g kg^{-1} clay) and sandy loam in Horizon B (610 g kg^{-1} sand, 140 g kg^{-1} silt and 250 g kg^{-1} clay). Terrain is flat to slightly wavy, with mean slope of 0.04 m m^{-1}. The area was cropped with bean (*Phaseolus vulgaris* L.) at a density of 16 seeds per linear meter and 0.45 m space between the planting rows.

Physical attributes of soil

Water-dispersible clay (WDC) and flocculation degree (FD) were determined from soil samples collected only in the 0-0.20 m layer. Soil samples collected at 0-0.20 m and at 0.20-0.40 m were used to determine mean geometric diameter (MGD) and weighted mean diameter (WMD) in order to characterize wet aggregate stability, soil bulk density, macroporosity, microporosity and total porosity.

Calibration of the rainfall simulator

Rainfall simulation with the InfiAsper simulator (Alves Sobrinho et al., 2008) was used to evaluate soil and water loss. The simulator operates using Veejet 80.150 emitters positioned 2.30 m above the ground and at a working pressure of 35.6 kPa, producing drops with a mean diameter of 2.0 mm. The area assigned to rainfall simulation corresponded to a 0.70 m^2 (1 m × 0.7 m) test plot, demarcated with galvanized steel sheets that allowed surface runoff collection.

As adopted in similar studies, the rainfall simulator was regulated to produce a 60 ± 5 mm h^{-1} rainfall intensity (García-Orenes et al., 2009; Oliveira et al., 2010; Donjadee and Chinnarasri, 2013). In addition, plots were pre-wetted using drippers before rainfall was applied in order to provide uniform moisturizing (Cogo et al., 1984). Time to surface runoff, the period between the onset of rainfall application and surface runoff, was recorded for each experimental plot. Each rainfall simulation test lasted 60 min.

Soil roughness, rainfall energy, and evaluation of soil and water loss

Rainfall simulation tests were performed in areas under three soil management systems: Conventional tillage with primary and double secondary disking (0.30 m and 0.10 m in depth) (CT); minimum tillage using a chisel plow with five shanks spaced 0.25 and 0.30 m in depth (MT); no-tillage (NT).

In NT management system, soil and water loss were evaluated in areas covered with four levels of crop residues on the soil surface: No residue (NT-0), 3 Mg ha^{-1} (NT-3), 6 Mg ha^{-1} (NT-6) and 9 Mg ha^{-1} (NT-9).

Surface roughness was determined according to Panachuki et al. (2010). Calculations of the kinetic energy produced in each rainfall event were based on the characteristics of the simulated rainfall.

Assessment of soil and water losses was performed by collecting surface runoff for 1 min, every 2 min, totaling 31 samples per test plot. Runoff depth was obtained from the relation between the volume of water drained and plot area. At the end of each precipitation event, runoff samples were taken to the laboratory to determine soil mass and runoff volume. Each collecting flask was weighed and added with 3 drops of hydrochloric acid to accelerate decantation of solids and facilitate excess water drainage. The flasks were kept in an oven at 60°C until complete water evaporation, and then weighed with the dried soil.

Statistical procedures

The treatments were arranged in a randomized block design with four replications. Data on physical soil attributes, soil and water loss were subjected to ANOVA, and statistically different means contrasted by the Tukey test (α=0.05).

RESULTS AND DISCUSSION

Physical attributes of soil

Soil from CT and MT did not exhibit differences in terms of WDC. FD was also similar among the treatments, and MGD and WMD were higher in NT and MT than in CT (Table 1). Araya et al. (2011) and Garcia-Orenes et al. (2012) consider that conservationist systems, with adequate soil cover, lead to high aggregate stability and decrease rates of soil and water losses during rainfall.

