Soil Organic Carbon Content of a Typic Argiudoll in Uruguay under Forage Crops and Pastures for Direct Grazing: Effect of Tillage Intensity and Rotation System

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ABSTRACT

Reduced information exists regarding tillage intensity effect on soil carbon (SOC) in rotation systems that combine forage crops and pastures grazed directly. A 72 ha experiment comparing 4 soil use intensities (SUI) was installed in 1995 in Uruguay on a Typic Argiudol. SUI were Continuous Cropping (CC): double crop of C3 grasses in winter and C4's in summer, Short Rotation (SR): 2 years idem CC and 2 years of biannual grass and legume pasture, Long Rotation (LR): 2 years idem CC and 4 years of perennial grass and legume pasture, and Permanent Pasture (PP): natural pasture overseeded with perennial legumes. There are no synchronic replications, but yearsare the replications for statistical analysis. Experimental units occupy 6 ha, containing all rotations phases synchronically. Conventional experiments with RCB design are conducted annually inside CC and in the experimental units of SR and LR in the first crop following the pasture; treatments are tillage intensities (Conventional: CT, Reduced: RT, and No-Till: NT). SOC is determined annually in composite samples collected 0-15 cm depth. Results showed that under CC, SOC decreased 24%, 12% and 7.5% from 1995 to 1999 with CT, RT and NT, respectively. Using NT, SOC was 12-20% and 23-30% higher in SR and LR, respectively, compared with CC. Compared with PP, SOC was 11% and 14% higher in SR and LR, respectively. It is concluded that CC for intensive animal production is not sustainable, even with NT. Forage Crop-pasture rotations, however, were demonstrated to maintain and improve SOC, being sustainable.

KEYWORDS

Soil Organic Carbon, Conservation Tillage, No-Till, Crop-Pasture Rotations

INTRODUCTION

Uruguay, located in South America between 30 and 35 degrees of latitude, has an important experience in integrating crops and pastures in rotations systems. The area served by the Experimental Station INIA-Treinta y Tres, in Eastern Uruguay, represents 30% of the country. The dominant soils are Typic Argiudols with low to moderate soil fertility (1.5 to 2% SOC). They occupy a landscape of gently sloping hills of modest altitude, where the erosion risk is moderate to high. Also, because of a strongly developed argillic B horizon, these soils are sometimes poorly drained. Because of their natural limitations, they are between land capabilities III and IV in the USDA Land Capability Classification. Because of their limitations for grain crop production, natural livestock pastures are the predominant production system in this area. The adoption of No-Till technology started during the 90's, allowing the development of more intensive animal production systems based on forage crops and pastures rotations.

Soil organic carbon is recognized as the main soil quality indicator (Doran and Parkin 1994; Reeves, 1997; Seybold *et al*., 1997). Mid and long term effects of tillage and rotation on SOC in grain crops production systems have been extensively reported (Diaz, 1992; Reeves, 1997). Results from the oldest long-term experiment in South America (started in 1962 in INIA-La Estanzuela, Uruguay) indicate that continuous cropping with conventional tillage results in a continuous SOC decline, but in crop-pasture rotations SOC declines during the arable cropping cycle but is recovered during the planted pasture cycle. These opposite effects tend to lead to a long term SOC equilibrium, despite a small downward trend (Diaz, 1992). The SOC recovery produced by pastures improves nitrogen availability (reducing the need of fertilizers) and soil physical conditions for the following crop phase of the rotation (García Préchac, 1992). The rotations of crops and pastures also have an important effect in reducing the long term average annual erosion (Terra and García Préchac, 2001), because half of the time the soil remains covered suffering no tillage.

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Little information is available in rotation systems that combine forage crops and pastures grazed directly. In these conditions, due to animal utilization or harvesting for hay or silage, the amount of biomass incorporated into the soil (conventional tillage) or left as residue on the surface (no-till) is less than in the systems where grain harvesting is the only biomass exported during the crop cycle of the rotations.

Soil compaction in the top 10-15 cm caused by livestock trampling also can be a problem in the adoption of NT by farmers. Results of Ernst and Siri (2000) suggest that RT for the first crop following the pastures is necessary to achieve the same crop yield as with CT during the rest of the cropping cycle using NT. No tillage is needed, however, if it is possible to have enough fallow time between the herbicide application and the first crop planting. There is evidence of this fallowing effect on better soil N availability (Terra and García Préchac, 2001) and reduced surface compaction (Ernst, not published, cit, by García Préchac *et al.,* 2002).

The objective of the present paper is to present SOC results evaluating the effect of rotations, including forage crops and pastures for direct grazing, with different tillage and cropping intensities.

MATERIALS AND METHODS

A 72 ha experiment was installed in 1995 on a Tipic Argiudol at the Palo a Pique experimental unit of the National Institute of Agriculture Research (INIA) located in Eastern Uruguay. The experiment compares the following four soil use intensities (SUI) for livestock production.

