EFFECT OF PERENNIAL-PASTURE AND TILLAGE SYSTEMS ON SOIL ORGANIC CARBON AND AGGREGATE STABILITY IN WESTERN URUGUAY

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ABSTRACT

Soil degradation due to unnecessary tillage is the main restrain to sustainable agriculture in Uruguayan soils. The impact of crop-pasture rotation by tillage systems interaction has not been evaluated or is scare in the long-term. The experiment located in western Uruguay was established in 1993 on a clay loam (Typic Argiudol) to determine the influence of tillage systems and inclusion of perennial pasture on soil properties. Pasture (with or without perennial pasture) and tillage systems (conventional and no-till) were evaluated through 1993 to 2005. Soil samples at three depths (0-2.4, 2.4-4.8, and 4.8-7.2 in) were taken twice (1994 and 2005) and analyzed for soil organic carbon content (SOC), Total SOC (TSOC) and water stable aggregate (WAS). Interaction among inclusion of perennial pasture and tillage systems occurred on SOC and TSOC after 12-y. Conventional tillage without pasture resulted in the lowest SOC and TSOC (9% and 10% less than the overall mean, respectively). Within no-till systems, perennial pasture did not have effect on SOC content. No-till systems had more SOC and TSOC stratification than conventional ones. Within conventional tillage, continuous agriculture had 58% lower WAS than crop pasture rotation. On the other hand, within no-till systems did not have effect on WAS. No-till systems significantly improved soil fertility indicators with or without pasture, but for conventional tillage, the inclusion of pasture was necessary.

INTRODUCTION

Maintenance and improvement in soil organic carbon (SOC) content is generally accepted as being an important objective for any sustainable system of agriculture. Soil organic carbon and soil aggregation declines quickly in the first years after cultivation of unperturbed soil (Six et al., 1999). The magnitude and speed of the loss vary with the soil type, weather conditions, crop sequence, soil tillage, quantity of stubble returned to the soil (Paustian, el al., 1997). These authors found that SOC was improved with systems that include pastures or grazed crops. Haynes et al. (1991) reported that aggregate stability increases quickly, both due to a lack of tillage disturbance and the characteristic dense and fibrous root systems of the perennial grasses. These changes are stabilized if the perennial pasture stays in time, but they are lost quickly if soil is tilled again. In Uruguay, Díaz, (1994) quantified after 28 years a SOC loss of 25% for continuous annual crops systems with tillage systems in relation to the initial value. This negative tendency was reverted with a crops-pasture rotation. A synthesis of the produced information about crop-pasture rotation in Uruguay was presented by García-Préchac et al. (2004). About 35% of the dry crop production system in Uruguay was planted in no-till system in 2001. This area under no-till systems without pasture in the rotations has extended quickly in the last 10 years, due to farmers and technicians were looking for means to increase crop profitability and reduced soil erosion and soil degradation.

The objective of this study is to quantify the effect of tillage system in crop-pasture rotation in relationship to the continuous annual crops in changes in soil organic carbon and aggregates stabilities.

MATERIALS AND METHODS

Site description

The long-term crop-pasture tillage system experiment is located 10 km from Paysandu (32° 21' S and 58° 02' W; 61m elevation) in the northwest of Uruguay, South America. The region is mesothermal sub-humid climate with a mean daily temperature of 77^o and 55^o F for summer and winter seasons, respectively. The area receives an average of 43-in of annual precipitations, with a moderately uniform throughout months, but very unpredictable among years. Potential evapotranspiration is greater during summer than winter season, consequently, through summer exists water deficits (maximum in January, 4 in) and during winter exists water excess (maximum in July, 2.5 in). Soil at the site is a fertile Typic Argiudol (Table 1).

Table 1. Surface (0-8-in) characteristics of the experimental site where tillage systems with inclusion or not of pastures were evaluated in the long-term experiment in Paysandú, Uruguay (1993-2005).

Classification	Typic Argiudol
Texture	clay loam
% Clay	29
% Silt	44
% Sand	27
Soil organic carbon (%)	2.4
pH	7.0
P content (mg kg^{-1})	15
K content (cmol kg^{-1})	1.9
Ca content (cmol kg^{-1})	27.7
Mg content (cmol kg^{-1})	2.4
Cation exchange capacity (cmol kg^{-1})	32.7

Site Management

The experimental area was under continuous crops (a wheat-fallow rotation) under conventional tillage among 1940 to 1970. Since 1970 until 1993, the experimental area was under crop-pasture rotation (3 year pasture-3 year crops) with conventional tillage. The long-term experiment was established in 1993 following a sod-legume pasture composed originally by Birdsfoot Trefoil (*Lotus corniculatus*), White Clover (*Trifolium repens* L.) and Tall Fescue (*Festuca Arundinacea* L.) dominated by bermudagrass (*Cynodon Dactylon* L.)