Tavares Filho et al. (2012) highlight the fact that the mechanisms for producing different sized aggregates are affected by the tillage system adopted and specific soil attributes. They also consider that no-till management increases aggregate and macroaggregate stability. The highest clay levels found in NT, as well as the lowest WDC levels, show the importance of clay, together with organic matter, for soil aggregation and structuring, affecting WMD and MGD levels. Stavi and Lal (2011) emphasize that the direct plantation system, with adequate soil covering, reduces the negative impact of the tillage operations on the soil structure and increases the aggregate stability. No-tillage farming favors soil microbiological activity and soil structuring. It facilitates root development, improves the chemical attributes of soil and affects the quality of organic matter. Since it reduces clay dispersion, it also improves the physical conditions

Table 1. Water-dispersible clay (WDC), flocculation degree (FD), mean geometric diameter (MGD) and weighted mean diameter (WMD) of soil under conventional tillage (CT), minimum tillage (MT) or no-tillage (NT).

Soil layer (m)	Treatment	WDC (%)	FD (%)	MGD (mm)	WMD (mm)
0 - 0.20	CT	6.4^{A}	44.3^{A}	1.9^{B}	3.1^{B}
	MT	6.3^{A}	50.2^{A}	2.7^{AB}	3.8^{AB}
	NT	5.1^{B}	52.0^{A}	3.7^{A}	4.4^{A}
0.20 - 0.40	CT	-	-	1.4^{A}	2.3^{A}
	MT	-	-	1.9^{A}	2.8^{A}
	NT	-	-	2.3^{A}	2.9^{A}

Means followed by a same uppercase letter in a column are similar for a same soil layer (Tukey test, $P>0.05$).

Table 2. Soil density, macroporosity and total porosity as a function of the treatments and depths sampled.

Depth	CT	MT	NT
Soil bulk density (Mg m^{-3})			
0 - 0.10 m	1.38^{Ab}	1.40^{Ac}	1.44^{Ac}
0.10 - 0.20 m	1.42^{Bb}	1.56^{Ab}	1.63^{Ab}
0.20 - 0.40 m	1.63^{Aa}	1.66^{Aba}	1.70^{Aa}
Macroporosity (%)			
0 - 0.10 m	21.12^{Aa}	18.52^{Aa}	15.36^{Ba}
0.10 - 0.20 m	16.76^{Ab}	13.10^{Bb}	8.59^{Cb}
0.20 - 0.40 m	11.03^{Ac}	9.10^{Ac}	6.26^{Bb}
Microporosity (%)			
0 - 0.10 m	18.90^{Aa}	18.62^{Aa}	18.62^{Aa}
0.10 - 0.20 m	19.25^{Aa}	19.32^{Aa}	19.32^{Aa}
0.20 - 0.40 m	18.98^{Aa}	18.68^{Aa}	19.68^{Aa}
Total porosity (%)			
0 - 0.10 m	40.02^{Aa}	37.13^{Ba}	34.63^{Ba}
0.10 - 0.20 m	36.01^{Ab}	32.432^{Bb}	29.11^{Cb}
0.20 - 0.40 m	30.01^{Ac}	28.78^{Ac}	26.55^{Bc}

CT, Conventional tillage; MT, minimum tillage; NT, no-tillage; for each variable, means followed by the same uppercase letter in a row and lowercase letter in a column are statistically similar (Tukey test, $P<0.05$).

of surface layers in cropped areas.

Topsoil showed the lowest soil density in all the tillage systems (Table 2), but it tended to be higher in NT. With the increasing of the soil depth it was observed an upward trend in the value of the soil density, as verified by Liu et al. (2013) in different tillage systems after three years of cultivation. The increase in soil density can be observed in the subsurface layer, possibly due to the lower organic matter content of deeper layers and the pressure applied by upper layers.

The effects of soil turnover on the top layers must be considered in CT and MT because it increases macroporosity up to the depth reached by the tillage implements that disturb the soil. In addition, at greater depths soil particles naturally adjust to empty spaces over pedogenetic evolution, with layer densification at depth irrespective of human interference.

