SOIL USE INTENSITY IMPACTS ON TOTAL AND PARTICULATE SOIL ORGANIC MATTER IN NO-TILL CROP-PASTURE ROTATIONS UNDER DIRECT GRAZING.

José A. Terra[1], Fernando Garcia-Préchac[2], Lucía Salvo[2], and Jorge Hernández[2]
[1] Instituto Nacional de Investigación Agropecuaria (INIA), Ruta 8 Km. 281, Treinta y Tres, Uruguay (jterra@inia.org.uy). [2] Departamento de Suelos y Aguas, Fac. de Agronomía, Universidad de la Republica Oriental del Uruguay. Garzon 680, Montevideo, Uruguay.

ABSTRACT
Soil organic carbon (SOC) is important for animal production systems sustainability under grazing. We evaluated soil use intensity effects on SOC and particulate organic carbon (C-POM; 53-2000 µm) in a 72 ha no-till crop-pasture rotation experiment in Uruguay (Typic Argiudols). Treatments included: 1) continuous cropping (CC) of *Lolium multiflorum* Lam. or *Avena sp.* in winter and *Sorghum bicolor* L. or *Setaria italica* in summer; 2) short rotation (SR): two years idem CC and two years pasture of *Trifolium pretense* L. and *Lolium multiflorum*; 3) long rotation (LR): two years idem CC and four years pasture of *Dactylis glomerata* L., *Trifolium repens* L. and *Lotus corniculatus* L.; 4) permanent pasture (PP): natural pasture overseeded with legumes used in LR. All rotation phases were present each year. After 8 years, LR increased SOC (0-15 cm depth) by 19% compared to CC (31.8 Mg ha^{-1}); no SOC differences were found between LR, SR and PP. Plots containing pastures had 14 % greater SOC than plots containing crops (33.7 Mg ha^{-1}). Crops rotated with pastures (LR, SR) had 5% greater SOC than crops in CC (31.8 Mg ha^{-1}). There were no differences on SOC between pastures in LR and PP, but 3-4 years pastures had 33% greater SOC than 1-2 years pastures (34.4 Mg ha^{-1}). The lowest and greatest C-POM was found in CC and in 3-4 years pastures of LR (8.2 and 12.6 Mg C ha^{-1}, respectively). No till crop-pasture rotation systems including long-term pastures preserved SOC, even in high biomass extractive grazing systems.
Keywords. Soil use intensity, no-till, crop pasture rotations, soil organic carbon, particulate organic matter.

INTRODUCTION
Preserving soil quality is critical for maintaining sustainable agricultural systems for next generations. Soil organic carbon is perhaps the most significant single indicator of soil quality and productivity of agricultural soils because of it influences on other physical, chemical and biological indicators of soil quality (Doran and Parkin, 1994; Reeves, 1997). Additionally, a growing body of science indicates that C sequestration on soils may help to mitigate climate change (Batjes, 1998).
Long-term experiments have shown that soil management practices, in particular tillage, crop rotations and manure additions can have major influences on SOC dynamics (Reeves, 1997). In general, continuous cropping with conventional tillage reduces SOC although the decline is affected by cropping system, climate and soil. On the other hand, cropping systems that minimize tillage operations and include high residue producing crops or perennial pastures in the rotation improves long-term SOC and productivity (Reeves, 1997). However, because SOC is a relatively temporal stable soil property, the impacts of soil management practices on it are mostly observed in long term field experiments. Soil organic C can itself be characterized into a set of sub-attributes composed of organic C fractions with different decomposition stages, chemical complexity, turnover time and responses to management practices (Christensen, 2001). Carbon from particulate organic matter (C-POM, 53-2000 µm), in addition to other more active pools of SOC (e.g. microbial biomass, soluble C), is

known to be a sensitive indicator of soil management practices impacts on SOC (Franzluebbers et al., 2000). Because the most significant changes on SOC related to soil management practices are mostly observed in the top soil and in C-POM, the C-POM-to-total SOC ratio and the SOC stratification ratio had been proposed as more sensible soil quality indicators than total SOC (Franzluebbers et al., 2000; Franzluebbers, 2002).