The crop rotation used included: wheat (*Triticum aestivum* L.), barley ((*Hordeum vulgare* L.), and oat (*Avena sativa* L.) for winter crops and corn (*Zea mais* L.), sunflower (*Helianthus annus* L.), sorghum (*Sorghum bicolor* L. *Moech.*), and soybean (*Glycine max* (L.) Merr.) for summer crops. The table 2 shows the crops order used for all treatments among 1993 to 2005. The experimental design was a randomized complete block (RCB) design with two replications in 1994 and three replications for 2005. Four treatments were evaluated from 1993 to 2005.

Table 2. Crops evaluated in a combination of two tillage systems and two rotations (inclusion or not of pastures) in the long-term experiment in Paysandú, Uruguay (1993-2005).

Year	Crop-Pasture Rotation (ROT)		Continuous Cropping (CC)	
	Winter	Summer	Winter	Summer
1993	Barley	Sorghum	Barley	Sorghum
1994	Wheat	Sunflower	Wheat	Sunflower
1995	Wheat/pasture	Pasture	Wheat	Sorghum
1996	Pasture	Pasture	-- †	Corn
1997	Pasture	Pasture	Oat	Soybean
1998	Pasture	Corn	--	Corn
1999	Wheat	--	Wheat	--
2000	Wheat	Soybean	Wheat	Soybean
2001	--	Sunflower	--	Sunflower
2002	Wheat/pasture	Pasture	Wheat	Soybean
2003	Pasture	Pasture	--	Sunflower
2004	Pasture	Pasture	Barley	Soybean
2005	Pasture	Pasture	Wheat	

† means fallow due to impossibility to plant for weather conditions

These treatments included the combinations of two tillage systems with the inclusion or not of perennial pastures:

1. Continuous cropping with conventional tillage (CC $_{Conv}$). Continuous cropping for twelve years using conventional tillage systems. The tillage includes a combination of moldboard or chisel (depending on year) to a depth of 8-10 in followed by disking to a depth of 4-6 in previous to winter crops. A disk harrow to a depth of 6-8 in together with field cultivator to a depth of 4-6 in was used previous summer crops.

2. Continuous cropping with no-till (CC $_{NT}$). Same crops than CC $_{Conv.}$ In no-till plots glyphosate were applied at the rate of 1.25 to 1.75 lb a.i. acre^{-1} depending of weed infestation and weather conditions.

3. Crop-pasture rotation with conventional tillage (ROT $_{Conv}$). The rotation was 3-yr crop-3-yr pasture cycle. This system is in operation since 1970. The same tillage used in CC$_{CONV}$. The pasture was planted together with the winter crop (in the same planting operation) in 1995 and 2002. The pasture consists of birdsfoot, trefoil white clover, and tall fescue.

4. Crop-pasture rotation with no-till (ROT $_{NT}$). The same tillage used in CC$_{NT}$. The rotation was the same used in conventional tillage (ROT $_{Conv}$)

Pre and post emergent herbicides were applied in all treatments to control weeds as needed. The experiment occupied approximately 5 acre with individuals' plots of 150 × 30 ft in size, thereby allowing use of field-scale equipment for all operations.

Soil Organic Carbon

Soil samples for SOC were collected two times: on January 1994 (six months after initiated the experiment) and June 2005. Ten samples were composited at each plot. These plots were sampled at three depths (0 - 2.4, 2.4 - 4.8, and 4.8 - 7.2 in). Samples were lightly crushed and sieved through a 2-mm mesh. Soil organic carbon was determined using the Walkey and Black technique (Nelson and Sommers, 1982). Soil bulk density ($?_b$) was determined by the core method (Blake and Hartge, 1986), with core dimensions of 1.81-in diameter by 2.36 in height. Core samples were taken at the same depths as SOC determinations at the same time, 5 replicates per plot, dried to 105^{o}C and weighed.

