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# Contribution of tillage systems on the organic matter of Gley soil and the productivity of corn and soybean

# Contribuição do sistema de cultivo sobre a matéria orgânica de um Gleissolo e a produtividade do milho e soja

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## Abstract

To evaluate the behavior of the organic matter in the profile of Gley soil and the productivity of corn and soybean in a temperate climate (Experimental Station of the University of Purdue - West Lafayette - Indiana - United States - Long: 86º 55' W and Lat: 40º 26' N). The effects of six treatments were studied, derived from three different tillage systems: conventional tillage, minimum tillage, and no tillage, with two successions of crops (soybean-corn and continuous corn), in an experiment conducted in the period of 1980 to 1995, with an experimental design of randomized blocks constituting six treatments arranged in subdivided parcels (split-plot), with three replications. In the experimental plots the treatments of succession of crops and the sub-plot were established with the systems of soil management. The sub-plot was constituted by three tillage systems: conventional tillage, minimum tillage, and no tillage. The soil samples originating from five depths and 11 positions and the data of productivity were analyzed, taken in a transversal line from the plot. With the results it can be concluded that: a) the percentage of organic matter increases in the superficial layer as the movement of the soil diminished, in the following sequence: no tillage system > minimum tillage system > conventional system; b) system of conventional tillage provided greater values of corn yield when associated to continuous crop and in succession with soybean; when compared with conservation tillage; and c) in the conditions of a temperate climate and hydromorphic soil, the content of organic matter showed a relation inversely proportional to productivity, with a smaller performance for the succession of soybean and corn.
**Key words:** No tillage, conventional system, minimum tillage, gley soil

## Resumo

O comportamento dos teores de matéria orgânica em um Gleissolo e da produtividade do milho e soja foi avaliado em condição de clima temperado (Estação Experimental da Universidade de Purdue – West Lafayette – Indiana - Estados Unidos - Long: 86º 55' W e Lat: 40º 26' N). Estudaram-se os efeitos de seis tratamentos (três diferentes sistemas de cultivo: convencional (SC), plantio direto (PD) e cultivo mínimo (CM), com duas sucessões de culturas (soja-milho e milho cultivado continuamente)),

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com delineamento experimental de blocos casualizados, constituindo seis tratamentos arranjados em parcelas subdivididas (split-plot), com três repetições. Nas parcelas experimentais foram estabelecidos os tratamentos de sucessão das culturas e a sub-parcela, os sistemas de manejo do solo. Analisaram-se amostras de solo provenientes de cinco profundidades em 11 posições, de uma linha transversal na parcela e a produtividade de grãos. Os teores de matéria orgânica aumentam na camada superficial à medida que diminuiu a movimentação do solo, na seguinte seqüência: PD > CM > CC. O CC proporcionou maiores valores de produtividade do milho quando associado ao CM e em sucessão à soja; quando comparado com os sistemas conservacionistas e, nas condições de clima temperado e quando em solos hidromórficos, os teores de matéria orgânica estabelecem relação inversamente proporcional à produtividade, com menor expressão para a sucessão de soja e milho.
**Palavras-chave**: Plantio direto, sistema convencional, cultivo mínimo, gleissolos

## Introduction

Corn is a universal crop that has been grown in small to large areas, as much for human as for animal consumption. In 2005, the worldwide market for corn was fueled primarily by three countries: the United States, Argentina, and South Africa, where the largest world producers are the United States, China, and Brazil, which produced 280,2, 131,1, and 35,9 million tons, respectively (GARCIA et al., 2006), thus highlighting the global importance of this crop.

Agricultural crop yield is mainly dependent on edaphoclimatic factors, as well as the management systems adopted, in particular, systems of soil tillage and fertilizer applications (ALBUQUERQUE et al., 2005).

To ensure productivity levels are more sustainable, technologies such as the combination of the succession of crops and tillage systems over long periods have been developed, contributing to the change of soil properties, including the organic matter profile (GRANT; LAFOND, 1993).