Results from the oldest long-term experiment in Latin America (1962, INIA-La Estanzuela, Uruguay) indicate that continuous cropping with conventional tillage results in a constant SOC decline, but crop-pasture rotations significantly reduced SOC and erosion losses (Diaz, 1992, Garcia-Préchac et al., 2004). No-till technology was introduced to Uruguay in the early 90's and was rapidly widespread and adopted by farmers. Preliminary information from mid term experiments under no-till in Uruguay suggests that the integration of no-till and crop-pasture rotations can maintain or even increase SOC compared with initial conditions (Terra and Garcia-Préchac, 2002; Garcia-Préchac et al., 2004; Ernst et al., 2005). One of these experiments evaluates different crop-pasture rotations under no till for forage and animal production purposes and was installed in 1995 in Eastern Uruguay on soils of lower land capability (USDA III and IV) than those prevalent in INIA la Estanzuela.

There are limited information about SOC dynamics on no-till rotation systems combining forage crops and pastures grazed directly. Under these systems, due to animal biomass consumption and trampling, the amount of residues left on the surface is lower than in systems based in grain production and soils are compacted. We hypothesized that under these conditions SOC can be reduced even under no-till systems if a significant proportion of perennial pastures are not included in the rotation. The objective of our research was to determine the effects of four soil use intensities on SOC and particulate organic C (C-POM; 53-2000 μm) in a 72 ha no-till crop-pasture rotation experiment in Uruguay (Typic Argiudols) after 8 years of adoption.

MATERIALS AND METHODS

A field-scale study was installed in 1995 at the 'Palo a Pique' experimental unit of the National Agricultural Research Institute (INIA) in Treinta Tres, Uruguay (33°:15'36"S, 54°:29'26"W, 60-m elevation). The site was a 72-ha field covered by regenerated native pasture vegetation after few years of cropping with soybeans (*Glycine max*) and barley (*Hordeum vulgare* L.) under conventional tillage (chisel plowing/disking) in the 80's. Soils at the site are Typic Argiudols and their main attribute in the 0-30-cm layer were clay, 220 g kg^{-1}; sand, 390 g kg^{-1} ; SOC, 20 g kg^{-1}, available P, 0.003 g kg^{-1}; and pH (soil:water), 5.2. Mean annual rainfall and temperature at the site are 1350-mm and 17° C, respectively.

The experiment evaluated four different soil use intensities under no-till, mainly for beef cattle production. Soil use intensities treatments were differentiated on the proportion and length of crops vs. pastures phases in the rotation: (i) Continuous Cropping (CC); (ii) Short Rotation (SR, 2 yr crops and 2 yr pastures); (iii) Long Rotation (LR, 2 yr crops and 4 yr pastures); and, (iv) Permanent Pasture (PP). The continuous cropping consisted on double annual cropping of oats (*Avena sp.*) mixed with annual ryegrass (*Lolium multiflorum* Lam.) for grazing in winter, and sorghum (*Sorghum bicolor* L) or foxtail millet (*Setaria italica*) for grazing or silage in summer. The short rotation included two years like CC followed by a biannual pasture of ryegrass and red clover (*Trifolium pretense* L.). The long rotation (LR) was two years like CC followed by a 4 yr perennial pasture including orchardgrass (*Dactylis glomerata* L.), white clover (*Trifolium repens* L.), and birdsfoot trefoil (*Lotus corniculatus* L.). Finally, the permanent pasture (PP) consisted in the native regenerated pasture which was overseeded every four years with annual ryegrass, white clover, and birdsfoot trefoil. Management practices in all treatments, including fertilization and agrochemicals applications, were similar. Pastures in all treatments were normally fertilized with 30 kg ha^{-1}

of N and 60 kg ha^{-1} of P_2O_5 at planting and refertilized each fall with 50 kg ha^{-1} yr^{-1} of P_2O_5. Either winter or summer annual crops of all treatments were generally fertilized with 30 kg ha^{-1} of N and 30 kg ha^{-1} of P_2O_5 at planting, and refertilized during the growing season with 35 kg ha^{-1} yr^{-1} of N. after grazing or cutting. All crops and pastures were planted with no-till practices.

