

# Soil carbon reservoirs at high grassland ecosystems in the Andean plateau of Apolobamba (Bolivia)

M.A. Muñoz<sup>A</sup>, A. Faz<sup>A</sup>

Sustainable Use, Management and Reclamation Soil and Water Research Group. Agriculture and Science Technology Department, Technical University of Cartagena, Paseo Alfonso XIII, 52. 30203-Cartagena. Murcia. Spain. [mangeles.munoz@upct.es](mailto:mangeles.munoz@upct.es)

## Abstract

High grassland ecosystems are presented in the National Apolobamba Integrated Management Area (ANMIN-A) of Bolivia. This area is the natural habitat of camelid populations, such as vicuna (*Vicugna vicugna*), which is recognized as an endangered species. On the other hand, there is no much information related to soil carbon reservoirs in these ecosystems. The objectives of this study were to: (i) provide information about C stocks in high grasslands in the Andean plateau and (ii) determine the quantity and quality of these C reservoirs. These goals were achieved through the analyses of physico-chemical soil properties using different techniques like <sup>13</sup>C CP/ MAS- NMR spectroscopy. Results showed that Wakampata and Puyo-Puyo zones could be excellent carbon reservoirs. Taking into account the total organic matter, there seems to be a good relation between the quality and the quantity of soil organic matter (SOM). Overall NMR spectra pointed out that the degradation of SOM is higher in the Ucha-Ucha, Ulla-Ulla and Caballchiñuni than the other studied areas. Therefore, it is necessary to carry out some soil protection actions in these studied zones in order to improve the sustainable vicuna management and preserve high grassland biodiversity in Apolobamba.

## Keywords

Vicuna, *puna*, soil organic matter, <sup>13</sup>C CP/ MAS- NMR spectroscopy, biodiversity, degradation processes.

## Introduction

Global carbon cycle, mainly, depends on the Soil Organic Matter (SOM) dynamic and The Kyoto Protocol includes the soil C reserves in the grasslands for the reduction of greenhouse effects (Kenneth *et al.* 2007). However, there are no many studies related to C stocks in high grasslands. In many cases, ecosystems in the *puna* or grasslands in the Andean plateaus are degraded as a consequence of anthropogenic activities (Rocha and Saenz 2003), in addition to excessive cattle grazing. Vicuna is an endangered species recognized by The World Conservation Union (IUCN 1996) and its management in the Apolobamba area is an example of sustainable management in indigenous communities. The objectives of this study were to: (i) provide information related to C stocks in grasslands in the high plateaus and (ii) determine the quantity and quality of these C reservoirs.

<sup>13</sup>C CP/ MAS- NMR spectroscopy technique is used to determine the distribution of some C forms in the SOM. It allows to obtain information without the destruction of C components or the physic-chemical separation (Preston 1996), through the study of chemical region in order to characterize SOM quality and composition.

## Materials and methods

The study area, Apolobamba, is located in the northwest of La Paz, in Bolivia. The research was carried out in the *puna* of Apolobamba, the zone with the highest altitude range and also the vicuna habitat. The study area is characterized by udic and frigid soil moisture and temperature regimes (USDA 2006) with an annual average temperature of 4.5 °C and total precipitation of 505 mm (SERNAP 2006). Vicuna population density was the main reason to select studied zones both alpaca (*Lama pacos*) densities, vegetation species, geomorphological, and hydrological landscape elements. Eight zones or census places, separated areas with geographic barriers, with different vicuna and alpaca densities were selected: Ulla-Ulla and Killu (low vicuna density, 2.1-9.4 animal/km<sup>2</sup>), Ucha-Ucha and Wakampata (medium vicuna density, 9.4-16.5 animal/km<sup>2</sup>), Sucondori and Caballchiñuni (high vicuna density, 16.5-23.1 animal/km<sup>2</sup>) and Puyo-Puyo and Japu (very high vicuna density, 23.1-58.1 animal/km<sup>2</sup>).

A representative soil profile was taken in each census location and three replicate plots of 5 x 5 m were selected. Three replicates, surface and subsurface soil samples, were collected per plot: 0-5 cm and 5-15 cm. Total Organic Carbon (TOC) in the soil was measured using TOC Analyzer (Shimadzu 5000, Japan); both Total Nitrogen (TN) according to Duchafour's (1970) method. Water Soluble Organic Carbon (WSOC) was

determined using TOC Analyzer following Herbert *et al.* (1993) methodology with some variations: samples were shaken two hours and centrifuged 25 min at 4500 rpm and  $^{13}\text{C}$  CP/MAS-NMR technique (Varian Unity 300 spectrometer, Germany) was applied in the surface samples of one plot per zone. We divided the spectrum in four functional groups (Faz *et al.* 2002; Kögel-Knabner 2000): alkyl (0-50 ppm), O-alkyl (50-112 ppm), aromatic (112-163 ppm), and carboxyl (163-190 ppm).

