Response to comments on “Effect of deforestation and subsequent land-use management on soil carbon stocks in the South American Chaco” by Natalia Andrea Osinaga et al. P. G. Gottschalk (Referee)

Response to Referee Comments:

General comment:
Reviewer: Although all sites are Haplustolls and Argiustolls and respective soil parameters are given in Table 1 and they are similar enough to classify them as one for the results’ interpretation, it would be good to see the actual variability of the soil parameters (at sampled depth possibly) at the sites and how the soil C stocks and BD correlate with these. The soil parameters per sites could be given in the appendix and Table 1 then lists mean values and respective standard deviations.

Authors:
Haplustolls are dominant soils under forest and pasture management, while Hapludolls and Argiustolls are equally represented in cropped sites. Soil particle size distribution in all sites was only evaluated for the 0-20 cm layer (included in a new Table).
New Table. Table 2. Mean values and standard errors of soil particle size distribution in the 0-20 cm layer for different land uses. Page 4.

Reviewer: Line 22-24 (Abstract)
This sentence suggests that the study investigated the effect of pasture as an intermediate phase during otherwise continuous cropping which is not true. Same formulation is used in the *conclusions* and should be adjusted.
Authors:
We changed to (Abstract):
“The permanent pasture of warm season grasses allowed to sustain higher C stocks than cropping systems and so could be considered a sustainable management practice”. Page 1, lines 23-24
We changed to (Conclusions):
“Permanent pasture of warm season grasses proved to be a sustainable practice to mitigate C stock loss compared with cropping systems”. Page 8, lines 7-8.

Reviewer: Please reference Mollisols, Haplustolls and Argiustolls as classified according to the USDA Soil Taxonomy or other but consistent.

Authors: The Mollisol column was deleted in Table 1 (since no other US Soil Taxonomy Soil Order was studied) and keeping the references to subgroup according to USDA Soil Taxonomy. Page 4, Table 1.

Reviewer:
Page 3, line 14: of how many individual samples consisted one composite sample? Please specify.
Authors:
We added: A composite sample built up from 4 subsamples. Page 3, line 16.

Reviewer:

Page 4, line 5: Please elaborate shortly on the MWD-method, describe the method and how its specification makes it suitable for its designed purpose here. Please explain for what purpose the method is applied here, also for the penetration analysis.

Authors:

We added (Page 4, line 9-16):

Aggregates of 3 to 5 mm in diameter were dried at 40 ° C for 24 hours and then subjected to three pre-treatments: fast wetting of air-dry aggregates with distilled water, wet agitation (previously treated with ethanol) and low wetting (capillarity with distilled water). After applying these pre-treatments, the distribution of the aggregates according to their size was determined using a series of sieves (0.05 mm, 0.1 mm, 0.2 mm, 0.5 mm, 1 mm and 2 mm). The aggregate mean weight diameter (MWD) for each pre-treatment was calculated as an index of the structural stability obtained as the algebraic sum of the percentage of the total mass of soil retained in each sieve, multiplied by the opening of the adjacent sieves. The MDW for each three pre-treatments was estimated and also an integrated value of MDW was calculated.

We added (Page 5, line 2-5):

We measured MWD and penetration resistance as erosion and compaction are the main soil degradation processes in the studied region. Soil MDW index is conversely related to soil susceptibility to erosion and soil penetration resistance allows characterizing soil compaction derived from machinery transit and animal trampling.

Reviewer:

Please describe more carefully the sampling design and how “situation” (page 4, line 6, page 3, line 14) and “plot” (page 4, line 7) relates to each other.

Authors:

We changed “situation” or “plot” denominations by “site”. We sampled 32 sites, eight by each management studied categories. Page 3, line16; page 4, lines 8 and 18; page 5, line 14; page 6, line 2; page 7, lines 2 and 23.

Reviewer:

Page 4, lines 6-9: I do not understand why the sampling of penetration resistance and soil water content is not consistently sampled although the direct relation is explicitly mentioned. Please explain e.g. why the two samples of soil water content is sufficient in contrast to the penetration measurements every 5 cm.

Authors:

Soil penetration resistance was determined up to 40 cm in each 5 cm soil player. Soil water content was only determined for the 0-20 cm and 20-40 cm layers. So, the relationship between soil resistance and water content was constructed by integrating soil penetration resistance data for 0 to 20 cm and 20 to 40 cm layer depths. We clarified this in the text. Page 4 line 4 to page 5 line 2.

