Comparative assessment of soil carbon stocks in different agroecologies in Southern Peru

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Abstract

Soil carbon sequestration in cropping systems, in spite of its importance, is seldom quantified in Peruvian soils. A study was conducted to analyze soil carbon sequestration in different ecosystems of Peru, as affected by soil type, altitude, climate, cropping system and management regimes. Soils were sampled from a transect of approximately 1000 km from sea level to 4000 masl and spanning the coast, the plateau and the eastern hillsides. Potato is usually the rotation head of most of these systems, except in the Amazonian sites. Samples from 0 to 30 cm depths were taken and processed for total carbon stocks (CS). Whole soil samples were also characterized using the Laser-Induced Fluorescence (LIF) Spectroscopy to assess the carbon stability in the different agroecologies. The soils in the Amazonian site presented higher CS -together with dry valleys- but with lower stability, when compared to other agroecologies. Higher soil carbon stability increased with depth, due to the presence of recalcitrant carbon, while at the surface the presence of labile carbon dominates due to constant input of plant residues. The data supports the hypothesis that diversified production systems with potato, alfalfa, oat, corn, beans, onion – depending on the altitude- and livestock are more stable from a system's whole productivity point of view, which includes CS and stability. Thus diversification strategies are needed to guarantee the conservation of ecosystems with high CS and might be essential to help farmers adapting to the effects of climate change, a challenge to be faced in the near future.

Keywords: Peruvian soils, soil carbon stocks, carbon stability.

Introduction

Carbon sequestration in plant and soil systems provides an opportunity for agriculture to contribute to the mitigation of the greenhouse effect. Although the Clean Development Mechanism (CDM) protocol has prioritized only aboveground carbon sequestration via reforestation and forestation, the soil, including some agricultural soil, might represent even a larger carbon sink. One of the challenges for the incorporation of agriculture into post-Kyoto agreements is to develop simple and effective methodologies for measuring, monitoring and verifying soil carbon in cropping soils. For this end, field-level measurements that guarantee reliable assessments of soil carbon contents and quality are needed. EMBRAPA has been very active in the development of portable equipment to suit these needs. The best examples are the laser induced breakdown (LIB) spectroscopy to quantify- amongst other elements- carbon contents in the soil (Ferreira et al., 2008; Da Silva et al., 2008) and the laser induced fluorescence (LIF) spectroscopy, which relies on the fluorescence emitted by rigid conjugated systems and thus can be used to assess the degree of humification in the organic matter of whole untreated soil samples (Milori et al. 2006).

The LIF signals emitted by whole soil samples after excitation with ultraviolet radiation (351 nm) are unambiguously due to the organic matter fraction and the results agree with other spectroscopic methods such as Electron Paramagnetic Resonance (EPR) (Saab & Martin-Neto 2004; Saab & Martin-Neto, 2008), Nuclear Magnetic Resonance (NMR) (Leifeld & Kögel-Knabner, 2005; Saab & Martin-Neto, 2007,) and Fluorescence spectroscopy (Milori et al., 2002; González-Pérez et al., 2007). According to Milori et al. (2002), fluorescence signals with excitation at near ultraviolet or blue radiation are more resonant with rigid conjugated systems in individual molecules or structures (probably aromatic) bearing constituents such as carbonyl and carboxyl groups.

The International Potato Center (CIP) and two Brazilian institutions –the Brazilian Agricultural Research Corporation (EMBRAPA) and the University of Sao Paulo (USP) - have joined forces and resources to: a) assess soil carbon sequestration in different agricultural soils in the Peruvian Andes; and, b) estimate the degree of chemical recalcitrance of the soil organic matter – organic matter resistance to biodegradation- using state of the art non-destructive analytical methods that determine not only the recalcitrance index but also a more detailed chemical composition present in the humic substances or the soil structure.

