SOIL ORGANIC CARBON FRACTIONS AS INFLUENCED BY SOYBEAN CROPPING IN THE HUMID PAMPA OF ARGENTINA

Influencia del Cultivo de Soja en las Fracciones de Carbono Orgánico del Suelo en la Pampa Húmeda Argentina

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SUMMARY

The sustainability of continuous cropping systems depends heavily on the years of intensive agricultural production and the choice of crop sequence that alters the fractions of soil organic matter. The aim of this study was to evaluate the impact of continuous soybean cultivation on fractions of organic carbon in the vertic Argiudolls of the Argentinean Pampas. Total organic carbon (TOC), particulate organic carbon (POC), fulvic acids (FA), humic acids (HA), humin (H) and carbon produced by microbial respiration (Cresp) were assessed in plots with continuous production of soybean for over 15 years (SP) and grassland plots that were considered the change control (GP). A significant reduction of TOC and POC variables in cultured soybean SP plots, relative to grassland GP, was observed. The POC / TOC and Cresp / TOC ratios were significantly lower in soybean plots than in grasslands used as controls. These ratios were interpreted as a preferential tendency to maintain high rates of mineralization of labile carbon forms and increased biological stability of humified forms in cultured soybean plots. The shapes of the humic fractions of less complexity, FA and HA, were significantly reduced in the latter plots compared with grasslands, while no significant changes occurred in the more stable and recalcitrant forms of carbon, such as humin, in either plot type.

Index words: *cropping systems, soil organic matter, soil organic carbon fractions.*

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RESUMEN

La sostenibilidad de los sistemas agrícolas continuos depende en gran medida de los años de producción agrícola intensiva y de la elección de la secuencia de cultivos que alteran las fracciones de la materia orgánica edáfica. El objetivo de este trabajo fue evaluar el impacto del cultivo continuo de soja en las fracciones de carbono orgánico en Argiudoles Verticos de la Pampa Húmeda Argentina. El carbono orgánico total (COT), carbono orgánico particulado (POC), ácidos fúlvicos (AF), ácidos húmicos (AH), huminas (H) y carbono producido por la respiración microbiana (Cresp) fueron evaluados en parcelas con producción de soja continua de más de 15 años (SP), y en parcelas de pastizales que se consideraron como control (GP) del cambio. Se observó una reducción significativa en los contenidos de TOC y POC en las parcelas cultivadas con soja SP en relación a las de pastizales GP. Las relaciones POC / TOC y Cresp / TOC fueron significativamente más bajas en las parcelas con soja que en los pastizales empleados como control, que fueron interpretadas como una tendencia preferencial de mantener altas tasas de mineralización de las formas lábiles de carbono y mayor estabilidad biológica de las formas humificadas en parcelas cultivadas con soja. Las formas de las fracciones húmicas de menor complejidad, FA y HA, se redujeron significativamente en estas últimas parcelas en comparación con los pastizales, mientras que no hubo cambios significativos en las formas más estables y recalcitrantes de carbono, como las huminas, en ambos tipo de parcelas.

Palabras clave: *sistemas de cultivo, materia orgánica edáfica, fracciones húmicas.*

INTRODUCTION

Soil organic matter is directly linked to key functions in ecosystems, such as nutrient supply, improvement of soil aggregation and stimulation of microbial activity (Carter, 2002).

Continuous and intensive cultivation in recent years has promoted nutrient removal from soils. However, it has also increased the amount of crop residues returned to the soil that might have enhanced the soil organic C pool. Long fallow periods under temperate and humid conditions, in which soil is partially covered by decomposing crop residues, promote nutrient losses through runoff, especially of nitrogen (Caviglia and Andrade, 2010; Sasal *et al.*, 2010). Management trends in the last years suggest that crop residue inputs can lead to higher soil organic matter levels and a greater potential for nutrient cycling and that this effect would even increase with time (Campbell *et al.*, 2000; Grant *et al.*, 2002).

Election of the crop sequence has a significant impact on the sustainability of continual agricultural systems, since losses of carbon through oxidation and erosion by intensive cropping should be at least countered by carbon inputs through the return of crop residues (Grant *et al.*, 2002). Soybean (*Glycine max* L. Merril) is the main crop cultivated and exported by Argentina and one of the most important items of the country's economy. Soybean cultivation, however, is originating a marked decrease in fertility in many soils of the Argentinean Pampa, even though these soils are endowed with naturally high fertility (Austin *et al.*, 2006). Due to the high contribution of biological N fixation (50-60% of the total present in the biomass), soybean crops are rarely fertilized with N (Salvagiotti *et al.*, 2008). Moreover, N provided by symbiosis is insufficient to compensate the extraction by harvested grains; producing negative N balances (Austin *et al.*, 2006).