Wet Aggregate Stability

Soil samples were collected to evaluate wet aggregate stability on June 2005 using a wet sieving procedure of Yoder (1936) as modified by Kemper and Rosenau (1986). Three samples for the 0-6 in layer were collected from each plot. Immediately after collection, aggregates of between 4.5 and 9.5 mm were separated form the composite sample. To facilitate this, large clods were gently broken by hand to free aggregates of the preferred size. Moist aggregates (30 g) of between 4.5 to 9.5 mm were spread evenly on the uppermost sieve of a nest of 4.5, 2.8, 2.0, 1.0, 0.6 and 0.3 mm diameter and were gently moistened to avoid sudden rupture of the aggregates. The water level in the shaking apparatus was adjusted so that aggregates on the uppermost sieve were just submerged on the highest point of the cycle. Samples were oscillated from 15 min at 40 strokes per minute with the amplitude of the action set at 8 cm. The soil remaining on every sieve at the end of the 15 min was transferred into a beaker and oven-dried at 105^{o}C for 48 h and then weighed. The strength of aggregates in water was calculated as mean weight diameter (MWD) = S (X_i W_i), where X is the average diameter of the openings of two consecutive sieves, and W the weight ratio of aggregates remained on the $_i$th sieve. The multipliers used in our study after wet sieving were 7, 3.65, 2.4, 1.5, 0.8, and 0.45 mm for the sieves, respectively, and 0.15 mm for the residue.

Statistical Analysis

Treatment effects on soil indicators were evaluated using the appropriate randomized complete block (RCB) design with the PROC MIXED procedure of the Statistical Analysis System (SAS)(Littell et al., 1996). Replication and its interactions were considered random effects and treatments were considered fixed effects. Sampling depths were analyzed as a split in the design. Least square means comparisons were made using Fisher's protected least significant differences (LSD). A significance level of $P = 0.10$ was established *a priori*.

RESULTS AND DISCUSSION

Soil Organic Carbon

Soil samples were collected at intervals to 2.4 in until 7.2 in depth to identify any soil chemical changes among treatments. Changes on SOC and TSOC resulting from combinations of tillage systems and inclusion or not of perennial pastures averaged over the 0-7.2 in depth range in 1994 and 2005 are presented in Figure 1. For our study, only tillage treatments effects within crop-pasture rotation are presented in 1994 because continuous cropping did not impact at this moment. Six months after started the experiment (January 1994) there were no significant differences among tillage systems for soil organic carbon (SOC) (2.0 vs. 2.22 % for conventional tillage and no-till, respectively). However, for TSOC there were differences between these two tillage systems (19.65 vs. 22.59 tons acre^{-1}; $P \leq 0.03$, for conventional tillage and no-till, respectively). Our results are explained by higher bulk density of no-till at the beginning of the experiment (data not shown) between these two tillage systems. Ellert and Bettany (1995) found that estimates of TSOC at fixed sampling depth (calculates as the product of concentration, bulk density and thickness) usually resulted in comparisons among unequal soil masses. These authors concluded that bulk densities and masses of no-till systems often are greater than those of conventional ones. Based on this demand, estimate TSOC (include bulk density) for our study would be smaller for calculations bases on an equivalent mass than for calculations bases on fixed sampling depths.

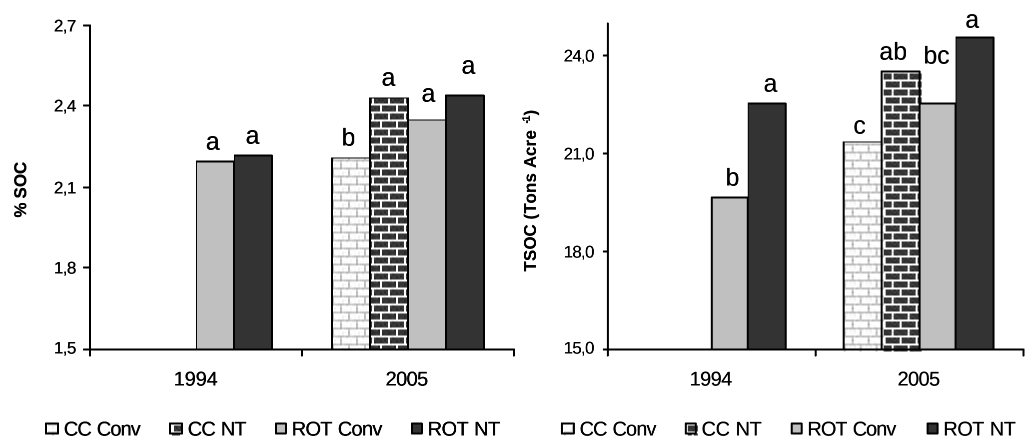

Figure 1. Soil organic carbon and total soil organic carbon at two sampling dates (1994 and 2005) at 0-7.2 in depth in response to tillage type and inclusion or not of pastures in the long-term experiment in Paysandú, Uruguay (1993-2005). The means market with the same letter in the same year are not significantly different at p=0.10.