The loss rates of organic matter are mainly affected by soil tillage, especially the intensity of tillage, whereas the rate of addition is affected by systems of rotation/succession of the crops used, primarily in relation to the amount of plant residues returned to the soil annually (BAYER; MIELNICZUK, 2008). Neves, Feller and Larrouy (2005) confirm that the soil organic matter is an important component of the sustainability of agricultural area.

The incorporation of conservation tillage in the agricultural production process is of fundamental importance in the choice of practices to minimize soil degradation and thus maintain or increase the sustainability of agricultural activity.

The objective of this study was to evaluate the content of organic matter through the profile of Gley soil and its relation to the productivity of corn associated with tillage systems and crop succession in a long-term experiment.

## Material and Methods

The experiment was conducted at the Experimental Station of the Department of Agronomy, Purdue University, located in West Lafayette (86° 55’ W and 40º 26’ N - altitude: 210 m), in the State of Indiana, located in the belt of corn and soybean production (*Corn Belt*) of the United States, from 1980 to 1995. The annual average of total precipitation was 922,5 mm annual, or 76,9 mm de medium precipitation per month (minimum average: February – 40,1 mm and maximum average: June – 107,7 mm). The average of low temperature was is 18 ºC and average of high annual temperature was is 30 ºC in summer (warmest month is July). The average of low temperature was is 1 ºC and average of high annual temperature was is -8 ºC (coolest month is January) (HOLANDA et al., 1998).

For the study, six treatments were employed combining two successions of crops: continuous corn

(*Zea mays* L.) systems and soybean (*Glycine max* (L.) Merr.) in succession with corn, and three tillage systems (conventional tillage, minimum tillage, and no tillage), in a randomized block design and arranged in split-plots, with three replications. The soil of this study is called Gley soil Melanic (United States Soil Conservation, 1999), from the textural class of silty loam (fine-silty, mesic, mixed Typic Haplaquoll), corresponding to a Gley soil Melanic in the Brazilian System of Soil Classification (EMBRAPA, 1999). In the experimental plots treatments of crop successions of soybean/corn and continuous corn systems were established. The sub-plot consisted of tillage systems. Each plot for evaluation of parameters had an area of 510m2 harvested (10,2 m wide by 50 m long).

In mid-October 1980, the period equivalent to the fall in the northern hemisphere, the primary tillage of plowing (moldboard plowing) in the conventional soil management system was used immediately after harvest. In the system of minimum tillage, chisel plowing was used. In early May, the period equivalent to the northern hemisphere´s spring, in the conventional tillage system, secondary tillage with harrowing (disc harrows) was utilized shortly before planting (Table 1). In the minimum tillage

**Table 1.** Summary of the fertilization executed in the cultivation of corn and soy in an experiment of extended duration from 1981 to 1995.

| Year | Fertilizer | First tillage | Second tillage |
|---|---|---|---|
| 1981 | 250 kg ha$^{-1}$ NH3 in pre-planting<br>100 kg ha$^{-1}$ 28-28-0 with starter<br>0-90-180 broadcasting/fall of 1990 | Moldboard plowing in fall in CT<br>Chisel plowing in fall in MT | Discing and Cultivating in CT<br>Cultivator in MT |
| 1986 | 250 kg ha$^{-1}$ $NH_3$ in pre-planting<br>100 kg ha$^{-1}$ 18-46-0 with starter<br>0-115-210 ($N$-$P_2O_5$-$K_2O$) broadcasting /fall of 1984 | Moldboard plowing in fall in CT<br>Chisel plowing in fall in MT | Discing and Cultivatin in CT<br>Cultivator in MT |
| 1994 | 200 kg ha$^{-1}$ NH3 between rows<br>95 kg ha$^{-1}$ 34-0-0 with starter | Moldboard plowing in fall in CT<br>Chisel plowing in fall in MT | Discing and Cultivating in CT<br>Cultivator in MT |
| 1995 | 180 kg ha$^{-1}$ NH3 between rows<br>Application of nitrification inhibitor<br>95 kg ha$^{-1}$ 34-0-0 with starter | Moldboard plowing in fall in CT<br>Chisel plowing in fall in MT | Discing and Cultivating in CT<br>Cultivator in MT |

systems.