Reviewer:
Page 4, line 14-16: Pasture C also decreased sig. in the layer 60-80 and increased sig. in layer 80-100. Please elaborate and discuss. The latter maybe due to the higher C inputs of grass roots in lower layers.

Authors: Already discussed in page 5, lines 16-18 .

Reviewer:
Swap paragraphs 2 and 3 of the results and discussion section to keep the topics of SOC stocks versus SOC fractions apart.
Authors: Done.

Reviewer:
Page 4, line 21: Replace "treatment" with land use type or similar.
Authors: We can changed in all cases to land uses.

Reviewer:
Page 5, line 1-2: Add the soil depth for which the 36 and 53% soil C reductions is representative.
Authors: for 0-20 cm depth. Added. Page 5, line 24.

Reviewer:
For the discussion on the change of C in different soil size fractions check the papers of Balesdent at al., e.g. Balesdent, J., et al. (1998). "The dynamics of carbon in particle-size fractions of soil in a forest-cultivation sequence." Plant and Soil 201: 49-57.
Authors:
We added: "Our results are similar to those of Balesdent et al. (1998), who found that the total C contents of soils decreased rapidly in the first seven years of cultivation and more slowly after and the decrease affected mostly the coarse CPC fractions". Page 5 line 35 to page 6 line 2.
We also added the reference: Balesdent, J., Besnard, E., Arrouays, D., Chenu, C. The dynamics of carbon in particle-size fractions of soil in a forest-cultivation sequence, Plant and Soil, 201, 49-57, 1998. Page 9, line 11-12.

Reviewer:
Page 5, lines 12 – page 6, line 2: The discussion of BD values is a bit weak and not very conclusive. I suggest to at least adding the soil parameter description along the profile and discuss how soil texture could be related to the different BD values.

Authors:

As mentioned above, soil texture for all studied sites was only determined in the 0-20 cm layer (new Table 2).
We added: Finally, soil BD in 0-20 cm was highly correlated with SOC (r= - 0.9; p>0.0001) but not with soil particle size fractions. Page 6 line 16.

Reviewer:
Page 6, lines 5-12: It is not clear what message the authors want to convey here and since the MWD-method has not been properly introduced it is difficult to follow a story line here.

Authors:
We added a complete the description of the Le Bissonnais method for aggregate stability in the Materials and Methods section. Page 4, line 9-16.

Reviewer:
Page 6, line 19: Please add the R2-value and p-value of the negative correlation (possibly in the graphs of Figure 3).
Page 6, line 19-26: Here, only the results a presented with no explanation or discussion. Please explain the significance of the different penetration levels in respect to something, e.g. root growth, and relate the results to findings of other studies.

Authors:
We added: Penetration resistance at 0-20 cm depth showed a negative correlation with SWC (r=-0.72; p<0.0001; Figure 3A). Page 7, line 17.
At a greater depth (20-40 cm), no correlation was found between those two variables (p= 0.32; Figure 3B). Page 7 lines 19-20.
The practical significance of the values of PR were already explained and discussed in Page 7 line 23-25.

Reviewer:

Technical corrections: Page 3, line 14: I suggest to replace “In each situation” with “at each site”.
Authors: done. Page 3, line 16.

Effect of deforestation and subsequent land-use management on soil carbon stocks in the South American Chaco

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Abstract. The sub-humid Chaco region of Argentina, originally covered by dry sclerophyll forest, has been subjected to clearing since the end of the ‘70 and replacement of the forest by no till farming. Land use changes produced a decrease in aboveground carbon stored in forests, but little is known about the impact on soil organic C stocks. The aim of this study was to evaluate soil C stocks and C fractions up to 1 m depth in soils under different land use: < 10 yr continuous cropping; > 20 yr continuous cropping, warm season grass pasture and native forest in 32 sites distributed over the Chaco region. The organic C stock content up to 1 m depth expressed as equivalent mass varied as follows: forest (119.3 Mg ha^{-1}) > pasture (87.9 Mg ha^{-1}) > continuous cropping (71.9 and 77.3 Mg ha^{-1}), with no impact of the number of years under cropping. The most sensitive organic carbon fraction was the coarse particle fraction (2000 μm -212 μm) at 0-5 cm and 5-20 cm depth layers. Resistant carbon (<53 μm) was the main organic matter fraction in all sample categories except in the forest. Organic C stock, its quality and distribution in the profile were sensitive to land use change. The conversion of the Chaco forest to crops was associated to a decrease of Organic C stock up to the meter depth and with the decrease of the labile fraction. The ~~incorporation of~~permanent pastures of warm-season grasses allowed to sustain higher ~~was able to mitigate the decrease of~~ C stocks ~~caused by~~than cropping systems and so could be considered a sustainable management practice. As soil organic carbon losses were not restricted to the first few cm of the soil, the development of models that would allow the estimation of soil organic carbon changes in depth would be useful to evaluate with greater precision the impact of land use change on carbon stocks.