Soil bulk density was in general lower than the critical limit of 1.85 Mg m^{-3}, proposed by Reinert et al. (2008), for crop development in ultisol. In all the soil tillage systems evaluated, macroporosity was higher in topsoil. Macroporosity was lower in NT at all depths, probably because the lack of soil turnover favors its consolidation. Total porosity was higher in topsoil in all the systems. This result is likely associated to the higher organic matter content in these layers, irrespective of the

Table 3. Mean initial and final soil moisture, soil surface roughness, time to surface runoff, and kinetic energy of the simulated rain.

Soil tillage system and level of plant residue					
CT	MT	NT-0	NT-3	NT-6	NT-9
Initial soil moisture (% mass base)					
17.33^a	14.60^a	15.88^a	15.97^a	15.61^a	15.30^a
Final soil moisture (% mass base)					
20.85^a	21.42^a	20.33^a	19.31^a	16.83^a	16.96^a
Soil surface roughness (mm)					
3.58^b	11.93^a	5.39^b	5.62^b	6.23^b	5.42^b
Time to surface runoff (min)					
6.91 ^{b}	60.20^a	7.26^b	5.65^b	13.14^b	18.94^b
Kinetic energy of simulated rainfall (kJ m^{-2})					
1.62^b	2.91^a	1.63^b	1.58^b	1.77^b	1.91^b

CT, conventional tillage; MT, minimum tillage; NT-0, no-tillage without plant residues; NT-3, no-tillage with 3 Mg ha^{-1} plant residue; NT-6, no-tillage with 6 Mg ha^{-1} plant residue; NT-9, no-tillage with 9 Mg ha^{-1} plant residue. Means followed by a same lowercase letter in a row are statistically similar (Tukey test, P<0.05).

management system adopted. The high root volume on the soil surface also favors soil structuring, thereby increasing TP, which is directly associated to macroporosity.

No differences between initial and final soil moisture were observed, corroborating the positive and homogenizing effect of plot wetting prior to the tests (Table 3).

Surface roughness, a major variable affecting water infiltration in soil, was similar between NT and CT. In general, the lower the surface roughness, the lower the time to onset of surface runoff.

In MT, onset of surface runoff was delayed, likely because of the chiseling applied just before soil tillage. This practice disturbs soil, promoting incorporation of crop residues, increasing surface roughness and favoring infiltration. Therefore, soil surface in MT had greater exposure to rainfall and higher kinetic energy was produced by the simulated rain. Castro et al. (2006) observed runoff delay in treatments with rainfall application soon after soil tillage, showing that soil turnover reduces or even avoids soil loss by erosion.

Soil and water losses

Cumulated soil loss was higher in CT than in the other systems (Table 4) because of the lack of residue cover, which allowed higher soil exposure to rainfall action, and effective topsoil turnover, as verified by Meijer et al. (2013).

The efficiency of the conservation tillage systems was especially observed in NT-9, NT-6, NT-3 and MT, which exhibited soil losses of nearly 3, 5, 10 and 6% of that found in CT, respectively. Conservation tillage reduces soil losses compared to non-conservation systems because of the plant residues deposited on the soil surface. Donjadee and Chinnarasri (2013) also concluded that surface runoff volume decreases with the increase in grass load deposited on the soil surface, and that 7.5 Mg ha^{-1} plant residue is the appropriate level to reduce runoff and soil loss. Jordan et al. (2010) evaluating the application of simulated rainfall at different levels of soil covered with wheat residues observed that waste fees exceeding 5 Mg ha^{-1} year^{-1} significantly decreased the rate of runoff. However, it can be considered that, in general, plant residues decrease the runoff speed, promoting the soil consolidation and reducing the soil disaggregation and the transport of the runoff.

Earlier studies showed that soil cover reduces erosion (Mello et al., 2003; Garcia-Estringana et al., 2013). Plant cover provides higher soil protection due to drop interception, increased surface roughness, increased organic matter supply, decreased soil disaggregation index owing to the reduced runoff sediment level and higher soil permeability.

At the onset of surface runoff CT exhibited low soil loss, but it soon increased, maintaining a linear tendency until the end of runoff collection. In the other treatments, soil loss per unit of time was maintained even over rainfall application.

