IMPACT OF WINTER COVER CROPS ON SOIL PROPERTIES UNDER SOYBEAN CROPPING SYSTEMS

Jorge Sawchik, Mario Pérez-Bidegain, Claudio García

Abstract

Agricultural systems in Uruguay exhibit a high frequency of soybean in crop rotations. This could adversely affect soil organic carbon (SOC) storage in the long term. The introduction of winter annual cover crops (CC) in these systems may improve SOC balance as well as reduce the impact of rainfall on soil erosion rates. The objective of this study was to evaluate the impact of the inclusion of CC on SOC storage and soil physical properties under continuous soybean (Glycine max [L.] Merr) cropping systems. A field experiment was established in 2003 in a vertic Argiudoll. A split plot design was used with CC and non CC as whole plot arranged in four randomized complete blocks. Cover crops were: oats (Avena sativa L)., annual ryegrass (Lolium multiflorum L.). Two termination dates comprised split plots: 60 or 30 days before soybean planting. Mean annual forage production over eight years was higher ($P \leq 0.05$) in oats compared to annual ryegrass for both termination dates. The inclusion of CC increased SOC concentration at the 0-7.5 cm depth, and at the 7.5-15 cm depth in the annual ryegrass treatment. Oats and annual ryegrass had 60 and 80 % more particulate organic carbon (POC) concentrations at the 0-7.5 cm, respectively than no cover crop treatment. No significant differences among treatments were observed for mineral associated organic C-MAOM at any depth. Nitrogen mineralization potential under ryegrass had a three-fold increase compared to the no cover crop treatment. Both CC treatments showed a higher ($P \leq 0.05$) percentage of macropores compared to the no cover crop treatment. In most of the years soybean grain yield was not affected by cover crops treatments. However, late termination dates often reduced soybean yields. The inclusion of CC in high frequency soybean cropping systems may enhance soil C storage, and improve related soil physical properties.

Keywords: cover crops, soil organic carbon, cropping systems

Introduction

The grain cropped area of South America has increase dramatically in the last ten years with soybean as the predominant crop. The relation between the area of soybean and that sown with other summer crops is ca. 6 in Argentina and Uruguay (1). In Uruguay, in particular, the soybean area has increased from 9000 ha in 1998 to more than 1.000.000 ha in 2010. This increase has been favored by the introduction of glyphosate-resistant genotypes, and adoption of no-tillage as well as by favorable international prices in comparison with cereals (1). This has resulted in crop rotations with less diversity. The high soybean cropping frequency in predominant agricultural systems raises concerns about the sustainability of our natural resources. Soybean crops provide a limited amount of residues with a low carbon: nitrogen (C:N) ratio (2). This enhances rapid stubble decomposition and exposes the soil to a greater erosion impact after soybean harvest. Estimated annual soil erosion rates for soybean dominated cropping systems are usually higher than soil loss tolerance under local conditions (3). Therefore, these systems may also affect soil organic carbon (SOC) storage in the medium and long term, leading to negative SOC balances (3, 4).

The inclusion of winter annual cover crops in grain crop rotations is a management practice promoted to protect soil resources and enhance water quality. Cover crops have been identified as important components of diversified crop rotations. Different studies have shown that cover crops improve soil erosion control, decrease nutrient losses through leaching and runoff, increase C sequestration (5,6).

Various cover crops species have been identified that diversify cropping systems. While legume cover crops may enrich soil inorganic N, and reduce nitrogen fertilizer needs for subsequent crops, nonlegume cover crops may also be effective in maintaining or increasing soil organic matter. The impact of grasses as cover crops is related to an increase in both aboveground and belowground biomass production compared with bare soil. Roots may play a dominant role in soil C and N cycles and may have relatively greater influence on soil organic C and N levels than aboveground plant biomass (7). The literature shows evidence that both supports and refutes the ability of cover crops to improve soil physical properties and soil organic matter (8). These authors evaluated the long-term effect of winter cover crops on soil organic matter and physical properties after 12 years. While aggregate stability increased with the inclusion of cover crops, no increase was observed in soil organic matter. In this study, heavier-textured soils exhibited no consistent differences attributable to winter cover crops.

The use of winter annual grasses as cover crops in crop rotations is not yet a widely adopted agricultural practice in Uruguay. The use of double cropping, wheat-soybean, is very frequent and the predominant cropping system. However, in many years no crops are planted on soybean stubble leaving the soil exposed during fall and winter months. The objective of this study was to determine the impact of two different winter annual cover crops on both SOC and more active soil C pools and selected soil physical properties after eight growing seasons.

