European Journal of Soil Biology 71 (2015) 28–36

Contents lists available at ScienceDirect

European Journal of Soil Biology

journal homepage: http://www.elsevier.com/locate/ejsobi

Original article

Effects of peasant and indigenous soil management practices on the biogeochemical properties and carbon storage services of Andean soils of Colombia

María-Cristina Ordoñez [a,*], Leopoldo Galicia [b], Apolinar Figueroa [a], Isabel Bravo [c], Miguel Peña [d]

[a] Grupo de Estudios Ambientales, Universidad del Cauca, Carrera 2 # 1A 25, 190003 Popayán, Colombia
[b] Instituto of Geografía, Universidad Nacional Autónoma de México, Circuito Exterior s/n, Ciudad Universitaria, 04510 México D. F., Mexico
[c] Grupo de Agroquímica, Universidad del Cauca, Cra 2 A # 3N-111, Tulcán Popayán, Colombia
[d] Universidad del Valle, Instituto Cinara, AA 25157 Cali, Colombia

ARTICLE INFO

Article history:
Received 24 September 2014
Received in revised form
2 October 2015
Accepted 3 October 2015
Available online 21 October 2015

Keywords:
Soil management
Andean volcanic soils
Total organic carbon stock
Pastures
Metabolic quotient

ABSTRACT

Indigenous and peasant management systems that produce food, fibre and fuel have long been used in many Andean cultures, but their effects on soil biogeochemical properties and storage of soil organic carbon have been poorly analysed. The aim of this study was to evaluate the physical, chemical and biological properties and carbon storage in Andean soils under three peasant and indigenous management practices in Popayan, Colombia: Natural Pasture (NP) (*Holcus lanatus*), Forage Crops (FC) (*Pennisetum purpureum*), and Natural Forest (NF) (dominated by *Quercus humboldtii*). In all, 216 samples were analysed over a 12-month period. The soils under the three soil managements had optimum texture (loamy and sandy loam), bulk density (<0.71 gr cm^3) and hygroscopic moisture content (11.45%) derived from the local Andosols. These soils were highly acid, particularly the forest soil (pH 4.68), but the high content of organic matter in the pasture and addition of calcium compounds to the cultivation soil had improved the pH (5.38 and 5.21 for NP and FC, respectively). Soil cultivation had produced a high metabolic quotient (qCO_2 2.46) in relation NP (0.85) and NF (0.75), perhaps owing to an imbalance of the microbial community caused by disturbances and by excess external organic carbon. However, the soils under all three management systems stored high contents of total organic carbon (TOC): 127, 111 and 110 t ha^{-1}, for NP, NF and FC, respectively. The presence of allophones in these soils leads to the formation of highly stable organo-mineral complexes, impeding mineralisation of the organic matter and allowing a high potential for soil carbon storage. A lack of temporal variability of the soil physical properties is due to the characteristics dominated by soil genesis and by the high resilience of Andosols. We conclude that the food production management practices of these indigenous communities and farmers are compatible with maintenance of the carbon storage service in these soils at the local scale.

1. Introduction

The current demand for food, fodder, fibre and fuel has led to the increased use of fertilisers, pesticides, and farming technology. These practices have had deleterious effects on soil properties and processes that determine soil fertility. For example, they increase water and wind erosion, reduce water storage capacity and water quality, alter metal and xenobiotic mobilisation and reduce productivity and sustainability [1]. Most studies have shown that significant amounts of total organic carbon (TOC) in the form of carbon dioxide have been lost because of the release of physically protected soil or because of the alteration of the microclimate when forests were transformed for the introduction of agriculture. Moreover, the increase in food production at the expense of soil ecological processes may undermine the sustainability of agro-ecosystems, including crop production.

Therefore, alternatives for managing agricultural systems must reduce soil perturbation, maximise coverage and stimulate the soil biological activity in order to counteract the adverse effects of intensive farming practices [2]. Traditional practices of integrated

* Corresponding author. Instituto Cinara, Universidad del Valle, Edificio 341 – Ciudad Universitaria Meléndez, Cali, Colombia.
E-mail address: macriso11@gmail.com (M.-C. Ordoñez).

http://dx.doi.org/10.1016/j.ejsobi.2015.10.001
1164-5563/

soil management (e.g., managed grazing, rotation of crops and introduction of earthworms and native species) favour the soil carbon content and prevent CO_2 emissions into the atmosphere. It is essential to recover beneficial soil attributes and improve soil biological properties that allow the subsequent establishment of animal species, food production and the flow of ecosystem services [3].

In the past decade, an attempt has been made to understand the multiple ecosystem services [4] that agriculture, pastures and forests provide: supply of food, timber and firewood; biomass production; provision of raw materials; carbon cycling and storage; climate regulation; and maintenance of biodiversity [5]. Traditional agropastoral methods are particularly illustrative of successful farm management because these methods follow some of the fundamental principles of sustainability of these systems. Food provision is a major concern, but consideration must also be given to ecosystem services that involve the properties, processes and functions of the soil and its microbial communities [6]. However, studies regarding ecosystem services that include the soil biological activity in Andean soils are scarce.