Keywords: Carbon sequestration, particulate carbon, land use change

1. Introduction

As one of the components of global change, land use change has a great impact on terrestrial ecosystems, altering their structure and function (Walker and Steffen, 1999). The most important land use change is due to agriculturization (Houghton, 1999), a process that involves replacement of natural ecosystems, such as forests, as world food demand increases (Volante et al., 2012).

In Argentina, since the late 1970s, there has been an advance of the agricultural frontier across the Chaco-region native forests due to conversion for production of annual crops (Gasparri et al., 2009). Thus it became one of the ten countries with the greatest forest loss in the world (FAO, 2015). The Eastern Subhumid Chaco is a large forest area that since 1997 has suffered a notable increase in cleared area (Albanesi et al., 2003; Grau et al., 2005; Volante et al., 2009). The average deforestation rate is among the highest in the world and in the country, mainly in the East of the province of Santiago del Estero, where Mollisols are the predominant soil type (Volante et al., 2009).

Deforestation together with inadequate subsequent management produces acceleration of erosive processes, reduction of organic matter input, decrease of soil aggregate stability (Cerdà, 2000; Cerdà et al., 2009; García Orenes et al., 2010), changes in microclimate, biodiversity loss, affects water basin functions and contributes to global climate change. These effects have been studied mostly in tropical and temperate forests but have been poorly evaluated in South America subtropical forests (Baccini et al., 2012; Harris et al., 2012; Hansen et al., 2013).

In the Subhumid Chaco, the intensity and seasonality of rainfall, the gently undulating landscape, the fragility of the environment and the subtropical climate predispose the soil to substantial physical degradation (Albanesi et al., 2003). No-tillage was introduced in Argentina, including in the Chaco region, in the mid-nineties. It was adopted due to its lower production costs, the possibility it offered of incorporating areas with greater limitations to crop yield (Satorre, 2005; Derpsch et al., 2010), to savings in operating time and to lack of soil disturbance that reduces soil erosion, recovers soil aggregate stability, conserves water and increases carbon sequestration (Díaz Zorita et al., 2002). Despite its many advantages, no-tillage can negatively impact some physical properties of the surface soil (bulk density, penetration resistance), as mechanical formation of macropores is reduced and there is a tendency to form laminar and massive structures (Strudley et al., 2008; Álvarez et al., 2009; 2012). All these effects are increased by the transit of heavy machinery that produces soil compaction of the first 40 cm of soil, especially when the soil is wet (Botta et al., 2004).

In the western part of the region, livestock production became important, replacing native forests by megathermic pastures. This activity has negative effects on soil physical properties and produces reduction of soil organic carbon levels due to forest clearance and animal transit (Caruso et al., 2012). However, it could have a smaller negative impact than continuous agriculture on carbon sequestration and on soil physical properties as animal trampling effects extend to a lesser depth and live roots are present in the soil all year long.

The objective of the present study was to determine carbon content and soil physical quality of Subhumid Chaco soils under different land uses: agriculture (less than 10 years and more than 20 years under cropping), pastures and natural forests.

2. Materials and Methods

The region of the sub-humid Chaco is part of the Great American Chaco and occupies the southern fringe of the eastern part of the semi-arid Chaco (Vargas Gil, 1988, Figure 1). In Argentina it covers an area of 45,199.33 km^2. Annual rainfall ranges from 700 mm in the West to 1000 mm on the limit with the humid Chaco (East) it has a monsoon regime, with periods of marked water deficit during the winter months and the beginning of spring. Average annual temperature is 21 ° C. The most representative soils are Haplustolls and Argiustolls (Vargas Gil, 1988). Crop production is mainly summer crops (soybean, corn, sorghum and cotton) sown in December and January, with winter months generally as fallow periods, in order to store soil water for the summer crop. In the west of the region, livestock production on megathermic pastures predominates. The natural vegetation is a xerophitic forest with dominance of various species of *Schinopsis*, *Prosopis nigra*, *Zizyphus mistol* and shrubs of the genus *Acacia*.