Materials and Methods

An experiment was set up in 2003 at La Estanzuela Experimental Station (INIA) located in Colonia (34º 25' S 58º 0' W), Uruguay, introducing winter cover crops in a continuous soybean cropping system. Soil type is a vertic Argiudoll with < 2 % slope. The field had been managed with no tillage and continuous crops since 2000. Before that period conventional tillage and crop pasture rotations were used throughout the experimental area for more than thirty years.

We evaluated three winter cover crop treatments: annual ryegrass (*Lolium multiflorum* L.), oats (*Avena Sativa* L.) and no cover crop (control) and two termination dates: 30 (late) and 60 (early) days before soybean planting. Treatments were arranged in a split plot design in randomized complete block with six replications. Cover crop was the main plot, and termination date the split plot treatment. Plot size was 30 x 10 m. Cover crops were sown every year under no tillage after soybean harvest (eight seasons). Seed densities were 20 and 80 kg ha^{-1} for annual ryegrass and oats respectively. Soybean (*Glycine Max* L.) was sown every year at 0.38 m row spacing and a density of 450.000 plants ha^{-1} using indeterminate cultivars (maturity group 5). At each termination date cover crops were killed with 3-4 l ha^{-1} of glyphosate (48 % active principle). Phosphorus (P) was applied according to soil test P values and current fertilizer recommendations, and nitrogen (N) was applied to cover crops at early tillering in almost all years at a rate of 40 kg N ha^{-1}. Soybean grain yield was evaluated with experimental combines.

At the beginning of the experiment basic soil physical and chemical characteristics were determined for each soil horizon. Every year above-ground biomass production of cover crops was determined at each termination date from two 1m^2 samples per plot. A subsample was ground, homogenized and passed through a 0.25-mm diameter sieve for N and P determinations.

Soil samples were taken twice from each experimental unit: spring of 2009 (before soybean planting) and summer 2012. In 2009, composite soil samples from the layers 0- to 7.5, and 7.5-15-cm depth were manually collected. Samples were then taken to the laboratory, wet sieved (2 mm) and stored at 4°C until analysis. Soil organic carbon (SOC) concentration was measured by dry combustion at 900° C with a LECO autoanalyzer. Total Nitrogen (TN) was measured after sulfuric digestion, distillation with microKjeldahl and titration. Carbon in particulate organic matter (C-POM) was determined following a modification of the method described by Cambardella and Elliot (1992) (9). Two C fractions were then generated: C-POM 212 and C-POM 53. The C fraction smaller than 53 microns (C-MAOM) associated with the mineral fraction was calculated as the difference between SOC and the sum of C-POM 212 and C-POM 53. Nitrogen mineralization potential (PMN) was determined by incubation under waterlogged conditions at 40°C and 7 days on wet sieved soil samples. In 2012, composite soil samples from the layers 0- to 7.5, 7.5-15, and 15-30 cm were taken from the late termination date (30 days) plots. These samples were analyzed for SOC, TN and PMN following the procedures already described.

Undisturbed cores were taken for the 0-7.5-, 7.5-15-, and 15-30-cm soil layers and soil bulk density (BD) from the treatments were assessed through the core method. Undisturbed soil cores were also taken for the

0-7.5-, and 7.5-15 cm depth and the water content at -6 kPa matric potential was determined on a tension table. Soil macroporosity was calculated as the percentage of pores larger than 50 μm (10). Ponded infiltration rates were measured for a 3-hour period with a double ring infiltrometer in early fall of 2012 (before soybean harvest). Soil stability was measured in 2008, before soybean planting, on oat cover crop with early and late termination date treatments and control using a micro rainfall simulator (11). Rainfall simulations were carried out after removal of crop residues on a 0.25 by 0.25 m plot. Previously, the soil was wetted to uniform soil water content among treatments. We applied a rainfall for 4 minutes equivalent to a 360 mm. hr^{-1}. The eroded soil was collected on aluminums cans until one minute after the rainfall ceased. The amount of eroded was used as an on site index of soil stability.

Analysis of variance was performed with SAS statistical package to assess the treatment effects for each soil variable and depth separately.

Results and Discussion

Annual aboveground biomass accumulation from cover crops ranged between 1.2 and 14.2 Mg ha^{-1} and differed between species and years (Table 1).

Table 1. Aboveground biomass yield (Mg ha^{-1}) in cover crops treatments during 2004-2011.