Methods

Sampling transect

Southern Peru has such contrasting agroecologies that might mimic the extreme conditions found in tropical agriculture throughout the world. Coastal, Amazon and high mountain regions are part of the landscape. The changing altitude and orography of the mountain chain produces a diversity of temperature, rainfall and humidity patterns, which have direct effect on soil development. Tropical rainforests are found at the windward eastern hillside while the leeward western hillside is a desert. Based on geology, soil, altitude, climate, and land use data, an approximate 1,000 km sampling transect was selected (Figure 1). The transect included five major agroecologies: arid coast, arid low altitude inter-Andean valley, arid high altitude inter-Andean valley, semi-arid high plateau, and the tropical rainforest. Soils from the main cropping systems within each agroecology were sampled. Irrigated agriculture on the western hillside, of about 500 years, is the most recent one. Most important crops in this agroecology include: maize, olive, alfalfa, potato, grape, and avocado. Further up, the high plateau is the center of origin of potatoes and one of the most important millenarian crop domestication centers in the world. Soils from rotational cropping systems, the predominant practice in the area, were sampled in this agroecology. On the Amazonian side, soils from a primary rainforest and cultivated shaded coffee were included.

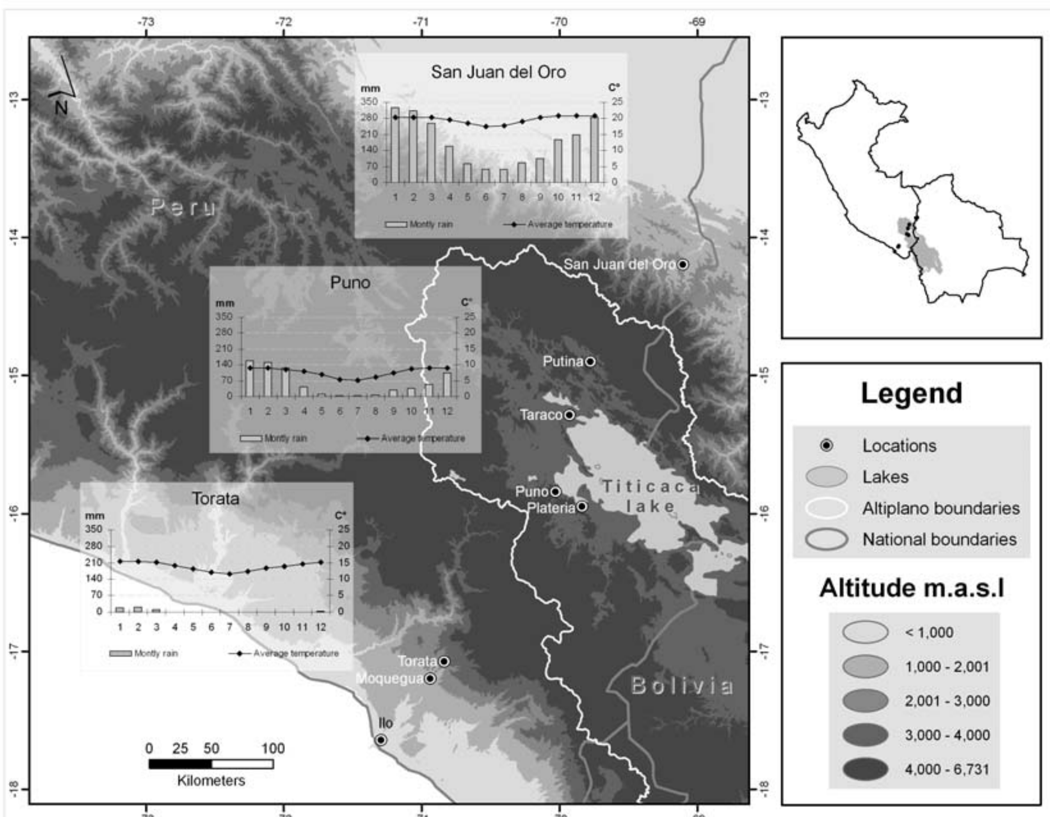

Figure 1. Sampling-transect to assess carbon contents and stocks in Southern Peru