ANOVA model was applied to identify significant differences between zones and Tukey's Test was used to establish homogenous groups. Residue normality was studied by Shapiro-Wilk's Test and Normal Probability Plot and Bartlett Test's confirmed the homogeneity of the variance.

## Results and discussion

Soils studied were classified into Entisols group (suborder Psamments, Orthents and Aquents) and Mollisols, suborder Udolls, (USDA 2006) and Regosols (suborder Arenic, Haplic and Gleyic) and Phaeozems, suborder Haplic, (FAO-ISRIC-ISSS 2006). Exchange capacity exhibited medium values with the exception of Wakampata and Killu, with high mean values over 20  $\text{cmol}_+/ \text{kg}$  in surface samples (Muñoz and Faz 2009). The soils were strongly acid and extremely acids in KCl (Soils Survey Division Staff 1993).

Table 1 exhibits TOC and WSOC mean contents and standard errors and C/N ratio. Wakampata and Puyo-Puyo presented the highest mean TOC content ( $91.7 \pm 5.6$  and  $72.7 \pm 3.8$   $\text{g}/\text{m}^2$ , respectively) in surface (0-5 cm) and a statistically significant difference was found with other zones. In the contrary, Sucondori exhibited lowest mean TOC value ( $37.3 \pm 2.0$   $\text{g}/\text{kg}$ ), both Ulla-Ulla, Caballchiñuni ( $45.9 \pm 2.3$   $\text{g}/\text{kg}$ ) and Ulla-Ulla ( $51.5 \pm 6.4$   $\text{g}/\text{kg}$ ), respectively) and subsurface samples results exhibited similar TOC contents (Table 1). These zones could receive more MOS as a consequence of the higher *Pycnophyllum* grassland plant covert (Muñoz and Faz 2009). However, all studied zones showed medium C/N values with the exception of Puyo-Puyo ( $14.3 \pm 0.9$ ), where humification processes could be a bit more intense.

According to WSOC results (Table 1), Japu is the zone with the highest WSOC mean value ( $671.1 \pm 129.5$   $\text{mg}/\text{kg}$ ); on the contrary, Ulla-Ulla exhibited the lowest WSOC content ( $249.2 \pm 46.4$   $\text{mg}/\text{kg}$ ). Wakampata, Puyo-Puyo and Japu surface samples showed WSOC concentrations within the average described by Halvorson and Gonzalez (2008) in grasslands, while all subsurface WSOC contents were above in Apolobamba studied zones. According to Zhao *et al.* (2008) there is a positive relation between WSOC fraction and mineralization processes. Therefore, the mineralization processes could be more intensive in 5-15 cm, especially in Japu, as C/N ratio showed (Table 1).

**Table 1. TOC and C/N mean contents and standard errors in surface (0-5 cm) and subsurface samples (5-15 cm) (n=9); WSOC in surface and subsurface samples (n=3).**