The experiment did not have synchronic replications, but all phases of the rotations were present simultaneously; hence there were 12 experimental units of 6-ha each. Beef cattle grazed crops and pastures directly and machinery operations were performed similar to any commercial farm. Cattle stocking rates were adjusted based on seasonal forage production. Flexible rotational grazing systems were used in all treatments and each experimental unit was grazed during one week 8-10 times a year.

A detailed soil survey and an elevation map of the site were used to delineate three contrasting landscape positions in each experimental unit: summit, back slope and toeslope containing similar soils. Soil core samples (2.5-cm dia.) were collected in October 2003 to a depth of 15-cm at twenty randomly selected points within each delineated topography zone of every experimental unit. Soil cores were sectioned into 0-5, 5-10, and 10-15-cm increments, composited, dried at 45° C during 48 hours and ground to a 2-mm sieve. Carbon from particulate organic matter (C-POM) was determined by a physical fractionation similar to the method described by Cambardella and Elliot (1992). Dispersed soil samples were passed through nested sieves of 2000, 200 and 53 µm. The material remaining on the 200 and 53 µm sieves was analyzed for total C using the Mebius technique (Nelson and Sommers, 1982) and defined as the coarse (200-2000 µm) and fine (53-200 µm) C-POM fractions, respectively (Willson et al., 2001). A soil core sampler (5-cm dia.) was used to determine soil bulk density (0-15-cm) in 5-cm increments collecting 10 sub-samples per site to compute SOC on a volume basis (Mg SOC ha^{-1}). Stratification ratios were calculated from SOC at 0-5-cm divided by SOC at 0-15-cm as explained by Franzluebbers (2002).

The experiment was analyzed as a complete block design with three replications where the topographic zones acted as a pseudo blocks. All data were analyzed using general linear model (GLM) procedure in SAS® (SAS Inst., Cary, NC). Fisher's protected LSD was used for treatments means separation. Orthogonal contrasts were used to compare different phases and components of the rotations. An F statistic with $P \leq 0.1$ was used to determine the significance of all analyses.

RESULTS AND DISCUSSION

A significant SOC reduction of 17% in the 0-15-cm depth was observed at the site in CC relative to other treatments containing high proportion of perennial pastures in the rotation (LR and PP) (Table 1). However, no significant differences either on SOC or C-POM fractions were found in the 0-15-cm layer between soil use intensities containing any proportion of pastures in the rotation. Moreover, all soil use intensities containing perennial pastures (LR and PP) had similar SOC in the 0-15-cm layer than adjacent uncultivated native grassland (38.2 Mg ha^{-1}). As would be expected, the major decrease (47%) on SOC in CC relative to PP was observed in the coarse C-POM fraction (200-2000 µm). Although no differences on other SOC fractions were found between soil use intensities in the 0-15-cm depth, there was a great trend for CC ($P=0.13$) to have lower fine C-POM (53-200 µm) than PP as well. Data suggest that CC decreased SOC relative to original conditions and that pastures had the ability to recover SOC lost during the cropping phase of the rotations (LR and SR), even under no-till systems. The lack of SOC differences between treatments containing pastures at the end of 8 yr suggests that perennial pastures are essential components to sustain SOC in no-till rotations including forage crops.