Experimental

In each sampling site, five layer samples from 0 to 30 cm depths were taken and processed for total carbon analysis (Table 1), which was performed on approximately 200 mg aliquots of soil samples using a total carbon analyzer (LECO model CR 412). Carbon contents (CC, in g kg^{-1}) and Carbon stocks (CS, Mg ha^{-1}) were estimated in each layer and throughout the entire profile. Humification degree of organic matter present in whole soil samples was estimated using LIF spectroscopy through the estimation of the H_{LIF}, a ratio of the area under the fluorescence emission (excitation range 350 - 480 nm) and the total organic carbon content in the sample. Soil pellets of approximately 0.5 g, 1 cm of diameter, and 2 mm thickness, were inserted into a home-assembled apparatus to acquire LIF data (Milori et al., 2006). Samples were excited with 458 nm blue radiation, emitted by argon laser equipment (Coherent Innova 90-6, Coherent Inc., Santa Clara, CA) with power of around 300 mW. The system apparatus was assembled according to Milori et al. (2006). Using a nested sampling scheme, CC and CS were compared, among cropping systems within agroecologies and among agroecologies.

Results and discussion

As shown in table 1, both the shaded Amazonian coffee and alfalfa in the high altitude inter-Andean valley presented the largest CS in the soil (91 Mg ha^{-1}). These cultivated areas had larger CS than the tropical rainforests soils (75.2 Mg ha^{-1}). The olive orchards in the arid coast had the lowest CS (38 Mg ha^{-1}). Carbon stocks in potato and maize systems varied from 42 to 56 Mg ha^{-1}, depending on the location. Our results also showed that soil organic carbon increased with elevation in the arid environments, as evidenced by the fact that when CS was analyzed as a function of altitude for different agroecologies, within the same texture class, a linear relationship ($r \sim 0.8$) was obtained, which confirms some observations found in the literature.

The degradability of the readily bioavailable dissolved or water-extractable OM fraction is often negatively correlated with its aromatic compounds content, which in turn has been associated with recalcitrance (soil carbon stability). The results are given in arbitrary units (a.u), typical of indexes, and are calculated by dividing the area of the LIF spectra (a.u.) by the corresponding carbon concentration (g kg^{-1}). The soils in the Amazon site presented lower carbon stability. Soil carbon stability increased with depth, due to the presence of recalcitrant carbon, while at the surface the presence of labile carbon dominates due to constant input of plant residues.

Organic matter in soils under irrigation and subjected to conventional tillage in the arid ecosystems is more recalcitrant (I don't observe this in B3, B3 is similar than A4 and B4, they are more labile) than in soils with less tillage or where tillage is done manually like in the plateau. In the literature this is usually related to the decomposition of labile organic matter caused by tillage. It was also noteworthy the uniformity in the humification degree across layers in soils under conventional tillage, which is usually associated with the homogeneity imparted by tillage disturbances of the top layers of these soils. Less- or no-tilled soils showed a gradient, attributed to the higher input of recent organic matter by crop residues and plants to the top layer. These findings confirmed trends found in previous research by the team.

Table 1. Carbon stocks (Mg ha^{-1}) by soil layer and total carbon storage per soil site. Data from soil sampled in 2008, in different cropping systems

Depth (cm)	Carbon Stocks (Mg ha^{-1})#									
	Ilo		Moquegua			Torata		San Juan del'Oro		Puno
	A1	B1	A2	B2	C2	A3	B3	A4	B4	A5
0-2.5	4.4	3.6	5.9	4.7	6.5	7.4	11.9	10.6	8.3	3.7
2.5-5	4.0	3.4	4.9	4.7	6.4	7.6	10.8	9.2	7.0	3.8
5-10	6.8	6.5	7.2	9.0	11.3	14.8	15.9	15.3	11.1	9.8
10-20	13.4	12.8	19.5	18.0	23.3	22.4	28.3	32.2	26.5	17.2
20-30	13.8	11.8	19.2	19.2	17.7	16.0	25.0	24.0	22.3	12.4
Total	**42.4**	**38.1**	**56.7**	**55.6**	**65.2**	**68.2**	**91.9**	**91.3**	**75.2**	**46.9**