Zones	Surface			Subsurface		
	TOC ( g/kg)	C/N	WSOC (mg/kg)	TOC ( g/kg)	C/N	WSOC (mg/kg)
Ulla-Ulla	$51.5 \pm 6.4$ cd	$11.9 \pm 0.6$ ab	$249.2 \pm 46.4$ d	$44.5 \pm 4.0$ abc	$13.6 \pm 0.9$ a	$223.8 \pm 27.2$ d
Killu	$58.9 \pm 5.2$ bc	$11.7 \pm 0.8$ b	$456.6 \pm 120.3$ bc	$47.8 \pm 2.0$ abc	$10.0 \pm 0.2$ c	$501.6 \pm 17.4$ ab
Ucha-Ucha	$55.0 \pm 3.1$ bc	$12.2 \pm 0.5$ ab	$353.5 \pm 26.8$ c	$38.8 \pm 2.2$ cd	$11.4 \pm 0.6$ abc	$300.2 \pm 1.8$ c
Wakampata	$91.7 \pm 5.6$ a	$12.7 \pm 0.2$ a	$586.6 \pm 141.7$ ab	$56.2 \pm 2.0$ ab	$10.6 \pm 0.1$ bc	$443.5 \pm 27.5$ bc
Sucondori	$37.3 \pm 2.0$ d	$11.7 \pm 0.2$ b	$269.2 \pm 32.5$ cd	$30.0 \pm 2.1$ d	$12.3 \pm 0.6$ ab	$241.9 \pm 14.3$ d
Caballchiñuni	$45.9 \pm 2.3$ cd	$11.9 \pm 0.4$ ab	$317.8 \pm 73.5$ c	$57.3 \pm 2.7$ a	$13.1 \pm 0.7$ a	$435.1 \pm 26.9$ bc
Puyo-Puyo	$72.7 \pm 3.8$ ab	$14.3 \pm 0.9$ a	$549.5 \pm 132.7$ ab	$50.4 \pm 2.6$ abc	$13.1 \pm 0.3$ a	$381.8 \pm 33.8$ c
Japu	$61.1 \pm 5.9$ bc	$11.3 \pm 0.2$ b	$671.1 \pm 129.5$ a	$43.9 \pm 4.0$ bc	$11.3 \pm 0.2$ abc	$579.7 \pm 34.1$ a

Taking into account the percentages of carbon functional groups (Figure 1), Wakampata or Japu have more carbohydrates contents considering the higher O-alkyl-C mean percentage,  $44 \pm 1\%$  and  $45 \pm 1\%$  respectively, in both zones (Figure 1). As a consequence, the microbiological action could degrade much easier the SOM through humification processes in these zones. On the contrary, Ucha-Ucha, Ulla-Ulla and Caballchiñuni presented lowest mean O-alkyl-C percentages ( $35 \pm 1$ ,  $40 \pm 0\%$ ,  $40 \pm 0\%$ , respectively). Figure 1 exhibits a relative homogeneity in the aromatic compound distribution, which increased slightly in Japu and Ulla-Ulla ( $13 \pm 1\%$ ). These may be zones where degradation processes would develop slightly. A higher lignin concentration in Japu could explain the lower decomposition processes speed in comparison to other zones.

This lignin could come mainly from the native vegetation where *Stipa sp.* was identified (Muñoz and Faz 2009). The fact that the higher carboxyl-C percentages found in Ulla-Ulla and Caballchiñuni (11±1 and 11±0%, respectively) reveals that SOM oxidation degree is higher in these areas, which might lead to certain soil degradation in these census places (Kiem *et al.* 2000) probably due to camelid cattle overexploitation. According to aromatic and carboxyl percentages, the SOM mineralization speed could be faster in Ulla-Ulla and Caballchiñuni with lower SOM stabilization.

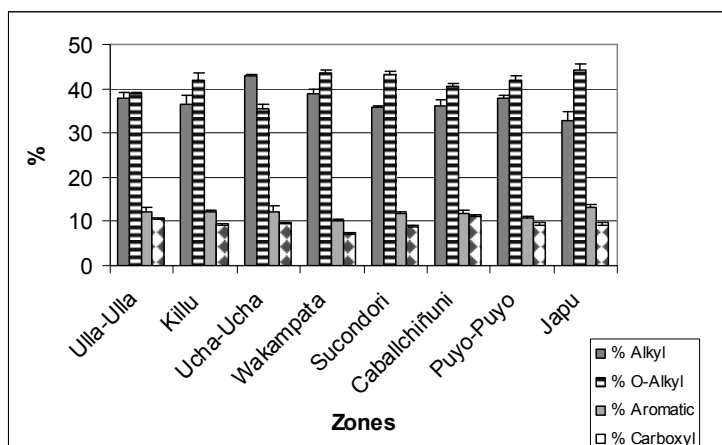


Figure 1. Percentages of <sup>13</sup>C-NMR functional groups of the surface soil (0-5 cm; n=3)

## Conclusions

In conclusion, some studied zones located in high grasslands in the Andean plateau in Bolivia such as Wakampata and Puyo-Puyo could be an excellent carbon reservoir regarding TOC contents and mineralization processes. In addition, humification and mineralization processes are equilibrated, according to C/N relation.

A good quality and quantity of SOM was found in the studied soils although they are prone to degradation. Thus, it is necessary to carry out some soil protection actions in the studied zones, especially in Ulla-Ulla and Ucha-Ucha, in order to improve the sustainable vicuna management and preserve high grassland ecosystems and their biodiversity in Apolobamba.

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