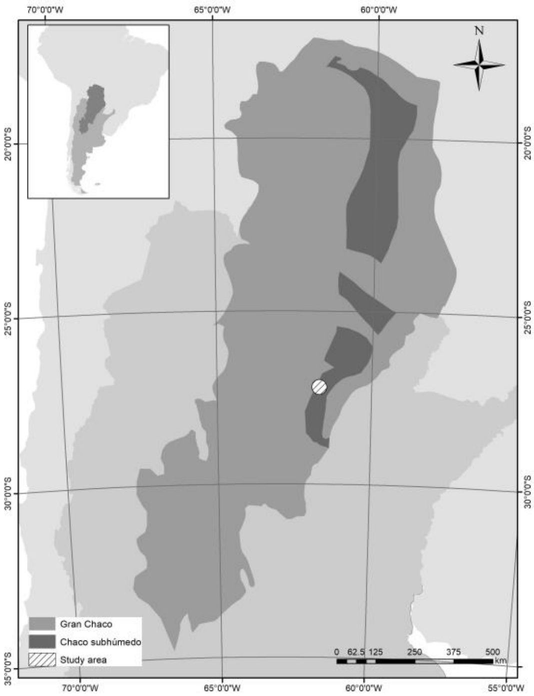

Figure 1: Location of the Gran Chaco, the Subhumid Chaco and the study area.

A total of 32 sites were selected in an area of 320,000 ha to the E of Santiago del Estero province (Figure 1), which were representative of the most common forms of land use of this region: native forest (reference), continuous cropping (rotation of soybean-soybean-corn under no-till) during different periods (6-9 years and > 20 years) and more than 10-year old pastures (pasture, Gatton Panic, *Panicum maximum*) on the most representative soils (typical Haplustolls and Argiustolls) with silty and clayey texture (Table 1). From each category, 8 sites (n = 8) located in different farms were sampled. Mean values and standard errors of soil particle size distribution in the 0-20 cm layer for different land uses are presented in Table 2.

In each ~~situation~~site, a composite sample~~s~~ built up of four subsamples were taken up to 1m depth from the 0-5 cm layer, the 5-20 cm layer, and then every 20 cm. Soil organic carbon (SOC) was determined by wet combustion using the Walkley-Black method (Nelson & Sommers, 1996) and coarse particulate organic carbon (2000 µm - 212 µm, CPC), fine particulate organic carbon (212 µm - 53 µm, FPC) and resistant organic carbon (<53µm, RC) were determined (Cambardela & Elliot, 1992). Bulk density (BD) was determined by the cylinder method (Burke et al., 1986) using 100 cm^3 cylinders. Carbon content mass per unit area was estimated using sample BD values

Table 1: Main characteristics of the soils of the study region.

	Area (%)	**Horizon**	**Clay ($g\ kg^{-1}$)**	**Silt ($g\ kg^{-1}$)**	**Sand ($g\ kg^{-1}$)**	**pH**
Typic Haplustoll	80	A	20	43	37	6.6
		AC	35	47	18	6.7
Typic Argiustoll	20	A	25	47	28	6.8
		Bt	41	40	19	6.6

Table2: Mean values and standard errors of soil particle size distribution in the 0-20 cm layer for different land uses.

Land use	**Clay ($g\ kg^{-1}$)**	**Silt ($g\ kg^{-1}$)**	**Sand ($g\ kg^{-1}$)**
Forest	240±11.1	400±13.0	360±12.4
Pasture	240±15.8	390±26.2	370±28.1
Cropped 6-9 y	290±39.3	430±25.5	280±44.1
Cropped > 20 y	300±22.4	440±47.7	260±52.1
All land uses	270±37.7	410±34.5	320±60.1