The lowest carbon concentrations after twelve years initiated the experiment were obtained using conventional tillage without pasture (9% and 10% for SOC and TSOC less than the overall mean, respectively; Figure 1). It is well established that SOC is lower with conventional tillage than no-till systems attributable to several reasons: quick residue decomposition, more oxidation process, erosion, etc. (Dalal et al., 1989). Nevertheless, studies in Argentine have reported that no-till systems after 15 years had higher loss of CO2-C compared to plow tillage (Alvarez et al, 1998). These authors hypothesized that to change from conventional to no-tillage exist an initial phase of carbon accumulation but is followed by a phase of increase in carbon losses. This increase would be due to soil cover that affects the decomposition and mineralization process. Our study has 12 years, and could be considered in a transition phase between conventional to no-till systems.

There was a tillage type and pasture use interaction for SOC. The differences on carbon concentration were detected between the uses or not of pasture in the conventional tillage, and did not have effect in the no-till systems for SOC contents (Figure 1). These results agree with the general finding of Amstrong et al. (2004) and Heenan et al. (2004) where the use of pasture increased the soil organic carbon and total nitrogen. As mentioned previously from Amstrong et al. (2004), these authors found a quick increase in SOC over 3 years partly due to retaining plant residues on the plots. Grace et al, 1995 found that the inclusion of longer term pasture reduced the decline in SOC level. After 68 years of different crop rotation, SOC declined linearly with increasing frequency of fallows and decreasing frequency of pasture in the rotation. In contrast, increasing the frequency of pasture in the rotation caused SOC to increase significantly (Grace et al, 1995). The relative effect of particular rotation phases on SOC showed an increase during pasture phase and a decrease during crop phase. Our soil cores in June 2005 were taken after three years of pasture phase, then we expected an increase in the SOC level in the treatment than include pasture in the rotations.

Janzen et al, (1998) estimate a gain in SOC about 2.64 tons acre^{-1} or less within a decade by adoption of improved practices, like conservation tillage, intensification cropping systems, improved crop nutrition and perennial pastures in Canadian prairies. This change in SOC content is of finite duration and magnitude. For our study, TSOC averaged with or without pasture, we found an increase of 2.93 and 0.86 ton acre^{-1} for use of no-till systems and conventional ones, respectively after twelve years.

Treatment effect on soil organic carbon and total SOC were principally limited to the surface 2-in (Table 3). A significant treatment $\times$ depth interaction was obtained for SOC and TSOC in both years (Table 3). Significant stratification of SOC and TSOC occurred just only 6 months after establishment of the experiment with the inclusion of no-till system (ratio of 0-2.4/4.8-7.2 in depth was 1.36 and 1.43 for SOC and TSOC, respectively). In 2005, after 12 years initiated the experiment, the stratification was similar found in 1994, but for the conventional tillage, that stratification was only 1.18 averaged with or without pasture rotation. These results confirms early finding of Franzluebbers et al. (2002) that most the impact of no-till systems is observed in surface soil.

Twelve years after initiated the experiment, within no till systems, continuous crops had higher SOC content in the first 0-2.4-in compared to pasture rotation (3.0% vs. 2.77%, p=0.07). However, in the following depth (2.4-4.8 in) ROT_{NT} had higher SOC content than CC_{NT} (2.42% vs. 2.19%). This could indicate the more capacity that the pasture can have to increase SOC in deepest area for the root systems. Within conventional tillage, the inclusion of pasture increased the SOC content in the first 0-2.4 in depth (2.67% vs. 2.32% for ROT_{Conv} and CC_{Conv}, respectively) without difference in deepest zones.

Comparing tillage systems in continuous crops (CC_{NT} vs. CC_{Conv}), the no-till systems presented only in the shallowest area more SOC than conventional ones (3.00% vs. 2.32%). In deepest areas no difference were detected. However, some authors have reported higher SOC contents at deeper layers under conventional tillage compared to no-till due to residue incorporations by burying. On the other hand, comparing these tillage systems with use of pasture rotations (ROT_{NT} vs. ROT_{Conv}) did not show difference for SOC content for any profile under study. Primarily continuous cropping with conventional tillage resulted in the worst-case scenario, presenting the lowest SOC and total SOC content.