Tropical America (Mexico, Central America and South America) covers 11% of the land on which 8% of the world population lives, and 23% of this population relies on rural activities. Agropastoral and silvopastoral grasslands cover 77% of tropical America (548 million ha) and 11% of the land devoted to agriculture in the world [7]. Savannahs (250 million ha) and tropical forest (44 million ha) are the most important ecosystems in tropical America for grazing and for silvopastoral production. Mountain ecosystems predominate, with the Andes covering 960 000 km^2 of Peru, Ecuador, Colombia and Venezuela. In Colombia, the Andean region occupies 300 000 km^2 and is the most populated area of the country, with 74% of the indigenous and rural population inhabiting this area. Agricultural practices are conducted in this area: management practices are intensive (modernised) in the lowlands with the production of various crop plants, whereas systems in the highlands are more extensive and subsistence-based (a higher proportion of the land is used for food production and use of the area's natural resources) [7]. However, the effects of these practices on the ecosystem services of the soil are not monitored or evaluated. To assess the changes made by agricultural practices in these Andean ecosystems will require an understanding of carbon storage and CO_2 emissions via biogeochemical cycle management under different management practices [8]. Therefore, the aim of this study was to evaluate the effects of three practices of indigenous and peasant management on physical, chemical and biological soil properties and soil carbon storage. This information is crucial for adaptive management to correct or improve soils and their contribution to the ecosystem service of carbon storage and nutrient cycling in these ecosystems that are so widely distributed in the Colombian Andes.

2. Materials and methods

2.1. Study area

The study was conducted in the basin of the Las Piedras River, which is representative of the South American tropical Andes owing to its physiographic features. This basin (2°21′35″ N, 76°33′10″ W) has an area of 66.26 km^2 and a perimeter of 39 km (Fig. 1). The terrain is mountainous, with slopes between 16% and 50%. The soils have Andosol properties; they are derived from volcanic ash, with a medium clay-loam texture that is loosely structured and well drained. They show strong acidity (pH between 4.6 and 5.0), high aluminium saturation and low amounts of calcium, magnesium and phosphorus [9]. This region has a typical equatorial mountain climate with climatic zones (temperate, cold and páramo climates and sub-Andean and Andean bioclimatic zones) that are affected by the trade winds. The average temperature varies between 10.4 °C and 18.4 °C [10]. This region has orographic precipitation, with a mean monthly rainfall of 136 mm: 183 mm $month^{-1}$ between October and May, and 42 mm $month^{-1}$ during the dry season from June to September.

This area corresponds to the Andean forest formations [11]; according to the Holdridge classification, these formations belong to lower montane wet forest. The vegetation is characterised by Oak (*Quercus humboldtii*), Laurel (*Nectandra* sp.), Alder (*Alnus acuminata*), Motilon (*Brunellia* sp.), Myrtle (*Myrcianthes* sp.), Encenillo (*Weinmannia* sp.), Mano de oso (*Oreopanax* sp.), Huesillo (*Critoniopsis* sp.), Siete cueros (*Tibouchina mellis*), Wax laurel (*Myrica pubescens*), Guarango (*Mimosa* sp.), *Palicourea angustifolia*, grasses and ferns; also present are root crops, vegetables and forage grasses.

The basin is populated by indigenous families belonging to the Nasa of the Páez de Quintana reserve and to the Kokonucos and by peasant families included in the Association of Peasants of Popayán and Reserve Network and in the Peasant Association of Quintana Asoproquintana [10]. The peasants work as individuals, whereas the indigenous people organise themselves into community crop production based on subsistence agriculture and the presence of family productive units. Tropical Andean areas have heterogeneous climatic zones and vegetation types, and the various mixed crops raised by small farmers are primarily potatoes, grains, legumes and fodder. Already, 90% of the land with human intervention has problems of overuse. The practice of soil management in these areas is also diverse and depends primarily on the social customs, economy, geographic location and access to technology. The importance of water conservation is recognised, and many of the practices are directed towards forest maintenance and water conservation.

Management practices are based primarily on the establishment of the following three systems. 1) Natural pasture (NP) (*Holcus lanatus*) is managed by rotating livestock between fields, allowing the land to rest to retrieve and store organic carbon and moisture, and then using it to feed the cattle once more every 3 months. Normally, nitrogenous compounds such as urea and faeces remain on the pasture after cattle grazing. 2) Forage Crops (FC) (*Pennisetum purpureum*) are managed by manual tillage and weeding as well as by added compost, composted manure product and lime to improve the pH and to control pests, and these crops are very productive for 5 years. 3) Natural Forest (NF) management by communities (silvopastoral areas and timber extraction) tends towards conservation through the establishment of barriers (field fencing) to encourage natural regeneration. The forest is characterised by *Quercus humboldtii*, *Guarea kunthiana* A. Juss., *Myrcianthes* sp., *Nectandra reticulata* Mez, *Chrysochlamys* sp. and *Croton* sp. The forest is about 100 years old.

2.2. Selection of sampling sites

A 594.08 ha portion of the Andean basin strip in the municipality of Quintana was chosen on the basis of the heterogeneity of its microclimate, soil type and use, its coverage and the anthropogenic interventions; its average height was 2495 m a.s.l. The experimental units (plots) were selected according to soil managements, NF, FC and NP, and the total area for each [12]. Approximately 50% of this land supports livestock (natural pasture), 35% comprises protected areas (natural forest), and 15% is used for agriculture (forage crop).

Establishment of two experimental plots of 200 m^2 for each of the three soil managements led to a total of six plots, and each of