Additionally, four soil sub-samples from the 0-20cm layer were taken in each ~~situation~~ site to determine the structural stability according to the methodology described by Le Bissonnais (1996). Aggregates of 3 to 5 mm in diameter were dried at 40 ° C for 24 hours and then subjected to three pre-treatments: fast wetting of air-dry aggregates with distilled water, wet agitation (previously treated with ethanol) and low wetting (capillarity with distilled water). After applying these pre-treatments, the distribution of the aggregates according to their size was determined using a series of sieves (0.05 mm, 0.1 mm, 0.2 mm, 0.5 mm, 1 mm and 2 mm). The aggregate mean weight diameter (MWD) for each pre-treatment was calculated as an index of the structural stability obtained as the algebraic sum of the percentage of the total mass of soil retained in each sieve, multiplied by the opening of the adjacent sieves. The MDW for each three pre-treatments was estimated and also an integrated value of MDW was calculated.~~The aggregate mean weight diameter (MWD) was used as an index of structural stability.~~ Penetration resistance was determined every 5 cm up to 40 cm depth with a 30º-conical tip dynamic penetrometer (Burke et al., 1986), taking 4 determinations per ~~plot~~site. At the same time soil water content was determined at two depths (0-20 and 20-40 cm), as penetration resistance varies with it. As soil water content was only determined for the 0-20 cm and 20-40 cm layers, the relationship between soil penetration resistance and water content was constructed by integrating soil penetration resistance data for 0 to 20 cm and 20 to 40 cm layer depths. We measured MWD and penetration resistance as erosion and compaction are the main soil degradation processes in the studied region. Soil MDW index is conversely related to soil susceptibility to erosion and soil penetration resistance allows characterizing soil compaction derived from machinery transit and animal trampling.

Data were analyzed using analysis of variance (ANOVA) after checking data normality (Shapiro-Wilks test) and variance homogeneity.

3. Results and Discussion

SOC was affected by land use up to a depth of 1m (Table ~~2~~3). As land use produces changes in BD (Table ~~2~~3), SOC content data has been corrected by BD. Mean SOC content up to 1m decreased as follows: forest (120.17 Mg ha^{-1}), pasture (94.57 Mg ha^{-1}) and cropped fields (81.82 and 76.49 Mg ha^{-1}, 6-9 years and >20 years cropping, respectively).There was a significant reduction in SOC in the cropped ~~plots~~ sites compared to the forest in the first 20 cm and from 40 to 80 cm depth while pastures showed this decrease only in the surface layer. Between 34% and 48% of SOC was found in the first 20 cm, while in the forest it presented greater stratification (Jobbágy & Jackson, 2000). SOC vertical distribution tends to follow the distribution of the root system (Jobbágy & Jackson, 2000), the reason why pastures have a higher SOC is that roots are abundant down to a depth of 80-100 cm.

~~Land use had differential effects on SOC fractions (Figure 2). At both soil depths, coarse particulate carbon (2000 µm - 212µm, CPC) showed the greatest differences between treatments. Resistant organic carbon (<53µm, RC) was the main constituent of soil organic matter in all situations except in the forest, where CPC was the main fraction with 65% of total SOC in the superficial horizon and 55% in the 5-20 cm layer.~~

SOC content depended on the amount of carbon contributed by the vegetation that varied among vegetation types. Forest had the greatest content, due to its higher net primary productivity, pastures represented the intermediate situation, and the lowest contribution corresponded to crops that in this region consist of one summer crop per year (Follet et al., 2009). Comparing cropped and pristine soils in the Pampean region, Sainz Rozas et al. (2011) found that SOC reduction for 0-20 cm layer ranged between 36 and 53%, which placed our regional results in the middle of this range of variation. This loss of SOC can be explained by the lower contribution of crops, the greater mineralization and the greater susceptibility to erosion of these soils (Alvarez, 2001). Land use had differential effects on SOC fractions (Figure 2). At both soil depths, coarse particulate carbon (2000 µm - 212µm, CPC) showed the greatest differences between land uses. Resistant organic carbon (<53µm, RC) was the main constituent of soil organic matter in all situations except in the forest, where CPC was the main fraction with 65% of total SOC in the superficial horizon and 55% in the 5-20 cm layer. The SOC fraction most affected by land use change was the most labile (CPC, 212µm -200µm), which represented 6% of total SOC in cropped ~~plots~~ sites and 57% in pastures and forests. Our results are similar to those of Balesdent et al. (1998), who found that the SOC of soils decreased rapidly in the first seven years of cultivation and more slowly after and the decrease affected mostly the coarse CPC fractions. The higher CR content in the cropped ~~plots~~ sites (78% of total SOC), showed that there is a shift towards more humified fractions, which have a lower rate of nutrient mineralization, results that coincide with those obtained by Albanesi et al. (2003) and Galantini and Suñer (2008).