Table 3. Soil organic carbon (SOC) and TSOC at two sampling dates in response of tillage type and inclusion or not of pastures at three different depths in the long-term experiment in Paysandú, Uruguay (1993-2005).

		Treatments †							
Sampling Date		Soil Organic Carbon (SOC)				Total Soil Organic Carbon (TSOC)			
		CC_{CONV}	CC_{NT}	ROT_{CONV}	ROT_{NT}	CC_{CONV}	CC_{NT}	ROT_{CONV}	ROT_{NT}
	Depth	%				Ton $Acre^{-1}$			
January, 1994	0 - 2.4	--‡	--	2,36	2,61	--	--	6,95	9,16
	2.4 - 4.8	–	--	2,16	2,12	--	--	5,84	7,04
	4.8 - 7.2	–	--	2,08	1,94	--	--	6,85	6,39
	LSD $_{(0.10)}$ (treatment*depth)	*0,34*				*1,33*			
June, 2005	0 - 2.4	2,32	3,00	2,67	2,77	7,53	9,77	8,38	9,26
	2.4 - 4.8	2,22	2,19	2,24	2,42	7,09	7,09	7,12	7,99
	4.8 - 7.2	2,10	2,11	2,13	2,14	6,74	6,67	7,08	7,32
	LSD $_{(0.10)}$ (treatment*depth)	*0,19*				*1,05*			

† CC_{CONV} = Continuous cropping with conventional tillage; CC_{NT} = Continuous cropping with no-till; ROT_{CONV} = Crop-pasture rotation with conventional tillage; ROT_{NT} = Crop-pasture rotation with no-till.

‡ Since the treatments started in July, 1993, continuous cropping with or without tillage are not consider.

Wet Aggregate Stability

Mean weight diameter (MWD) calculated after wet sieving was significant different among treatments. In our study, within conventional ones, the use of pasture rotations increased by 140% the MWD compared to without pasture after twelve years initiated the experiment (Fig. 2). However, for no-till systems, this beneficial effect of use pasture to improve the aggregate stability did not happen. Changes in aggregate stability with no-till systems have been reported under different whether conditions (Dalal, 1989; Beare et al, 1994). Investigation by Haynes et al. (1991) indicated the strong influence of mixed cropping rotation on SOC and water stable aggregation. This relation was improved when microbial biomass carbon and soil carbohydrate content were considered (Haynes and Francis, 1993). Soil aggregate stability increase rapidly after perennial grasses are established both due to a lack of tillage disturbance and to characteristics of root systems of grasses (Paustian, 1997). In our study, the use of perennial pasture in no-till systems determined the highest soil aggregate stability. On the other hand, the worst case scenario in term of soil aggregate stability was continuous cropping in conventional tillage.

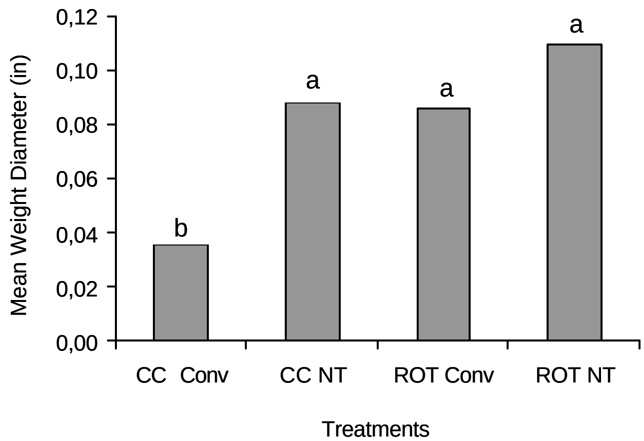

Figure 2. Mean weight diameter (in) among tillage and pasture combination at June 2005 in the long-term experiment in Paysandú, Uruguay (1993-2002). Same letter are not significantly different at p=0.10.

CONCLUSIONS

Our study indicates that conventional tillage without pasture resulted in the lowest SOC and TSOC (9% and 10% less than the overall mean, respectively) after 12 years initiated the study. Within no-till systems, perennial pasture did not have effect on SOC averaged over 0-7.2 in depth. However, CC_{NT} presented more SOC in the first 0-2.4 in than ROT_{NT}, but ROT_{NT} presented more SOC in the 2.4-4.8 in than CC_{NT}. No-till systems had more SOC and TSOC stratification than conventional ones. Within conventional tillage, continuous crops had 58% lower WAS than crop pasture rotation, and did not have effect within no-till systems on WAS. No-till systems significantly improved soil fertility indicators with or without pasture compared to conventional ones. The use of pasture was necessary to improve these soil indicators in the conventional tillage for the sub-humid climate conditions in Uruguay.