Continuous Cropping (CC)

Double annual forage crop of oats (*Avena sativa*) mixed with annual ryegrass (*Lolium multiflorum*) in winter and sorghum (*Sorghum bicolo*r) or foxtail millet (*Setaria italica*) in summer.

Short Rotation (SR)

Two years of CC followed by two years of a pasture of annual ryegrass and red clover (*Trifolium pratense*).

Long Rotation (LR)

Two years of CC followed by four years of a pasture including orchardgrass (*Dactylis glomerata*), white clover (*Trifolium repens*), and birdsfoot trefoil (*Lotus corniculatus*).

Permanent Pasture (PP)

This is a natural pasture which was overseeded every four years with ryegrass, white clover, and birdsfoot trefoil.

The experiment does not have synchronic replications, but all phases of the rotations are present simultaneously; there are 12 experimental units of 6 ha, where livestock grazes directly. For the statistical comparison of the 4 soil use intensities, years were taken as replications in a Randomized Complete Block (RCB) design. The results that are going to be presented come from three years: 1998, 1999, and 2000.

Despite all 6 ha, experimental units were managed with no-till in smaller areas inside them. Short mid-term analytical experiments were conducted comparing the effects of different tillage intensities: Conventional: (CT), Reduced (RT), and No-Till (NT). These experiments were arranged in RCB design with 4 replications. CC has contained one of these analytical experiments since 1995, with the same treatments applied to the same plots that were planted with forage crops twice a year. Identical experiments were conducted in 1998 and 1999 in the experimental units of SR and LR, corresponding to the first winter crop following the pasture cycle of the rotation. In SR and LR after this first crop, all the following crops were NT planted. Excessive soil degradation observed from 1995 to 1998 was the reason to exclude CT from the experiment in 1999.

Composite soil samples were collected in the fall from the top 15 cm in the 12 experimental units of the experiment that compared the 4 SUI. In each one of these units there was a selected 0.5 ha sampling area chosen for identical soil characteristics, including landscape position. The composite sample in these cases came from 15 2.5 cm diameter soil cores taken randomly in the sampling area.

In the 0.04 ha plots of the analytical experiments comparing tillage intensities, the composite soil samples were made of 10 subsamples taken randomly in all the plots' surface. The sampling in these experiments was made at the planting of the winter crop and after the following summer crop harvesting. SOC was determined using the Walkey and Black technique (Nelson and Sommers, 1982).

Data analysis was performed using SAS PROC GLM (SAS Institute, 1996). In the experiment comparing SUI, the treatment sum of squares was partitioned into three orthogonal contrasts of one degree of freedom: CC *vs.* other treatments, PP *vs*. SR and LR, and SR *vs*. LR.

In the experiments comparing tillage intensities on three different previous uses (CC, 2 yr. Pasture in SR, and 4 yr. Pasture in LR) in 1998 and 1999, a combined analysis was made using Blocks nested into Previous Use as the error term to test the previous use effect. The independent contrasts were: CC *vs*. Pastures, and 2 yr (SR) *vs*. 4 yr. (LR) pastures. In 1998 Tillage intensities independent contrasts were: CT vs. RT and NT, and RT vs. NT; in 1999 the only tillage intensity contrast was RT vs. NT. The interaction (Previous use x Tillage intensities) contrasts were the combinations of the indicated Previous Use and Tillage intensities contrasts.

When presenting and discussing the results, the indication of significant differences were based in the contrasts with equal or smaller probability of greater F than 0.05. The LSD's are presented as an indication of the experimental error, not to be used for means comparisons.

RESULTS AND DISCUSSION

The SOC means from 1998 thru 2000 were CC: 1.48%, PP: 1.6%, SR: 1.78%, and LR: 1.82%; the LSD was 0.2%. The independent contrasts indicated that CC had significantly lower SOC than the average of the other SUI. PP had significantly lower SOC than the average of the two crop-pastures rotations, and there were no significant difference between SR and LR.

The results of the Tillage intensity experiment inside CC are presented in Fig. 1. The general trends, best described (higher R^2) by quadratic functions, show SOC decline for the three tillage intensities, but these declines were different between treatments. Referred to the SOC before the experiment started, the reductions in the last measurement were 7.5%, 12% and 24%, in NT, RT and CT, respectively.

Because of the low return of biomass to the soil in CC, due to grazing of the winter crops and harvesting for hay or silage of the summer crops, it is conceivable to have some SOC reduction even with NT. It should be noted that the magnitude of SOC reduction in CC with NT in both experiments is very close. In the SUI experiment, the SOC under PP is representative of the initial value under natural pasture; the reduction under CC, compared with PP was 8%. Because of greater soil organic matter oxidation and soil erosion, a greater SOC decline with increased tillage intensity should be expected , as the results indicate.