The corn hybrid used for sowing in 1981 and 1986 was Beck's 65X, and in 1994 Beck's 6565 was used, with a population of 26,000 plants per hectare. The soybean varieties used in 1981 and 1986 were Century, and Edison in 1994, usually planted in the second half of May. The data in this study refers to the plots planted with corn, either in succession with soybean or continuous systems.

During the experiment, nitrogen and phosphorus fertilizers were applied in accordance with the requirements of corn and soybeans. Potassium fertilizers were not used because the soil had levels that met the nutritional requirements of corn and soybeans. In 1994, 95 kg ha$^{-1}$ of nitrogen (34-0-0) was applied as initial fertilization and 200 kg ha $^{-1}$ of $NH_3^+$ in the form of ammonium sulfate, as a cover between rows for the corn crop (Table 1).

Soil samples were taken with an auger sampler at 11 locations, in a diagonal line between planting rows at five depths (0-5, 5-10, 10-15, 15-20, and 20-25 cm, respectively) with positions 1 and 11 corresponding to the planting rows, and spaced at 7.5 cm, in a transverse line of 75 cm, corresponding to the distance between two rows of planting. A bar of wood with 11 holes spaced at 7,5 cm was used to ensure a correct and accurate sampling technique. Soil samples were collected soon after the grain harvest, the carbon content analyzed (combustion at 360oC for two hours) according to Storer (1984). The organic matter contents were determined by multiplying the carbon content by 1,727 (STEVENSON, 1994).

The control of weeds was done with herbicides following the recommendations described by Griffith et al. (1988). The other techniques used to control pests and diseases were those conventionally adopted in agricultural experiments.

The data was statistically analyzed by means of variance analysis and the averages compared by the Tukey comparison test ($P < 0.05$), using the SAS statistical program Statistical Package (1995).

## Results and Discussion

Table 2 shows the contents of organic matter at different depths and tillage systems (conventional, minimum tillage, and no tillage) submitted to a succession of crops (soybean-corn and continuous corn), from the agricultural crops of 1981 and 1994. It is observed that, on overall average, the contents of organic matter in the soil varied between the years 1981 and 1994, verifying that the greatest contribution during this time was achieved by the conventional tillage system (13%), followed by no tillage (7,1%), and minimum tillage (2,5%). The contents of soil organic matter within each tillage system and during the years of the evaluation decreased with increasing depth evaluated (Table 2), as observed in a study of organic fertilizer and sandy soil in a semi-arid tropical region (GALVÃO; SALCEDO; OLIVEIRA, 2008) and in southern Brazil evaluating the organic carbon of an Oxisol under conventional tillage systems, tillage and pasture (CARNEIRO et al., 2009). In temperate conditions, with average temperature nearest the zero oC, in winner per six month per year (HOLANDA et al., 1998), as in this study, the rate of decomposition of organic materials is lower, being motivated primarily by low contents of abiotic factors, influenced in turn by lower values of temperature when compared to tropical conditions (SILVA et al., 2007). Thus, the conditions of this study have a direct effect on the cycling of organic matter by retarding its rate of decomposition, and thus justifying the relatively higher content of C found in temperate soils, in contrast to the lower residual time, as commonly occurs in tropical soils (Table 2 and Figure 1). From these findings, it becomes necessary to direct studies towards sustainable agriculture in tropical regions, where the management of organic matter and the factors leading to the same dynamics are fully considered (DEMÉTRIO et al., 1998) in a way completely distinct from temperate regions, because of lower annual temperatures was very lower values in conditions of tropical regions;