Carbon stocks = 10 × (C × d × T); C is the carbon content in g kg^{-1}; T the sample layer thickness in meters and d the soil layer bulk density in Mg m^{-3};
A1: maize; B1: olive; A2: alfalfa; B2: potato; C2: grape; A3: avocado (intercropping); B3: alfalfa under irrigation; A4: coffee; B4: original forest; A5: alfalfa – potato – oat rotation

Table 2. Humification degree (H_{LIF}) of soil in different Peruvian sites, obtained through Laser Induced Fluorescence (LIF) spectroscopy at 0-2.5, 2.5-5, 5-10, 10-20 and 20-30 depths

			Depth (cm)				
	site	**crop**	**0-2.5**	**2.5-5**	**5-10**	**10-20**	**20-30**
H_{LIF} (a.u.)	Ilo	A1	21.5±1.4	24.4±0.1	24.6±1.3	23.8±1.2	24.6±1.8
		B1	27.6±0.2	28.3±0	28.4±0.0	29.0±0.3	32.0±0.3
	Moquegua	A2	18.9±0.1	22.6±0.1	21.1±0.1	23.3±0.2	22.4±0.8
		B2	23.5±0.2	23.8±0.0	24.5±0.1	24.1±0.1	22.5±0.1
		C2	19.4±0.1	19.5±0.1	21.4±0.0	23.6±0.0	30.2±0.1
	Torata	A3	18.6±0.2	19.9±0.2	19.2±0.5	29.7±0.3	37.4±0.2
		B3	10.5±0.0	11.5±0.1	15.9±0.2	18.6±0.1	19.2±0.1
	San J. Oro	A4	7.6±01	8.8±0.0	10.6±0.1	12.1±0.2	18.1±0.1
		B4	8.7±0.2	10.2±0.0	11.3±0.1	13.38±0	19.3±0.1
	Puno	A5	16.5±0.1	16.8±0.2	17.7±0.08	21.0±0.8	24.6±0.1

A1: maize; B1: olive; A2: alfafa; B2: potato; C2: grape; A3: avocado (intercropping); B3: alfafa under irrigation; A4: coffee; B4: original forest; A5: alfafa – potato – avena rotation

The study also included a successful preliminary evaluation of portable optical techniques for future agriculture applications in soil characterization. The portable LIF (optical sensor) might evaluate the soil organic matter in the field, connected to a GPS for producing soil quality maps. A portable LIBS (Laser Induced Breakdown Spectroscopy) system is also promissory equipment. LIB spectroscopy can carry out quantitative field analysis of carbon contents and other elements in the soil. With these new tools, soil carbon sequestration studies as well as macro and micro soil nutrients assessment for soil amendments and contaminants in the soil can be implemented in the field without (or minimal) sample preparation.

Conclusions

Soil carbon stocks varied across cropping systems in different Andean agroecologies. Well managed agricultural soils can result in positive carbon balances and contribute to clean (carbon dioxide wise) food production. As a matter of fact, carbon stocks in some of the cropped area were similar to those obtained in primary rainforests. Nonetheless, the degree of humification is higher in cropping systems than in primary forests indicating that carbon stocks in cropping systems tend to be more recalcitrant. However, the lack of metabolizable organic compounds must also be taken into account. The non incorporation of fresh available residues containing compounds necessary for the metabolism of microorganisms leads them to decompose the organic matter already existing in the soil more thoroughly. (Because this, a crop system with more recalcitrant carbon can't be good for carbon sequestration)

The study also demonstrated the potential of using spectroscopic systems of highly reliable results for field-level analysis of carbon contents and their degree of humification. The H_{LIF} ratio can be used to discriminate, in whole soils, the variation in degree of humification at depth for different crops and tillages, showing the effect of constant accumulation of plant residues in the topsoil.

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