As expected, in all treatments SOC was stratified in the soil profile with much higher SOC observed in the 0-5-cm depth relative to the 5-15-cm depth as usual in no-till systems (Table 2). Although, C-POM was correlated with total SOC, it became a higher portion of total SOC in the top layer, where both were greatest. Hence, not surprisingly the highest effects of soil use intensities on SOC were observed in the 0-5-cm depth and in C-POM pools. Most results observed on SOC in the 0-15-cm layer were found also in the 0-5-cm layer. Soil organic C in CC was 26% lower than in PP; but no significant differences on SOC were found between CC and LR despite the trend. Permanent pasture and LR had greater levels of coarse C-POM (74 and 60%, respectively) and fine C-POM (140 and 107%, respectively) than CC. No differences between soil use intensities were found on the non-C-POM fraction (< 53 µm).
Ratio of C-POM-to-total SOC in the 0-5-cm depth was lower in CC than in soil use intensities containing pastures. In this layer, C-POM represented 41, 45 and 46% of the total SOC in SR, LR and PP, respectively, but was only 33% in CC. On the other hand, stratification ratio of both, coarse and fine C-POM, were more sensitive to soil use intensities than stratification ratio of total SOC. Total SOC and non-C-POM (< 53 µm) stratification ratios were unaffected by soil use intensities at the site after 8 yr. However, either coarse or fine C-POM stratification ratios were greater in treatments containing any proportion of pastures compared with CC. Coarse C-POM in the 0-5-cm depth was 76, 82 and 78% of the coarse C-POM in the 0-15-cm layer in SR, LR and PP respectively, but was only 65% in CC. Similarly, fine C-POM in the 0-5-cm depth represented 74, 70 and 75% of the fine C-POM in the 0-15-cm layer in SR, LR and PP respectively, but represented only 53% in CC. The greatest C-POM stratification ratio in treatments containing perennial pastures suggests improved soil quality (Franzluebbers, 2002).
Data were consistent with other work (Franzluebbers et al., 2000; Franzluebbers, 2002; Moron and Sawchik, 2002; Garcia-Préchac et al., 2004). Franzluebbers (2000) indicated that a grazed tall fescue-bermudagrass pasture (20 yr old) had greater SOC (31%) and C-POM (66%), at a depth of 0–20-cm than a conservation-tillage cropland (24 yr old). Results from long-term studies in the UK (Low et al., 1963) and Uruguay (Diaz, 1992; Garcia-Préchac et al., 2004; Ernst et al., 2005) have shown that perennial pastures help to sustain SOC and productivity in conventional and no-till cropping systems. Diaz (1992) found that cropping systems under conventional tillage that included perennial pastures in the rotation had greater SOC in the 0-20-cm depth after 30 yr than continuous cropping systems. However, similar SOC was observed in that experiment between crop-pasture rotations systems with 33 to 66% of the time occupied by pastures. The author indicated that SOC lost by conventional tillage during the cropping phase of the rotations was partially recovered during the pasture phase, despite a small trend of SOC to decline in the long term. Moron and Sawchik (2002), working in the same trial found that a 6 yr crop-pasture rotation sequence with 50% of the time under pastures had 150% greater coarse C-POM and 100% greater fine C-POM (0-7-cm depth) than a continuous cropping system. A significant contribution of perennial pastures on total SOC and C-POM has been reported under Uruguayan conditions for no-till grain cropping systems in another experiment as well (Ernst et al., 2005; Salvo et al., 2005).

Table 1. Soil use intensity impacts on soil organic carbon (0-15-cm depth) and particulate organic C fractions (C-POM) from a 72-ha no-till field-scale rotations experiment in Uruguay (1995-2003).

	Soil Use Intensity †			
	Continuous Cropping	Short Rotation	Long Rotation	Permanent Pasture
Soil Organic C Fractions	(Mg C ha^{-1})			
Total C (<2000 µm)	31.8b‡	35.2ab	37.8a	38.8a
Coarse C-POM (2000-200 µm)	5.3b	6.0ab	6.8ab	7.8a
Fine C-POM (200-53 µm)	2.9a	3.7a	4.4a	4.7a
Non-C-POM (< 53 µm)	23.6a	25.5a	26.6a	26.3a

† Continuous cropping (CC): two forage crops each year; Short Rotation: two years idem CC and two years pasture; Long Rotation (LR): two years idem CC and four years pasture; Permanent Pasture: natural pasture overseeded with legumes used in LR.
‡ Least square means followed by the same letter within a row are not significantly different at P ≤ 0.1 level.

Table 2. Soil use intensity impacts on soil organic carbon (0-5-cm depth) and particulate organic C fractions (C-POM) from a 72-ha no-till field-scale rotations experiment in Uruguay (1995-2003).

	Soil Use Intensity†			
	Continuous Cropping	Short Rotation	Long Rotation	Permanent Pasture
Soil Organic C Fractions	(Mg C ha^{-1})			
Total C (<2000 µm)	15.3b‡	17.9ab	19.0ab	20.8a
Coarse C-POM (2000-200 µm)	3.5b	4.6ab	5.6a	6.1a
Fine C-POM (200-53 µm)	1.5b	2.7a	3.1a	3.6a
Non-C-POM (< 53 µm)	10.3a	10.5a	10.4a	11.1a

† Continuous cropping (CC): two forage crops each year; Short Rotation: two years idem CC and two years pasture; Long rotation (LR): two years idem CC and four years pasture; Permanent pasture: natural pasture overseeded with legumes used in LR.
‡ Least square means followed by the same letter within a row are not significantly different at P ≤ 0.1 level.