**Table 2.** Contents of organic material (g.kg$^{-1}$) at different depths and tillage systems (conventional, minimum tillage, and no tillage) submitted to succession of crops (soybean-corn and continuous corn), in the agricultural crops of 1981 and 1994 in Gley soil. (average of 9 repetitions).

| | Tillage systems | | | | | |
|---|---|---|---|---|---|---|
| **Depth (cm)** | **Conventional tillage** | | **Minimum tillage** | | **No tillage** | |
| | **1981** | **1994** | **1981** | **1994** | **1981** | **1994** |
| | | | g kg$^{-1}$ | | | |
| 0-5 | 41 bA | 47 bA | 47 bA | 49 bA | 49 bA | 55 aA |
| 5-10 | 41 aA | 48 aA | 44 aA | 47 aA | 46 aA | 47 aB |
| 10-15 | 41 aA | 48 aA | 42 aA | 44 aA | 43 aA | 45 aB |
| 15-20 | 39 aA | 44 aA | 38 aA | 39 aA | 40 aA | 41 aB |
| 20-25 | 34 aA | 37 aB | 33 aB | 33 aB | 35 aB | 37 aC |
| General Average | 39 a | 44 a | 41 a | 42 a | 42 a | 45 a |
| CV (%) | 4.7 | 2.7 | 3.9 | 3.7 | 5.2 | 5.4 |

Averages followed by the same small letter in the row and capital letter in the column do not differ statistically between themselves by the Tukey test 5%.

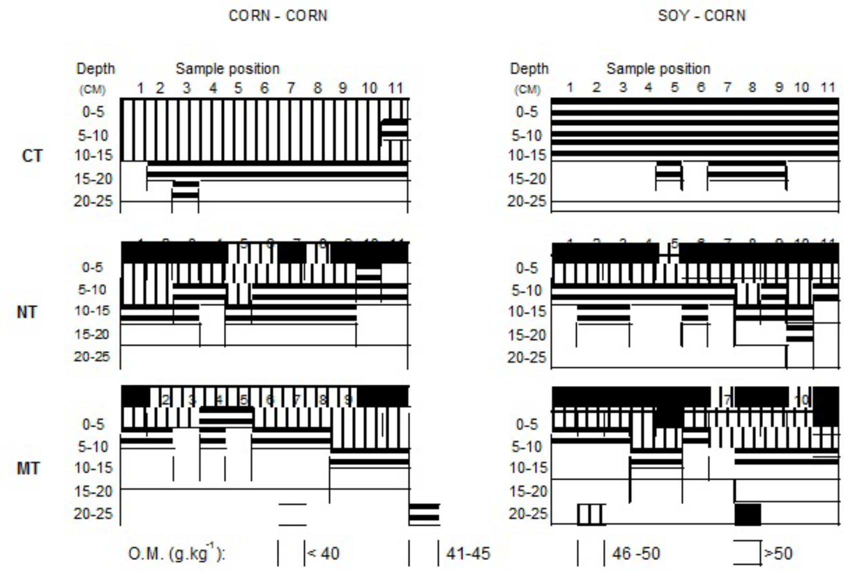


**Figure 1**. Range of contents of organic matter (g.kg$^{-1}$) in different positions and depths, in soil cultivated with continuous corn or in succession with soybean and in different planting systems, conventional tillage (CT), no tillage (NT), and minimum tillage (MT), in 1994, in Gley soil. (average of 9 replications).