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REFERENCES

Beare, M.H., Cabrera, M.L., Hendrix, P.F. and Coleman, D.C. (1994). Aggregated-protected and anprotected pools of organic matter in conventional tillage and no-tillage soils. Soil Sci. Soc. Am. J. 58: 787-795.

Bremner, J.M., Mulvaney, C.S. (1982). Nitrogen-total. In; Page, A.L., Miller, D.R. (Eds), Methods of Soil Analysis II. Chemical and Micro-biological Properties. American Society of Agronomy, Madison, WI, pp. 595-624.

Dalal, R.C. (1989). Long-Tern effects on no-tillage, crop residue, and nitrogen application on properties of a vertisol. Soil Science Society of American Journal 53: 1511-1515.

Díaz-Roselló, R. (1992). Evolución de la materia orgánica en rotaciones de cultivos con pasturas (Organic matter evolution in crops and pastures rotations). Revista. INIA-Uruguay Inv. Agr. 1, Tomo I. pp. 103-110.

Díaz-Rosselló, R. (1994). Long-term Changes of Soil Carbon and Nitrogen under Rotation of Legume Pastures and Arable Crops. In: Transactions of the 15th World Congress of Soil Science, Volume 9, pp. 304-305 pp.

Ellert, B.H. and Battany, J.R. (1995). Calculation of organic matter and nutrient stored under contrasting management regimes. Can. J. Soil Sci. 75: 529-538.

Eynarda A., Schumachera, T.E., Lindstromb, M.J. and Maloa, D.D. (2005). Effects of agricultural management systems on soil organic carbon in aggregates of Ustolls and Usterts. Soil Till. Res. 81: 253-263.

Franzluebbers, A.J. (2002). Soil organic matter stratification ratio as an indicator of soil quality. Soil Till. Res. 66: 95-106.

García-Préchac, F., Ernst, O., Siri-Prieto, G. and Terra, J.A. (2004). Integrating no-till into crop–pasture rotations in Uruguay. Soil Till. Res. 77: 1-13.

Haynes, R.J. Swift, R.S., Stephen, R.C. (1991). Influence of mixed cropping rotatiosn (pasture arable) on organic matter content, water stable aggregations an clod porosity in a group of soils. Soil Till. Res.19:77-87.

Haynes, R.J., Francis, G.S. (1993). Changes in microbial biomasa C soil carbohydrate composition and aggregate stability induced by growth of selected crop and forage species under field conditions. Journal of Soil Science 44:665-675.

Heenan, D.P., Chan, K.Y., Knight, P.G. (2004). Long-term impact of rotations, tillage and stubble management of the loss of soil organic cargon and nitrogen from a Chromic Luvisol. Soil Till. Res. 76: 59-68.

Janzen, H.H., Campbell, C.A., Izaurralde, R.C., Ellert, B.H., Juma, N., Mc Gill, W.B., Zenter, R.P. (1998). Management effects on soil carbon storage on the Canadian pairies. Soil Till. Res. 47: 181-195.

Littel, R.C., Milliden, G.A., Stroup, W.W., Wolfinger, R.D. (1996). SAS system for mixed models. SAS Inst., Cary, NC.

Miglierna, A.M., Iglesias, J.O., Landricini, M.R., Galantini, J.A. and Rosell, R.A. (2000). The effects of crop rotation and fertilization on wheat productivity in the Pampean semiarid region of Argentina. 1. Soil physical and chemical properties. Soil Till. Res. 53: 129-135.

Nelson, D.W., Sommers L.E. (1982). Total carbon, organic carbon, and organic matter. In; Page, A.L., Miller, D.R. (Eds), Methods of Soil Analysis II. Chemical and Micro-biological Properties. American Society of Agronomy, Madison, WI, pp. 539-579.

Paustian, K., Collins, H.P. and Paul, E.A. (1997). Management controls on soil carbon In: E.A. Paul, K. Paustian, E.T. Elliot and V.V. Cole (Eds.), Soil Organic Matter in Temperate Agroecosystems: Long-Term Experiments in North America. CRC Press, Boca Raton. FL, USA. pp 15-49.

Six, J., Elliott E.T., Paustian, K. and Doran, J.W. (1999). Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Sci. Soc. Am. J. 62: 1367-1377.