Cover crop	Termination date	Minimum	Maximum	Mean	Total†
		------------------------*Biomass (Mg ha^{-1})*----------------------------------			
Oats	Early	2.3	5.4	3.6	25.2
	Late	6.2	14.2	8.9	62.2
Ryegrass	Early	1.2	5.7	2.8	19.8
	Late	5.4	12.1	7.5	39.3

†Total aboveground cover crop biomass accumulation in seven growing seasons (2004-2011).

Oat biomass was significantly higher ($P \le 0.05$) than annual ryegrass production in all growing seasons.

Oat exhibits higher growth rates during fall and early winter than ryegrass while this cover crop outyields oats during late winter and spring. The control treatment had a maximum annual biomass production of 1.6 Mg ha^{-1}, since weeds were controlled during the growing season. Nitrogen concentration in aboveground biomass was also different between treatments (data not shown). Annual ryegrass exhibited higher ($P \le 0.05$) nitrogen concentration than oats for both termination dates resulting in a residue with lower C:N ratio.

Results from soil sampling done in the spring of 2009 (after 6 growing seasons) are depicted in Table 2.

Table 2. Mean values of measured soil variables at the 0-7.5 cm depth in the spring (before soybean planting) of 2009.

Cover Crop	Termination date	SOC†	C-POM†	C-MAOM†	PMN†
		-------------------*g kg$_{-1}$*------------------			*mg kg^{-1}*
Oat	Early	34.4a‡	12.2a	22.2a	91b
	Late	33.2a	10.3a	22.9a	83b
Ryegrass	Early	37.6a	13.9a	23.7a	175a
	Late	36.7a	14.1a	22.7a	165a
Control		29.5b	7.7b	21.8a	66c

† SOC= Soil organic Carbon concentration; C-POM = Carbon in particulate organic matter; C-MAOM = Carbon fraction smaller than 53 microns; PMN = Nitrogen mineralization potential.

‡ Numbers followed by different letter within a column are significantly different at $P \le 0.05$ by the least significant difference test.

Cover crops increased SOC concentration at the 0-7.5 cm depth, for both termination dates (Table 2). Ryegrass as cover crop also increased SOC at the 7.5-15 cm depth (data not shown). The increase in near-surface SOC concentrations may be attributed to the accumulation of aboveground and belowground residues under no-till conditions and has been previously reported in long-term cover crop studies (10). There were significant ($P \leq 0.05$) effects of treatments and depth on C-POM. Both cover crop treatments had greater C-POM than the no cover crop control at the 0-7.5 cm depth (Table 2). Our results are consistent with other findings (8,9,12) by showing C-POM changed rapidly in response to management practices. Overall, oat and annual ryegrass had 60 and 80 % more C-POM than the no cover crop control at the 0-7.5 cm depth. Since sampling was done before soybean planting in 2009 part of the treatment differences are likely due to fresh organic inputs to the soil after the winter cover crop period compared with fewer inputs in the control treatment. Nitrogen mineralization potential (PMN) exhibited the same tendency as observed with C-POM. Previous studies (9) have shown a highly linear correlation between these two variables suggesting that the more labile organic N is present in the C-POM fraction. Annual ryegrass had higher PMN than the other treatments probably related to a higher N content in above- and belowground biomass.

No differences between cover crop treatments ($P \leq 0.05$) were found among termination dates for all variables. Greater shoot biomass production with a higher C:N ratio in late termination dates probably increased carbon losses through microbial decomposition reducing the effectiveness to convert biomass C into SOC. Previous studies (13) have reported that relating total C addition by plants to total soil C revealed a rather poor linear relationship. This relation improved when relating only root-C addition to soil C stock indicating that accumulation of SOC under no tillage occurs primarily due to increased retention of root-derived C in the soil.

Late termination dates plots were sampled again before soybean harvest in 2012. Results from this sampling date are shown in Table 3. All treatments showed a clear stratification, typical under no-till soils, in all variables within the 0-15 and 15-30 cm depth (data not shown). In the 0-7.5 cm layer cover crops showed the highest SOC concentration following the same tendency observed in 2009. No significant differences were observed in SOC concentrations in the 7.5-15 and 15-30 cm depth (data not shown). Previous research has demonstrated that inclusion of annual cover crops might increase SOC concentration and stock at the near surface level (13). These findings indicated that effective C sequestration deeper in the soil profile was obtained including perennial pastures (alfalfa) in grain crops rotations, mainly due to C contribution by alfalfa roots.