Although soil losses in NT-0 were nearly 20% of those recorded in CT, they can be considered significant in relation to the other treatments, such as NT-9, whose soil loss was seven times lower. This occurs because the large amount of plant residue in NT-9 prevents soil particle disaggregation caused by the impact of

Table 4. Cumulated soil loss in Ultisol under different tillage system and levels of plant residue cover.

Cumulated soil loss (10^{-3} kg m^{-2})					
CT	**MT**	**NT-0**	**NT-3**	**NT-6**	**NT-9**
380.6^{A}	24.5^{D}	76.1^{B}	38.8^{C}	19.8^{D}	11.4^{E}
CV (%) = 21.41 and DMS = 44.22					

CT, Conventional tillage; MT, minimum tillage; NT-0, no-tillage without plant residues; NT-3, no-tillage with 3 Mg ha^{-1} plant residue; NT-6, no-tillage with 6 Mg ha^{-1} plant residue; NT-9, no-tillage with 9 Mg ha^{-1} plant residue. Means followed by a same lowercase letter in a row are statistically similar (Tukey test, P<0.05).

Table 5. Cumulated water loss in Ultisol under different tillage systems and levels of plant residue cover.

Cumulated water loss (10^{-3} m^{3} m^{-2})					
CT	**MT**	**NT-0**	**NT-3**	**NT-6**	**NT-9**
31.5^{A}	4.2^{C}	27.1^{A}	31.6^{A}	29.5^{A}	18.9^{B}
CV (%) = 15.1 and DMS = 8.1					

CT, Conventional tillage; MT, minimum tillage; NT-0: no-tillage without plant residues; NT-3, no-tillage with 3 Mg ha^{-1} plant residue; NT-6, no-tillage with 6 Mg ha^{-1} plant residue; NT-9, no-tillage with 9 Mg ha^{-1} plant residue. Means followed by a same lowercase letter in a row are statistically similar (Tukey test, P<0.05).

raindrops. According to Stavi and Lal (2011), the greater susceptibility of farming systems to the erosion process is related to the scarcity of soil covering and the degree of the plowing of the soil surface. Despite the disaggregating action of the chisel plow used in MT, this system exhibited lower soil losses than those obtained in NT-0, NT-3 and CT, probably because water percolation into soil was facilitated by the furrows opened by the tool.

During rainfall simulation tests in MT, surface runoff was not formed in some plots, showing the efficiency of this system in breaking up deeper and compacted layers and increasing surface roughness. This can reduce, in this way, the density of the soil in the areas of preparation and increases the surface roughness which, as Meijer et al. (2013), may favor the deposition of the soil in the microdepressions and, after this, minimize the soil loss. On the other hand, this condition tends to change with an increase in rainfall since the roughness promoted by methods such as MT has a shorter life than that produced by crop residue deposition (Panachuki et al., 2010).

Cumulated water losses were lower in MT (Table 5), corresponding to only 13.2% of those recorded in CT. Mean losses in MT were15.3, 13.2, 14.1 and 21.8% of those observed in NT-0, NT-3, NT-6 and NT-9, respectively. This occurs because of soil scarification, which disrupts soil at depth and increases roughness, reducing surface runoff.

The NT system was less efficient in preventing water than soil losses. In NT-9 treating, the cumulative loss of water was equal to 70, 60 and 64% of the losses observed in treatments NT-0, NT-3 and NT-6, respectively. This indicates that a minimum residue volume is needed for this system to restrain erosion. According to Adekalu et al. (2007), in order to prevent effectively the runoff water in the soil may be required levels of soil cover above 90%, especially in conditions of soils with low organic matter and the presence of compacted layers.

The CT treatment, without any plant residue on the soil surface and with soil surface roughness equivalent to 66; 64 and 57% which are observed in NT-0, NT-3 and NT-6 (Table 3), respectively, showed a cumulative loss of water similar to those observed in these treatments. This is due, possibly, to the effect of soil disturbance that occurred in the CT system and favored, temporarily, the water infiltration in the soil.