The organic matter content of soil at depths was not significantly influenced by tillage systems (Table 2), with a behavior found to be consistent with findings from other studies (HARGROVE et al., 1982; LEITE et al., 2009). However, analyzing these contents at just five depths in the conventional system, for the 1981 agricultural year there was no significant difference between the depths evaluated. Although for this system in 1994 the organic matter content was significantly lower at the depth of 20-25 cm when compared to the other depths (Table 2). In the minimum tillage system for both years evaluated, the content of organic matter in the soil was reduced with increasing depth evaluation, with lower contents of organic matter at the depth of 20-25 cm, which differed significantly from contents at superficial layers. A similar pattern was observed for the no tillage system in 1991. As for this system in the year 1994, the highest level of soil organic matter was found in the surface layer 0-5 cm deep, resulting from low tillage, typical of a conservation system, as seen in other studies (LÓPEZ-FANDO; PARDO, 2009; LEITE et al., 2009). The lower revolving of soil in conservation tillage systems evidenced the favorable conditions to provides a higher concentration of organic matter at the surface (LARSON, 1964), while the lowest values were observed in the conventional system (Figure 1), probably due to the faster removal of organic matter by oxidation and its subsequent mineralization. This is probably due to the greater tillage and, consequently, greater homogeneity in the soil, which also indirectly accelerates the decomposition (oxidation), contributing to less concentrated locations associated with lower contents, according to Albuquerque et al. (1995). This can be explained by the lower variability of values in the conventional system (Figure 1), reinforcing that when soil tillage is not promoted by the use of the no tillage system in countries of temperate climate it requires conditions conducive to the maintenance of organic matter (reinforced by the low temperatures), implying that it was merely an agricultural practice.

Grain yields have been influenced by tillage systems over the years of corn cultivation (Table 3). In the year 1981, with continuous corn systems, there was no observed effect of tillage systems on grain yield. While in 1994, it was found that the conventional and minimum systems were higher for grain yield in relation to the no tillage system (Table 3). This increase corresponded to 72 and 61% for the conventional and minimum system, respectively. But, when comparing the productivity within each tillage system, it was found that after 13 years of corn cultivation, the conventional and minimum systems favored an increase in grain yield, corresponding to 28 and 18%, respectively. In spite of the overall average, during the early implementation of the system (1981) until the year 1994, the increase in grain yield amounted to 7,5% (Table 3). For the soybean-corn cultivation system for the growing seasons studied there was no significant difference in the productivity of grain. But when compared to grain yield in each tillage system, it was found that in 1994 the corn yield in the systems was higher than in 1981, presenting increments of 22, 32, and 16% for the conventional, minimum, and no tillage system respectevely. Leguminous plants, in addition to being a quick source of organic matter by the low C/N ratio of biomass, are conducive to recycling to the soil surface layers, in addition to acting as sources of nutrients such as nitrogen and providing improved chemical, physical, and biological soil properties (TANAKA et al., 1992; ALBUQUERQUE et al., 2005; SILVA et al., 2007). However, it should be noted that, on average, the increase in grain yield during this period of early implementation of the system (1981) until the year 1994 amounted to 23,5%, higher than observed in the continuous corn systems (Table 3).

**Table 3.** Productivity of corn (kg $ha^{-1}$) under different systems of tillage (conventional, minimum tillage, and no tillage) and succession of crops (continuous corn and soybean-corn), in the agricultural crops of 1981 and 1994 in Gley soil. (average of 9 replications)

| Year | Tillage system | | | Average |
|---|---|---|---|---|
| | Conventional | Minimum tillage | No tillage | |
| | | Continuous corn | | |
| 1981 | 9464 aB | 9570 aB | 9218 aA | 9417 B |
| 1994 | 12074 aA | 11284 aA | 7011 bA | 10123 A |
| | | Soybean-Corn | | |
| 1981 | 9878 aB | 9537 aB | 9778 aB | 9731 B |
| 1994 | 12090 aA | 12611 aA | 11362 aA | 12021 A |

Averages followed by the same small letter in the row and capital letter in the column do not differ statistically between themselves by the Tukey test 5%.

The highest yields were observed in the succession of crops in which corn is grown in rotation with soybeans, regardless of the tillage system used (Figure 2), compared with the continuous corn systems (Table 3), a situation consistent with the results of Griffith et al. (1988). This behavior can also be attributed to the fact that the nitrogen fixed by leguminous plants previously grown is available to the soil, that can be contributed to the faster rate of decomposition of crop residues (residues with wide C:N ratio, such as corn), and thus, promote greater availability of this nutrient to be used by the crop. According to Oliveira, Carvalho and Moraes (2002), this may contribute to increased production and reduce nitrogen fertilization in corn and, consequently, increase the profit of the holding. Another beneficial aspect of the succession of crops is the improvement of structural conditions, especially in soils with drainage problems, as the hydromorphic conditions found in the present experiment.