Table 3. Mean values of measured soil variables at the 0-7.5 and 7.5-15 cm depths in early fall (before soybean harvest) of 2012.

Cover crop	SOC†		TN†		PMN†	
	g kg^{-1}		*g kg*$^{-1}$		mg kg^{-1}	
	0-7.5 cm	7.5-15 cm	0-7.5 cm	7.5-15 cm	0-7.5 cm	7.5-15 cm
Oat	34.6a‡	20.7a	3.07a	1.91a	80a	19a
Ryegrass	34.0a	20.7a	2.93a	2.03a	69ab	17a
Control	29.2b	19.7a	2.63b	1.90a	40b	11b

† SOC= Soil organic Carbon concentration; TN = Total Nitrogen; PMN = Nitrogen mineralization potential.

‡ Numbers followed by different letter within a column are significantly different at $P \leq 0.05$ by the least significant difference test.

Winter cover crops had greater TN concentrations than the control treatment at the 0-7.5 cm depth. No significant differences were observed in TN for the 7.5-15 cm layer, but there was a tendency for annual ryegrass to show the highest TN value. Oat had the largest PMN and the control no cover crop the lowest at both soil depths. Compared to the first sampling date in 2009, PMN values declined in all treatments. This is likely explained by a combined effect of temporal variability between sampling dates and times, and a lower nitrogen supplying capability from the soil. While in 2009 sampling was done before soybean planting, in 2012 sampling occurred before soybean harvest, at least six months after cover crops were killed. These results might also show a decline in N supplying capability. Soybean cropping systems exhibit a negative N balance because the contribution of biological N fixation is insufficient to compensate the extraction by harvested grains (14). On the other hand N fertilizer applied to the cover crops might not be enough to overcome the negative N balance. Thus, a decline in PMN in these cropping systems should be expected. Although PMN values were higher with cover crops at the 7.5-15 cm, absolute values reveal a poor potential N contribution from this soil layer regardless of the treatment.

The input of above- and belowground biomass from cover crops increase the SOC concentration. This increase in SOC concentration may also improve soil physical properties. Soil bulk density was measured several times and data from the last sampling (2012) are presented (Table 4). Cover crops had no effect on BD at any depth evaluated (0-7.5, 7.5-15 and 15-30 cm depth). Previous studies (12) on long-term cropping systems showed a limited effect of cover crops on this soil variable. Cover crop impacts will depend on soil type, cover crop specie, and climate among other factors. Cover crop had an effect on macropores only at the 0-7.5 cm soil layer and only data from 2012 is presented. Oat had the highest and the control no cover crop the lowest value. These soils with a large proportion of smectite clays in the soil matrix have the ability to generate structural pores (10). Cover crops improved near-surface hydraulic properties however the impact of cover crops on pore size distribution has not been analyzed to determine the percentage of mesopores.

Table 4. Mean values of soil physical properties in early fall (before soybean harvest) of 2012.

Cover crop	BD† (g cm^{-3})		Macropores (%)	Infiltration rate (mm h^{-1})
	0-7.5 cm	7.5-15 cm	0-7-5 cm	
Oat	1.00a‡	1.28a	14.5a	9.6a§
Ryegrass	0.99a	1.25a	13.8a	8.3a
Control	1.06a	1.28a	11.1b	1.5b

† BD= Soil bulk density

‡ Numbers followed by different letter within a column are significantly different at $P \leq 0.05$ by the least significant difference test.

§ Numbers followed by different letter within a column are significantly different at $P \leq 0.10$ by the least significant difference test.

Infiltration rates exhibited a high degree of variability. There was however a tendency to higher ($P \leq 0.10$) infiltration rates under both cover crops compared with the control treatment. The impact of cover crops on SOC concentration suggested that SOC also improve soil attributes (e.g. soil porosity and aggregation) that affect water infiltration. Previous findings suggested that earthworm under cover crops may develop more water conducting macropores, improving soil structure and increasing water infiltration (12).

The mean amount of eroded soil was 1.18 and 2.12 g. plot^{-1} on early and late oat termination dates, respectively. The control treatment eroded 6.77 g.plot^{-1}. The amount of eroded soil under the control treatment was higher ($P \leq 0.05$) than the mean of remaining treatments. These results suggest that the inclusion of CC on crop rotations with high soybean frequency enhance soil resistance to water erosion.