There were no SOC differences at any depth between crops in rotation with pastures compared with crops in CC, and just fourfold differences in the 0-5-cm depth between crops of LR and crops of SR (Table 3). Similarly, no SOC differences were found between pastures rotated with crops (LR and SR) compared with permanent pastures. However, 3-4 yr pastures of LR had greater SOC in the 0-15-cm depth (33%) and in the 0-5-cm depth (29%) than 1-2 yr pastures of the same rotation.

Similarly to what was reported for total SOC, no major differences on C-POM were observed either among crops of different treatments or between pastures in cropping rotations versus permanent pastures (Table 4). The major differences on SOC between pastures of LR vs. pastures of SR were explained for differences in C-POM. On the other hand, SOC differences between 3-4 yr pastures compared with 1-2 yr pastures were explained by differences on all SOC fractions. Data suggest that, even under no-till, SOC is reduced under annual forage crops but can be recovered including at least 2 yr pastures in the rotation; the inclusion of 4 yr pastures can sustain similar SOC than permanent undisturbed pastures.

Table 3. Soil organic carbon as affected by different rotation phases of four soil use intensities from a 72-ha no-till field-scale experiment in Uruguay (1995-2003).

Soil Depth	**0 -15-cm**	**0 – 5-cm**
Contrast Comparisons	(Mg C ha^{-1})	
Crops in rotation with pastures vs CC	(34.2-31.8) NS‡	(16.7-15.3) (NS)
Crops of Short Rotation vs Crops of Long Rotation	(33.1-35.3) NS	(17.8-15.6) *
Pastures in rotations vs Permanent Pasture	(38.4-38.8) NS	(19.8-20.8) NS
Pasture Short Rotation vs Pastures Long Rotation	(35.1-40.1) *	(18.0-20.7) ***
Pastures of 1 and 2 years vs. Pastures 3-4 years (LR)	(34.4-45.7) ***	(18.1-23.4) ***

† Continuous cropping (CC): two forage crops each year; Short Rotation: two years idem CC and two years pasture;
Long rotation (LR): two years idem CC and four years pasture; Permanent pasture: natural pasture overseeded with legumes used in LR.
‡ NS = not significant at $P \leq 0.1$ level

Table 4. Soil organic carbon fractions as affected by different rotation phases of four soil use intensities in a 72-ha no-till field-scale experiment in Uruguay (1995-2003).

Soil Depth	0 -15-cm			0 – 5-cm		
Soil Organic C Fraction	(2000-200 µm)	(200-53 µm)	(< 53 µm)	(2000-200 µm)	(200-53 µm)	(< 53 µm)
Contrast Comparisons						
Crops in Rotation with pastures vs CC	NS‡	NS	NS	NS	0.002	NS
Crops SR vs Crops of LR	NS	NS	NS	NS	NS	0.010
Pastures in rotations vs PP	NS	NS	NS	NS	NS	NS
Pasture SR vs Pastures LR	0.040	0.044	NS	0.039	NS	NS
Pastures 1-2 yr. vs. Pastures 3-4 yr. (LR)	<0.001	<0.001	0.006	0.007	0.009	0.008

† Continuous cropping (CC): two forage crops each year; Short Rotation: two years idem CC and two years pasture;
Long rotation (LR): two years idem CC and four years pasture; Permanent Pasture: natural pasture overseeded with legumes used in LR.
‡ NS = not significant at $P \leq 0.1$ level