Any management decision that alters the dynamics of soil organic matter would affect soil physical and biochemical environment, and thus, would modify soil quality status.

The composition and characteristics of humic fractions are related to their functionality and reactivity in soil. Three fractions are obtained by extraction with alkaline solution (Schnitzer, 1999): humic acids (HA), fulvic acids (FA) and humin (H).

The different fractions, especially the most labile (HA, FA), have been successfully used to evaluate the effects of different soil management regimes in the Argentinean Pampas (Galantini *et al.*, 2004)

The aim of this work was to evaluate the impact of continuous soybean cropping on the soil carbon fractions in Vertic Argiudolls of the Humid Pampa of Argentina.

Determination of the effect of soybean on each carbon fraction will provide a detailed picture of where the greatest changes occur and how they affect the functioning of the whole. This aspect is rarely studied in soybean soils of Argentina.

MATERIALS AND METHODS

Site and Sampling Description

The study was conducted in an area of undulating topography located in San Pedro, Argentina (33° 48' 31" S latitude and 59º 53' 57" length); average winter and summer temperatures are 10 °C and 25 ºC, respectively, with average annual rainfall of 900-1000 mm. Clay loam soils Vertic Argiudolls (Soil Survey Staff, 2010), belonging to the Ramallo series (GeoINTA) predominate. The main features of the A11 surface horizon (0-15 cm) are the following: soybean plots: clay 290 g kg^{-1}; silt 680 g kg^{-1}; organic matter 37.8 g kg^{-1}; Total N 2.9 g kg^{-1}; pH (soil: water 1:2.5) 5.8; cation exchange capacity 20.6 cmol c kg^{-1}, and grassland plots: clay 290 g kg^{-1}; silt 680 g kg^{-1}; organic matter 42.6 g kg^{-1}; Total N 3.1 g kg^{-1}; pH (soil: water 1:2.5) 5.9; cation exchange capacity 22.4 cmol c kg^{-1}. The soil has a good water storage capacity (25 to 30% of equivalent moisture) and is moderately well drained. The average depth is 1.90 to 2 m with a strong hard clay B horizon, high infiltration areas and hydromorphic features in depressed areas (INTA, 1990). In March 2010, in each plot 20 soil samples were collected from 0-10 cm depth, air-dried and sieved (< 2 mm) before analysis, from: i) ten plots where soybean had been cropped for more than 15 years (SP); ii) ten grassland plots considered controls (GP), both treatments belong to the Ramallo series described above. Crop sequence in cultivated sites was predominately wheat/soybean in the same year, inserting corn alone or soybean alone every three or four years. At sampling time, soybean was in the phenological stage of maximum grain size (green seed pods, completely filled the fruit cavity, some of the four upper nodes of main stem with fully developed leaves). Plots were N and P fertilized according to the usual modality for the region (N-urea 5 kg ha^{-1}, P-P_2O_5 20 kg ha^{-1}); weed control was performed with glyphosate and metsulphuron-methyl. Grasslands consisted of natural vegetation predominately *poaceaes*, with *Lolium multiflorum*, *Leersia hexandra*, *Briza minor*, *Piptochaetium* spp. and *Danthonia montevidensis* as main species in winter, and *Paspalum dilatatum*, *Sporobolus* spp. and *Panicum* spp. in summer. Plots were not fertilized or irrigated; yield was 5.70 to 12.80 Mg ha^{-1}.

Sample Analysis

Total organic carbon (TOC), particulate organic carbon (POC), fulvic acids (FA), humic acids (HA), humines (H) and carbon produced by respiration (Cresp) were evaluated.

Total organic carbon (TOC). Total organic carbon was determined by Walkley & Black method (Nelson and Sommers, 1982), which measures the easily oxidized carbon, divided by 0.86 (Richter *et al.*, 1973) to carry to total organic carbon. This is the official method for TOC in Argentina. Briefly, organic matter from the soil (1 g) was oxidized with $K_2Cr_2O_7$ 1 N (10 ml) in concentrated sulfuric acid for 30 min, followed by titration of excess $K_2Cr_2O_7$ with ferrous-ammonium sulfate 0.5 N and N-phenyl anthranilic acid to indicate the end point.