Soybean grain yields showed no effect of cover crops treatments for most of the years (data not shown). In three out of eight growing seasons, late termination dates had lower ($P \leq 0.05$) grain yields compared to early termination dates, when soybean was planted after either oat or annual ryegrass. Two main factors negatively affected soybean yields in late termination dates: the water use from the cover crop determined lower soil water availability for soybean during part of the growing season; the lack of adequate plant establishment due to very high amount of residues. Regardless of the cover crop treatment, diseases become more important with the number of years under soybean monoculture.

Conclusions

From the data and observations collected in this study we conclude that the inclusion of winter cover crops in soybean monocultures had a positive impact on SOC as compared to the control treatment. Carbon active pools and PMN showed higher sensitivity than SOC to detect changes due to management practices. However most of the observed effects were concentrated at the near-surface level (0-7.5 cm). The addition of more C by plants in late termination dates was not reflected in an increase in SOC storage. Cover crop treatments improve soil physical and mechanical properties relevant for our agricultural systems. The increase in infiltration rates and the improvement of resistance to water erosion are the most important since soil erosion is an important soil degradation factor in these systems. Cover crops can play a significant role in the design of grain crop rotations in Uruguay. However, other crops need to be explored in our cropping systems to enhance C and N balance and storage.

References:

1. Novelli, L.E., Caviglia, O.P., and R.J.M. Melchiori. 2011. Impact of soybean cropping frequency on soil carbon storage in Mollisols and Vertisols. *Geoderma 167-168, 254-260.*
2. Wright, A.L., and F.M. Hons. 2004. Soil aggregation and carbon and nitrogen storage under soybean cropping sequences. *Soil Science Society of America Journal 69,141-147.*
3. Clérici, C., Baethgen W., García Préchac, F. and M. Hill. 2004. Estimación del impacto de la soja sobre erosión y C orgánico en suelos agrícolas de Uruguay. *In: XIX Congreso Argentino de la Ciencia del Suelo, Paraná, Argentina. CD-ROM.*
4. Morón, A. 2009. Estimaciones del impacto de la ganadería y la agricultura en el suelo en Uruguay. *In: Simposio Efecto de la Agricultura, la Ganadería y la Lechería en el recurso natural suelo. Serie Actividades de Difusión INIA No. 587:17-23.*
5. Faé, G.S., Sulc, R.M., Barker, D.J., Dick, R.P., Eastridge, M.L., and N. Lorenz. 2009. Integrating winter annual forages into a no-till corn silage system. *Agron. J. 101: 1286-1296.*
6. Ruffo, M.L., Bullock, D.G., and G.A. Bollero. 2004. Soybean yield as affected by biomass and nitrogen uptake of cereal rye in winter cover crops rotations. *Agron. J. 96:800-805.*
7. Sainju. U.M., Singh, B.P., and W.W. Whitehead. 2005. Tillage, cover crops, and nitrogen fertilization effects on cotton and sorghum root biomass, carbon and nitrogen. *Agron. J. 97:1279-1290.*
8. Steele, M.K., Coale, F.J., and R.L. Hill. 2012. Winter annual cover crop impacts on no-till soil physical properties and organic matter. *Soil Sci. Soc. Am. J. In press.*
9. Morón, A., and J. Sawchik. 2002. Soil quality indicators in a long-term crop pasture rotation experiment in Uruguay. In: *17th World Congress of Soil Science, Symposium No. 32, Paper 1327. CD-ROM.*
10. Sasal, M.C., Castiglioni, M.G., and M.G. Wilson. 2010. Effect of crop sequences on soil properties and runoff on natural-rainfall erosion plots under no tillage. *Soil & Tillage Research 108:24-29.*
11. Kamphrost A. 1987. A small rainfall simulator for the determination of soil erodability. *Netherlands Journal of Agriculture Science 35*.
12. Blanco-Caqui, H, Mikha, M.M., Presley, D.R., and M.M. Claasen. 2011. Addition of cover crops enhances no-till potential for improving soil physical properties. *Soil Sci. Soc. Am. J. 75:1471-1482.*
13. Zendonadi dos Santos, N., Dieckow, J., Bayer, C., Molin, R., Favaretto, N., Pauletti, V. and J.T. Piva. 2011. Forages, cover crops and related shoot and root additions in no-till rotations to C sequestration in a subtropical Ferralsol. *Soil & Tillage Research 111:208-218.*
14. Restovich, S.B., Andriulo, A.E., S. Portela. 2012. Introduction of cover crops in a maize-soybean rotation of the Humid Pampas: Effect on nitrogen and water dynamics. *Field Crops Research 128: 62-70.*