Table ~~2~~ 3: Soil organic carbon (SOC) and bulk density (BD) variation in depth associated with land use: forest, pasture, 6-9 years and >20 years cropped soils. Different letters indicate significant differences between land use categories within each depth layer.

SOC (Mg ha^{-1})								
Depth (cm)	*Forest*		*Pasture*		*Cropped*			
					6 - 9 years		*>20 years*	
0 - 20	57.97	a	32.07	b	32.54	b	31.84	b
20 - 40	19.52	a	20.67	a	18.48	a	19.19	a
40 - 60	18.90	a	18.54	a	11.62	b	10.83	b
60 - 80	15.16	a	11.69	b	10.15	bc	7.89	c
80 - 100	8.62	bc	11.60	a	9.03	b	6.74	c
0 - 100	120.17	a	94.57	b	81.82	bc	76.49	c

BD (Mg m^{-3})								
Depth (cm)	*Forest*		*Pasture*		*Cropped*			
					6 - 9 years		*>20 years*	
0 - 20	0.89	c	1.10	b	1.11	b	1.21	a
20 - 40	0.96	c	1.09	b	1.07	b	1.14	a
40 - 60	1.00	d	1.17	a	1.07	c	1.13	b
60 - 80	1.08	a	1.11	a	1.10	a	1.09	a
80 - 100	1.14	a	1.15	a	1.15	a	1.16	a

In soils with native forest, BD increased with depth, from 0.88 Mg m^{-3} in the 0-20 cm layer to 1.14 Mg m^{-3} at 80-100 cm depth. The cropped fields did not follow this trend. Their BD was highest in the surface layer (0-20 cm) and in depth (80-100 cm) and lowest at 20 to 80 cm. The pasture under 15 years of livestock production had similar values to the fields cropped for 6-9 years. These higher surface BD values were a consequence of the decrease in SOC and machinery transit in cropped fields (Willhelm et al., 2004, Alvarez et al., 2012), and of the mechanical pressure exerted by livestock in the pastures (Alvarez et al., 2012). Soils under more than 20 years of agriculture had a BD of 1.20 Mg m^{-3} in the first 20 cm, 8% higher than soils under 6-9 years cropping or pasture (1.11 Mg m^{-3}) and 36% higher than the values of the forest soil (0.88 Mg m^{-3}). Finally, soil BD in 0-20 cm was highly correlated with SOC (r= - 0.9; p>0.0001) but not with soil particle size fractions.

The highest soil aggregate MWD values were measured in forest (1.61 mm) and pasture (1.74 mm) soils, values that were not statistically different. Cropped ~~plots~~ sites showed an average MWD of 0.76 mm, half that of forest and pasture soils and significantly ($P<0.05$) different to that of those two land-use categories. In all land use situations, fast wetting was the treatment that reduced MWD most, reducing the size of aggregates by 40% when compared with the treatment of less stress (slow wetting by capillarity). MWD, that characterizes structural stability, was directly related to CPC ($r = 0.6$, $p = <0.01$) and to SOC ($r = 0.48$, $p <0.01$). CPC loss of the first 20 cm largely explained the loss of MWD in cropped soils. Organic matter influences soil structure, but at the same time the formation of stabilized aggregates facilitates carbon sequestration and provides physical protection to soil carbon (Onweremadu et al., 2007). However pastures, despite having a lower amount of coarse particulate carbon (212µm -200µm) than the forest, had the same MWD values. This could respond to the presence of a fine root network of the pasture grass (Gatton Panic) that improved aggregate resistance to stress.