Particulate organic carbon (POC). POC was determined following the Cambardella and Elliott (1992) procedure. Briefly, 10 g of soil were dispersed in 30 ml of sodium hexametaphosphate solution (5 g L^{-1}) and shaken for 15 h on a reciprocal shaker. The dispersed soil samples were passed through a 53 mm sieve and rinsed several times with water; the material retained on the sieve was dried at 50 °C overnight. The dried samples were ground with a mortar and analyzed for total organic C (Nelson and Sommers, 1982).

Humic acids (HA), fulvic acids (FA) and humin (H). The approach described by Richter (1979) was performed. Briefly, 0.5 g of soil (sieved through 0.5 mm) were percolated with sulfuric acid 0.1 N and precipitated humic acids were separated from fulvic acids in solution, then dissolved in an alkaline solution (20 ml NaOH 0.5 N). After dissolution of the humic fraction, both fulvic and humic acids were assessed by titration with ferrous-ammonium sulfate and N-phenyl anthranilic acid to indicate the end point. Humins were determined on the remaining fraction of the percolates by Walkley & Black (Nelson and Sommers, 1982).

Carbon from microbial respiration (Cresp). Soil samples at 75% water holding capacity were incubated at 25 °C 7 d in hermetic flasks; the CO_2 evolved was trapped in excess 0.5 N NaOH. The alkali was titrated to the phenolphthalein with HCl in the presence of $BaCl_2$ to precipitate the carbonate (Frioni, 2011).

Data Analysis

An ANOVA was performed to evaluate differences among treatments from soil C fractions and soil respiration. Fisher's Least Significant Difference (LSD) mean separation was used with a 0.05 significance level.

RESULTS AND DISCUSSION

A significant reduction was found in both TOC (11% $P < 0.05$) and POC (29% $P < 0.05$) in cropped soybean plots as compared with grassland plots (Figure 1A), as a consequence of the low amount of soybean stubble and the low C:N ratio (soybean = 30/35:1; grassland = 55/60:1) of residue that can boost organic matter mineralization. The low annual input of organic carbon (~ 3.4 Mg de C ha^{-1} $years^{-1}$) by soybean residue and stimulation of organic matter mineralization due to nitrogen generated by biological N-fixation from the symbiosis of this crop with rhizobia are the two main factors that explain the loss of carbon (Austin *et al.*, 2006; Restovich *et al.*, 2012).

The POC has been reported as an early indicator that is more sensitive to changes in soil organic carbon due to agricultural management (Carter, 2002; Six *et al.*, 2002; Wander and Nissen, 2004). However, its effectiveness as an indicator depends on several factors such as soil texture, previous management, residue inputs, tillage (Domínguez *et al.*, 2009). The ratio between POC and TOC (Figure 1B) was significantly lower ($P < 0.05$) in soybean plots (0.37) than grassland plots (0.54). POC is an active fraction easily available for microbial biomass (Cambardella and Elliot, 1992); our results showed that the substrates more easily available for microbial mineralization decreased to a greater extent in plots under soybean cropping.

The $C\text{-}_{CO2}$ flux by microbial respiration allows assessment of C losses from soil (Nay and Bormann, 2000). Cresp was lower in soybean plots than in grasslands (Figure 2A). Losses of C from microbial respiration can be expected to be higher in soybean plots

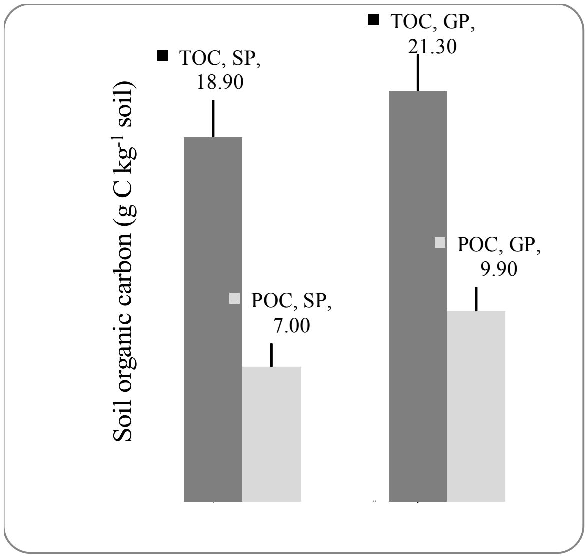

Figure 1A. Total and particulate organic carbon (TOC and POC, respectively) from soybean cropped plots (SP), n= 10; and grassland plots (GP), n=10.