Contrasting with CC, the SOC in the crop-pasture rotations is expected to be higher, but the results show that SOC in these rotations was even higher than in PP. The explanation for such result should be that the Carbon balance in the crop-pasture rotations is higher than in PP. The results of the Tillage intensity experiments in 1998 and 1999, presented in Table 1, indicate the same trend. At the planting of the winter crop in 1998, the combined analysis of the 3 experiments showed lower SOC in CC than in the experiments on pastures, and that in the experiment started on the 4 year pasture, the SOC was higher than in the one started on the 2 year pasture. The effect of the tillage intensity Treatments in the 3 experiments shows significantly higher SOC in NT than in the tilled treatments and no difference between them. The significant results at the 1999 winter crop planting also indicate that CC had the lower SOC and that between the two previous pasture uses, SOC was higher in LR than in SR. Between the two tillage treatments used in 1999, NT had higher SOC than RT. In both years the interaction contrasts were not significant.

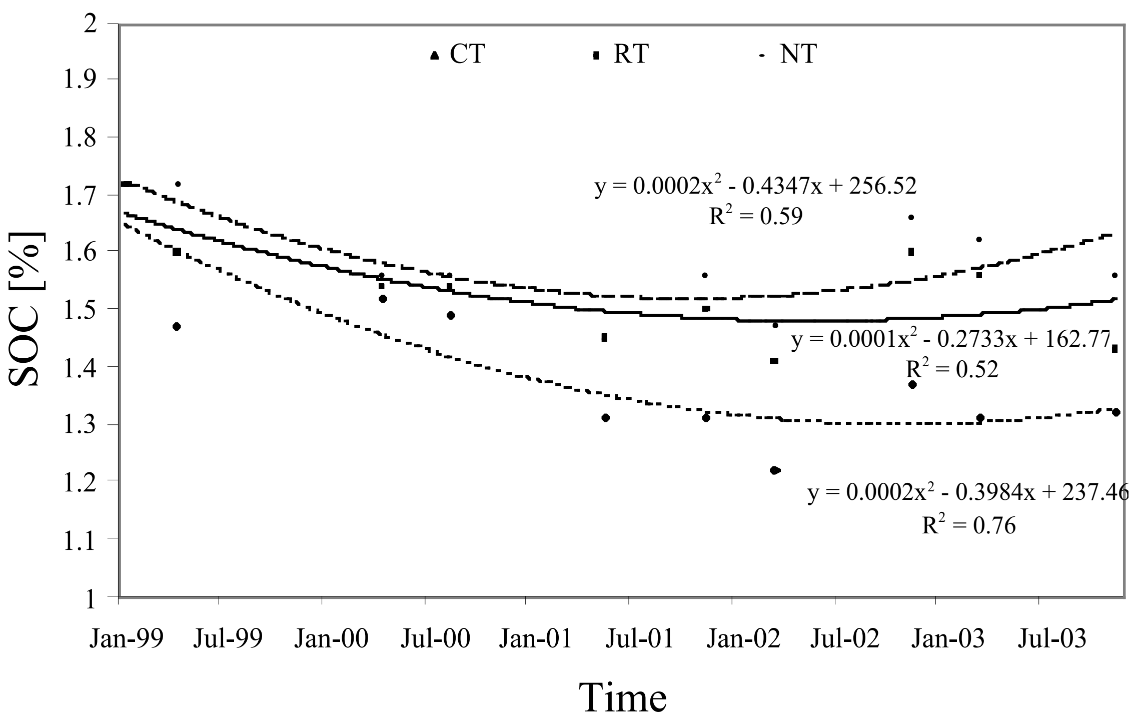

Fig. 1. Soil Organic Carbon content evolution with time in an experiment at the at the Palo a Pique experiment station in Eastern Uruguay comparing three tillage intensities, in continuous forage cropping.

Table 1. The effect of three soil use intensities (SUI) and three tillage intensities effect on soil organic carbon (SOC %) in the 0-15 cm depth during winter cropping season in two years.

SUI ➔	CC				SR				LR				LSD for	
Tillage Intensity:	CT	RT	NT	SUI MEAN	CT	RT	NT	SUI MEAN	CT	RT	NT	SUI MEAN	SUI	Tillage Intensity
1998 SOC%	1.44	1.56	1.68	1.56	1.71	1.67	1.85	1.74	1.86	1.93	2.02	1.94	0.21	0.08
1999 SOC%	1.31	1.56	1.62	1.50	-	1.63	1.75	1.69	-	1.99	2.23	2.11	0.29	0.14

CONCLUSIONS

SOC decreases with tillage intensity, independently of the previous SUI. SOC was higher under NT and lowest under CT. In a highly biomass extractive system like CC, even with NT there is some SOC decline.

The inclusion of seeded pastures in rotation with forage crops increases SOC, independently of the tillage intensity used. The results indicate that the inclusion of productive pastures in the rotations can determine that the carbon balance will be higher than in natural pastures of modest productivity, reaching higher SOC content.

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