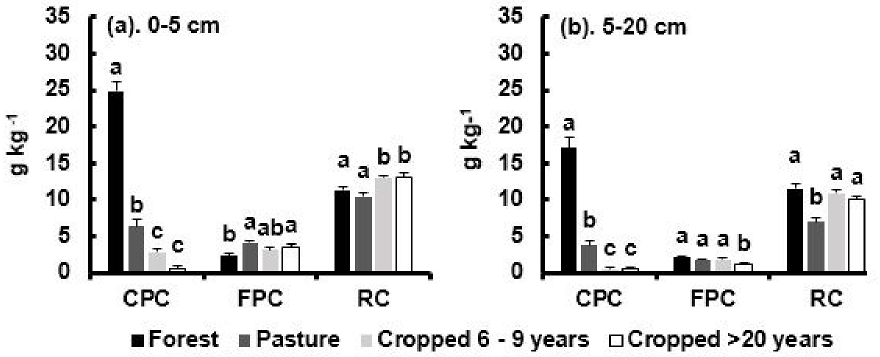

Figure 2: Variation of coarse particulate carbon (2000 µm - 212µm, CPC), fine particulate carbon (212µm - 53µm, FPC) and resistant organic carbon (<53µm, RC) associated with land use. A: Depth 0-5 cm. B: Depth 5-20 cm. Different letters indicate significant differences between land use categories within each depth interval ($P<0.05$).

Penetration resistance at 0-20 cm depth showed a negative correlation with SWC ($r=-0.72$; $p<0.0001$; Figure 3A). PR of cropped fields was 1.1 MPa with 29% SWC, pastures had the same PR value at that depth but with lower SWC (22 g kg^{-1}). Forest showed higher PR values (1.5 MPa) as at the moment of sampling, SWC was lower (13 g kg^{-1}). At a greater depth (20-40 cm), no correlation was found between those two variables ($p= 0.32$; Figure 3B). Fields under more than 20 years of cropping had an average PR of 3 MPa with high SWC values (27 g kg^{-1}). Soils with 6-9 years continuous cropping and forests had PR of 2.2 MPa, with a SWC of 25% and 14%, respectively. The pasture had the lowest PR (0.9 MPa) with a SWC of 21 g kg^{-1}. Below 20 cm depth there was soil hardening in cropped ~~plots~~sites; even with high SWC values (27 g kg^{-1}), their PR values were higher than 2 MPa, which could be critical for root development. This would indicate soil compaction due to continuous machinery transit. Lower than 1.50 MPa values at 0-20 cm depth could be attributed to the high organic matter content at that depth (Table ~~2~~ 3 and Figure 3).

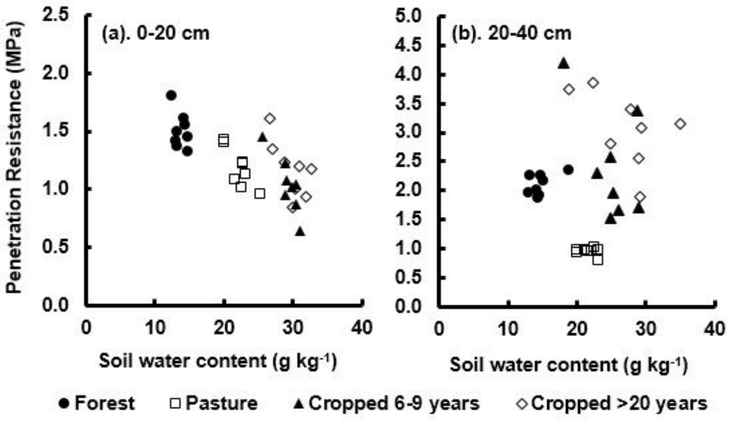

Figure 3: Functional relationships between soil penetration resistance and gravimetric water content for different land uses at two depths (A. 0-20 cm; B. 20-40 cm).

4. Conclusions

In the study region, SOC content, its quality and distribution in the profile were sensitive to the change in land use. The conversion of Chaco forests to crop production was associated with SOC reductions up to one meter depth and with the decrease of the labile fraction, which occurred mainly in the first years after deforestation. ~~The incorporation of~~Permanent pastures proved to be a sustainable practice to mitigate C stock loss compared with ~~produced by~~ cropping systems. It is of great interest to note that carbon losses are not restricted to the first few cm of the soil, as is generally shown in organic carbon maps or in greenhouse gas inventories. The development of models that would allow the estimation of SOC changes in depth would be useful to evaluate with greater precision the impact of land use change on carbon stocks. The change in land use also affected soil physical properties, such as compaction, loss of structural stability in the first 20 cm and hardening of the 20-40 cm depth layer in ~~fileds~~fields under no-till. Pastures, despite their lower SOC and CPC contents than the pristine soils, had a structural stability equal to that of the forest, showing that physical properties are not only correlated with the level of carbon in a soil, but also depend on the type of roots of the replacement vegetation and the stresses applied to the soil (i.e. machinery transit).

5. Acknowledgments

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6. References

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