Annual variations of grain production, especially in conservation tillage, as observed in this study (Figure 3), can be explained by greater amounts of residue left on the soil surface in most conservation tillage, contributing to the formation of mulch in no tillage, or partially incorporated as in the case of minimum tillage, which can also increase water retention and reduce evaporation, especially in lowland soils. In years with rainfall over the drainage capacity of the soil, this can contribute to delaying the germination and growth retardation due to the lower temperature of the soil and may directly affect the population of the crops, and consequently the production. Similar performances were found in a study conducted by Chang and Lindwall (1990), to assess the effects of long-term use of conventional tillage and no tillage on clay loam soil (Chernosol), who reported higher contents of organic matter in the surface layer in areas under no tillage, causing lower yields than in the systems of minimum and conventional tillage, as shown in Table 3 and Figure 2. Thus we observe that, unlike the no tillage system in tropical conditions, there is almost a requirement of soil mobilization in temperate climate conditions, such as the case of the present work, causing the reduction of carbon content in the soil, and also improving the conditions of water retention or drainage in the soil, according to Albuquerque et al. (2005).

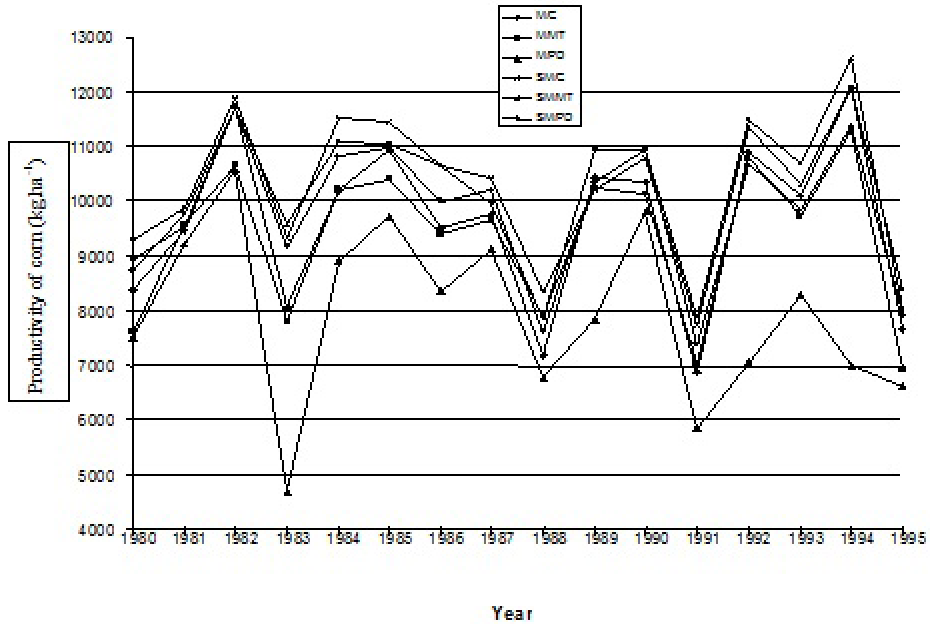


**Figure 2.** Productivity of corn cultivated under different systems of management (conventional tillage, minimum tillage, and no tillage) and succession of crops (continuous corn and soybean-corn) from 1980 to 1995, in Gley soil. (average of 9 replications)

A sharp drop in production for the years 1983, 1991, and 1995 was also observed, mainly for continuous corn under no tillage. This was lower than normally recorded at this time of year, at a critical stage for the development of the crop. This fact may have contributed to the enhancement of the allelopathic effects produced by corn residues, as shown by Yakle and Cruse (1984). According to Mannering and Griffith (1981), the high concentration of crop residues of high C:N ratio near the surface, keeps the soil temperature lower and consequently may reduce the residue decomposition and nutrient release. Furthermore, the occurrence of an also increased surface root density in no tillage may have contributed to its largest drop in production in the driest years – 1983, 1988, 1991 and 1995 – (being the maximum average precipitation occurs in June – in conditions of higher average temperature. The minimum average precipitation occurs in February – in conditions of lower average temperature) since, as the reduced availability of water can directly affect the absorption of nutrients more concentrated in the deeper layers soil.