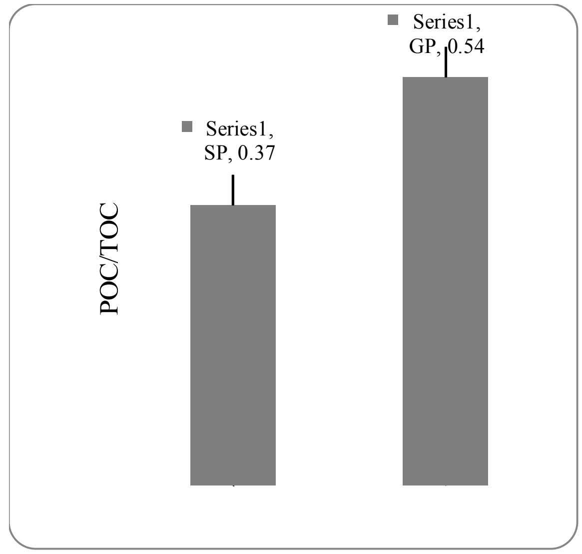

Figure 1B. Particulate and total organic carbon ratio (POC/TOC) from soybean cropped plots (SP), n=10; and grassland plots (GP), n=10.

due to the lower C: N ratio of mineralizable residue (Gómez *et al.*, 2001). Nevertheless, microbial respiration was higher in the grassland plots. The ratio Cresp/TOC (Figure 2B) suggests that soybean cropping is responsible for a particular dynamics of organic matter from the residue, with a preferential trend to a high mineralization rate of labile forms and a higher biological stability of the humified forms (Haynes, 2000).

Regarding humic forms, the less recalcitrant fractions, FA and HA, were significantly ($P < 0.05$) reduced in plots under soybean cropping compared with grasslands (28% FA, 18% HA, respectively), while there were no significant changes in the most stable forms of humified soil carbon such as humin (4% H) (Figure 3A).

Total soil organic carbon may be not sensitive enough to detect the effect of management on C dynamics (Tan

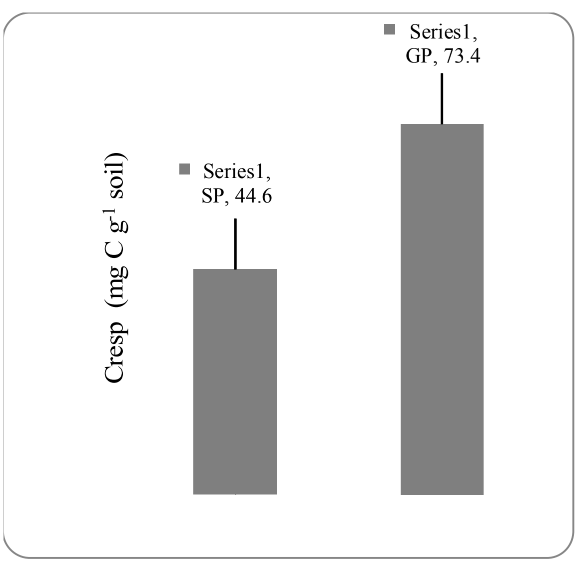

Figure 2A. C-$_{CO2}$ evolved from soil microbial respiration (Cresp) from soybean cropped plots (SP), n= 10 and grasslands plot (GP), n=10.

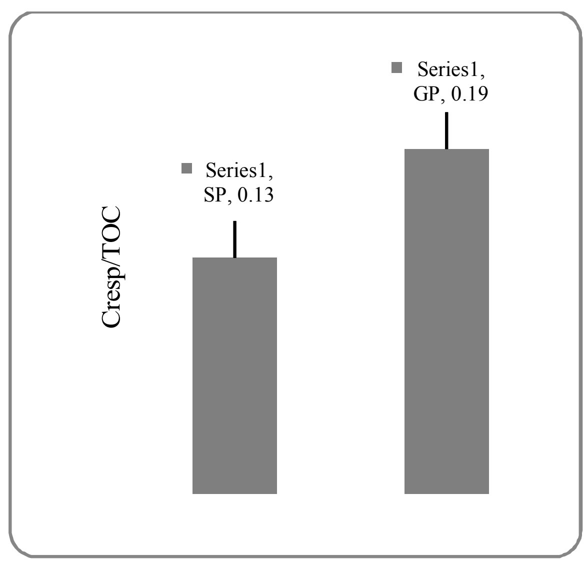

Figure 2B. C-$_{CO2}$ from soil microbial respiration and total organic carbon ratio (Cresp/TOC) from soybean cropped plots (SP), n=10, and grasslands plots (GP), n=10.