SUMMARY AND CONCLUSION

Continuous cropping of forage crops under direct grazing reduced total SOC compared with cropping systems including perennial pastures in the rotation, even under no-till. No differences on SOC were found between permanent pastures compared with crop-pasture rotation sequences with 50 to 66% of the time under pastures. The most significant changes on SOC related to soil uses intensities under no-till for forage production were observed in the top soil and in C-POM fractions. Treatments containing pastures had greater ratio of C-POM-to-total SOC and stratification ratio of C-POM than continuous cropping, thus greater soil quality. We speculate that SOC reduction in CC or in the cropping phase of the rotations is due to negative C balance generated by the above ground biomass extraction by grazing animals and silage operations. Conversely, the gain of SOC under pastures is though to be related to the greater biomass partitioned to the root system compared with crops and to the lower efficiency of utilization by grazing animals. The aggregate of data suggest that for undegraded soils in temperate climates, a soil management system for forage production including no-till and forage crops rotated with perennial pastures, can sustain SOC in the long term, even compared wit undisturbed soil under pristine vegetation or under improved natural pastures. These results add to the evidence of the importance of grass-legumes perennial pastures as components of the Uruguayan agricultural production systems in terms of soil and environmental sustainability.

REFERENCES

Batjes N.H., 1998. Mitigation of atmospheric CO_2 concentrations by increased carbon sequestration in the soil. Biol Fertil Soils 27:230-235.

Cambardella, C.A., Elliot, E.T., 1992. Particulate soil organic matter changes across a grassland cultivation sequence. Soil Sci. Soc. Am. J. 56:777-783.

Christensen, B.T., 2001. Physical fractionation of soil and structural and functional complexity in organic matter turnover. European J. Soil Sci. 52:345-353.

Díaz Roselló, R. M., 1992. Evolución de la materia orgánica en rotaciones de cultivos con pasturas. INIA, Investigaciones Agronómicas 1(I):103-110.

Doran, J.W., Parkin, T.B., 1994. Defining and assessing soil quality. *In*: Doran, J.W, Coleman, D.C., Bezdicek,D.F., Stewart, B.A. (Ed.), Defining soil quality for a sustainable environment. SSSA-ASA, Madison, WI, pp. 3-21

Ernst,O., Siri-Prieto, G., Cano, J.D., 2005. Rotación pastura-cultivo y sistema de laboreo en el Uruguay: a) Cambios del contenido de carbono y nitrógeno del suelo. In: Simp. Sobre plantio direto e meio ambiente, sequestro de carbono e qualidade da agua. Fed. Brasileira de plantio direto na palha, Foz de Iguaçu, Brazil, p.213.

Franzluebbers, A.J., Stuedemann, J.A., Schomberg, H.H., Wilkinson, S.R., 2000. Soil organic C and N pools under long-term pasture management in the Southern Piedmont USA. Soil Biol. Biochem. 32:469-478.

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

Franzluebbers, A.J., Stuedemann, J.A., 2002. Particulate and non-particulate fractions of soil organic carbon under pastures in the Southern Piedmont USA. Environmental Pollution. 116:S53-S62.

García-Préchac, F., Ernst, O.R., Siri-Prieto, G.C., Terra, J.A., 2004. Integrating no-till in livestock/crop-pastures rotations in Uruguay. Soil Tillage Res. 77:1-13.

Low, A.J., Piper, F.J., Roberts, P., 1963. Soil changes in leyarable experiments. J. Agric. Sci. (Cambridge) 60: 238-299.

Morón, A., Sawchik, J., 2002. Soil quality indicators in a long-term crop pasture rotation experiment in Uruguay. *In:* 17th World Congress of Soil Science, 14-21 Aug. 2002. Thailand.

Nelson, D.W, Sommers, L.E., 1982. Total carbon, organic, and organic matter. In: A.L. Page (Ed), Methods of Soil Analysis, Part 2, Agronomy No.9, Am. Soc.Agron., Madison, WI, pp. 539-579.

Reeves, D.W., 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil Tillage Res. 43:131-167.

Salvo, L., Hernández, J., Cano, J.D., Ernst, O., 2005. Rotación pastura-cultivo y sistema de laboreo en el Uruguay: b) Distribución del carbono en diferentes fracciones de la materia orgánica. *In:* Simposio sobre plantio direto e meio ambiente, sequestro de carbono e qualidade da agua. Fed. Brasileira de plantio direto na palha, Foz de Iguaçu, Brazil, p.213.

Terra, J.A., Garcia-Prechac, F., 2002. Soil organic carbon content of a Typic Argiudol in Uruguay under forage crops and pastures for direct grazing: Effect of tillage intensity and rotation system. *In*: E. Van Santen (ed.) Proc. 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. 24-26 June 2002, Auburn, AL. pp. 70-73.