Concomitantly, the rate of decomposition of organic matter determined in tropical conditions is much higher than those found in soils of cold and/or semi-arid climate regions, demonstrating the rapid degradation of agricultural soils in regions with hot and humid climates, when subjected to tillage systems with intensive mobilization and low input of plant residues. Research in these other regions have determined equivalent losses to half the original stock of organic matter in time periods ranging from 50 to 100 years of soil tillage (BOWMAN; REEDER; LOBER, 1990; NUERNBERG, 1998). This fact, coupled with lack of soil mobilization, such as in the no tillage system that probably contributed to the significant difference in corn yield in the conventional tillage system when grown continuously after 13 years of cultivation. Even when corn was grown in succession with soybean, grain yield differed significantly, providing results contrary to the continuous corn systems (Table 3). This can be attributed to the fact that residues of the soybean crop, reduced by the C/N ratio, decompose before the corn residues, providing less water retention in the soil, and the fact that the biomass of soybean increases the supply of N in the soil, improving the level of this nutrient for corn. . However, the corn residues contributed to lower yields of the crop in continuous corn systems, and this fact can be attributed to the wide C/N ratio of their residues, which potentially immobilizes a significant proportion of the availability of soil N by the action of microorganisms that work in the decomposition of previous plant residues, reducing the availability of soil N and, consequently for corn plants, according to Vargas, Selbach and Sá (2005) and Silva et al. (2007).

This behavior can be attributed to the fact that the nitrogen fixed by leguminous plants in past cultivation (soybean) is deposited in the ground, contributing to a higher rate of decomposition of crop residues, in a faster form, principally those with large C/N ration, such as corn, and thus promoting greater availability for passive absorption by the crops (SILVA et al., 2007). Aita (1997) reports that this may contribute to increased production as well as reduce nitrogen fertilization in the corn crop and, consequently, increase the profit of the holding. Another beneficial aspect of the succession of crops is the improvement in structural conditions, principally in soils with drainage problems (hydromorphic soils), as evidenced in the present experiment.

The behavior observed in this experiment highlights the importance of using plants from different families in crop successions. Thus, we must emphasize that the yield in the majority of crops under different soil management depends, among other things, the weather conditions of the agricultural year, the quality of management, the level of soil fertility, and the health status of the crop (KLUTHCOUSKI et al., 2000; NUNES, 2006). It should be noted that the no tillage system, to be focused on as a process of non-mobilization of soil exclusively in the planting row, as maintenance of crop residues of diverse composition completely on the soil surface, and as the rotation or consortium of cultivations, has a mechanism of transformation, of reorganization, and of support system for agricultural production. Thus, in temperate climate conditions, no tillage should be seen more as a practice, while in tropical conditions, this practice should necessarily be seen as a system, because there is a need for actions carried out jointly, since the integration of soil covering with quantity and quality of organic matter, lack of soil disturbance, and use of plants as ground cover, can provide better agricultural sustainability.

## Conclusions

The organic matter contents increase in the surface layer as the movement of soil decreases (in the sequence of no tillage system > system of minimum tillage > conventional system).

The conventional tillage systems provide higher values of corn grain yield, when combined with continuous cultivation and in succession to soybean, compared with conservation tillage.

In temperate climate conditions and in hydromorphic soils, the organic matter has an inverse relationship with the productivity of corn, which is lower when the succession of soybean and corn is employed.

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