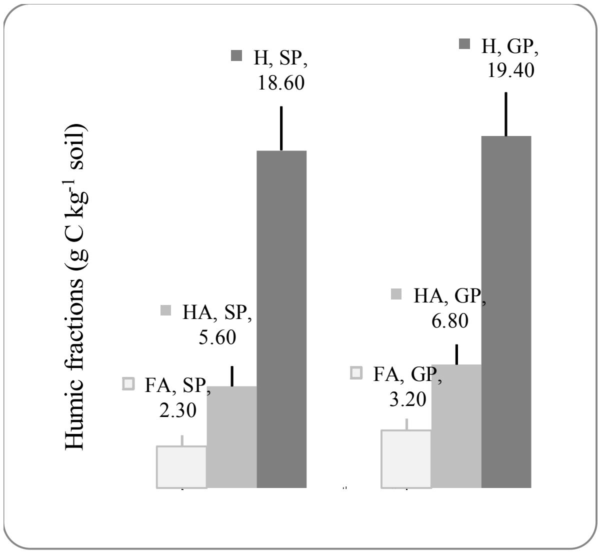

Figure 3A. Humic fractions from soybean cropped (SP) plots, n=10; and grassland plots (GP), n=10; FA: fulvic acids; HA: humic acids; H: humines

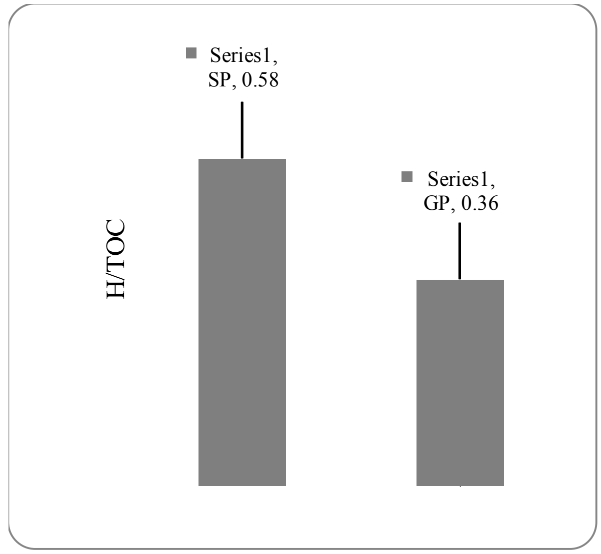

Figure 3B. Humine fraction and total organic carbon ratio (H/TOC) from soybean cropped plots (SP), n= 10 and grassland plots (GP), n=10.

et al., 2007; Domínguez *et al.,* 2009). Since the most abundant organic fractions in the soil are those of slower cycling, many years are needed to detect consistent differences in TOC (Gómez *et al.,* 2001). In this sense, more labile fractions of soil organic carbon (FA, HA, POC) could be a more useful indicator of soil quality and an efficient tool for detecting the progress of soil degradation and loss of fertility, as was found in this study.

More labile fractions of humus, such as FA and HA, were more sensitive to mineralization that forms the most recalcitrant humin and could be used to evaluate the effect of cultivation on soil quality (Haynes, 2000; Six *et al.*, 2002). Nevertheless, despite the detrimental effect on labile fractions of soil organic carbon observed after several years of soybean cropping, Alvarez (2011)**,** argues that land degradation occurs primarily by replacing pasture crops due to reduced C input from their residue.

This research found that plots with soybean production for over 15 years have produced an alteration in fractions of soil organic carbon, specifically in its most dynamic forms, FA, HA and POC, but still no significant changes were evident in the more recalcitrant forms. Cresp and different amounts of SP and GP agree with this change, showing greater potential of Cresp on the grassland plots. TOC levels have shown a lower minor decrease in SP relative to GP, probably because its content is primarily composed of humin (H), which is very strongly associated with high clay content of Vertic Argiudoll in which this study was conducted.

CONCLUSIONS

- Continuous cultivation of soybeans in the Vertic Argiudolls evaluated in this study significantly reduced labile organic fractions present in the soil. POC, FA and HA were the fractions having the greatest decrease. The humin fraction remained significantly unchanged.
- These findings are consistent with the differences found in Cresp in soybean and grassland plots: soybean production decreases mineralization of organic carbon due to the significant decrease of more labile and dynamic forms of carbon.
- In soils with continuous soybean cultivation, the loss of labile carbon may indicate evolution towards stable carbon reductions and a path to future soil degradation. It was also shown that POC is a better indicator of the effect of soybean production on soil organic carbon fractions than TOC.

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