Figure 1 shows that the soil and water loss can be explained by the linear regression model, with high values for the coefficient of determination. Thus, it can be considered that under intensity of constantly rain, the rates of the soil and water loss tend to be constant during the occurrence of rain.

In the PC treatment the rates of soil loss were low at the beginning of the runoff, increasing at the first moments and staying with linear trend until the final moment of the rain test. In other treatments the rates of soil loss were similar over time.

Comparing the no-tillage treatments, it was observed that the treatment NT-9 was the most effective one in the controlling of water loss, indicating that it is necessary a minimum amount of plant residue for this system to be effective at stopping the erosion process. Evaluating the three systems of tillage, it can be said that the MT treatment the operation of chiseling resulted in higher infiltration rates that resulted in lower runoff.

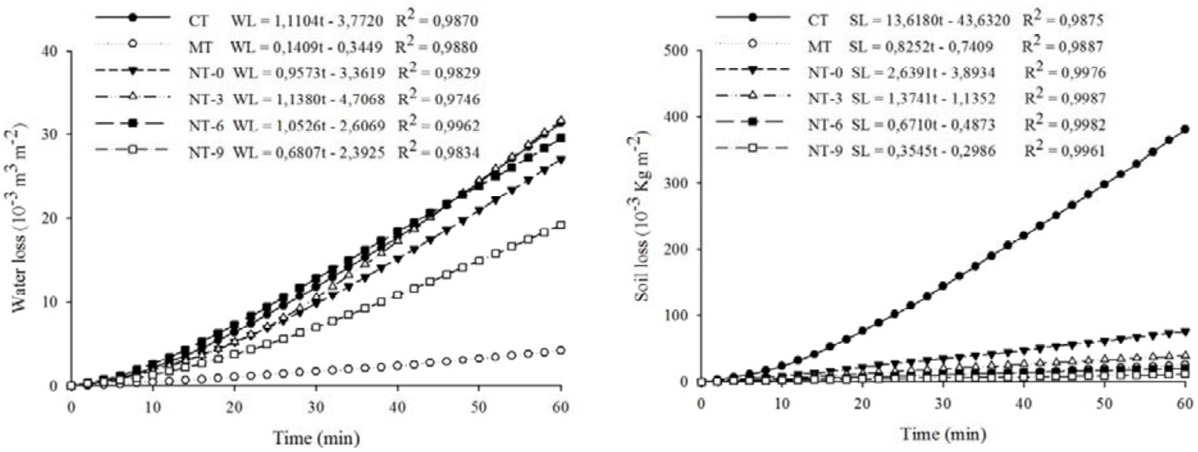

Figure 1. Soil and water loss in ultisol under different tillage systems and residue levels vegetable common bean.

Figure 1 also shows that the rates of water losses were less affected by variations of the level of vegetable residues than the soil losses. This occurs because, according to soil physical attributes, its water holding capacity is limited. Thus, a determined soil management system can decrease runoff rate only up to a certain value, which is defined by the difference between rainfall intensity and stable water infiltration rate. Gómez et al. (2011) consider that the conservative systems of tillage may not be in some cases more efficient in controlling runoff, especially in conditions of low soil cover. Because of this, these systems require practices that can mitigate eutrophication and contamination that fertilizers and pesticides can cause to the water bodies.

Conclusions

In Ultisol cropped with common bean soil loss ranging from 11.38 to 380.56 g m^{-2}, while water loss ranging from 4.15 to 31.57 × 10^{-3} m^3 m^{-2}. The highest soil losses were obtained with CT, and the lowest with minimum tillage (MT). In no-tillage (NT) planting, soil and water losses were more efficiently decreased in treatments applying the highest levels of residual crop on the soil surface, indicating that a minimum residue load is necessary to successfully contain erosion in this system.

Soil loss is more susceptible than water loss to variations in the type of tillage system and levels of plant residue.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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