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Impact of grazing on soil organic storage carbon in high lands of Anaime, Tolima, Colombia

Impacto del pastoreo en el almacenamiento de carbono orgánico de suelos en el Páramo de Anaime, Tolima, Colombia

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ABSTRACT

The mineralization of the soil organic matter may be accelerated by productive activities as grazing and pasture management. The objective of this study was to evaluate the impact of grazing on soil organic carbon (COS) in the high plateau of Anaime, Tolima, Colombia. An unbalanced completely randomized design was used, selecting three treatments: 1) pastures with 20 years in conservation; 2) pastures currently in use; and 3) Andean high-land native forests. The COS storage was estimated using organic carbon concentration and bulk density at a depth of 0-30 cm. Aboveground biomass (AB) of forage plants was also estimated in the case of pastures. Correlation and regression analysis were carried out between COS and time of use, occupation period and stocking rate. The pastures in use stored more COS than those conserved and native forests (P<0.05; 34.4 *vs* 22.0 *vs* 21.6 tC/ha, respectively). In contrast, conserved pastures stored more carbon in AB that those in use (P<0.05; 8.3 *vs* 2.1 tC/ha). It was found that extensive livestock management had a positive impact in the COS in the Páramo of Anaime. However, a change from forests to pastures would cause a CO_2 emission by effect of burns and/or decomposition of the organic matter and the loss of other environmental services as water regulation and those derived from conservation of biodiversity.

Key words: Aboveground biomass, bulk density, concentration of soil organic carbon, stocking rate.

RESUMEN

La mineralización de la materia orgánica puede ser acelerada por actividades productivas como el pastoreo y el manejo de pasturas. El objetivo de este estudio fue evaluar el impacto del pastoreo en el almacenamiento de carbono orgánico en suelos (COS) del Páramo de Anaime, Tolima, Colombia. Se realizó un diseño completamente al azar desbalanceado, seleccionando tres tratamientos: 1) pasturas que llevan 20 años en conservación; 2) pasturas actualmente en uso y 3) bosques nativos altoandinos. El almacenamiento de COS se estimó por medio de la concentración de carbono orgánico y la densidad aparente a una profundidad de 0-30 cm. La biomasa arriba del suelo (BAS) de forrajeras también fue estimada en el caso de las pasturas. Se realizaron análisis de correlación y de regresión entre el COS y el tiempo de uso, periodos de ocupación y carga animal. Las pasturas en uso almacenaron más COS que aquellas conservadas y los bosques nativos (P<0,05; 34,4 *vs* 22,0 *vs* 21,6 tC/ha, respectivamente). En contraste, las pasturas conservadas almacenaron más carbono en BAS que las pastoreadas (P<0,05; 8,3 *vs* 2,1 tC/ha). El manejo de ganadería extensiva tiene un impacto positivo en la acumulación de carbono orgánico en el suelo en el páramo de Anaime. No obstante, un cambio de bosques a pasturas causaría emisión de CO_2 por efecto de la quema y/o descomposición de la materia orgánica y la pérdida de otros servicios ambientales como la regulación hídrica y aquellos derivados de la conservación de la biodiversidad.

Palabras clave: Biomasa arriba del suelo, carga animal, concentración de carbono orgánico del suelo, densidad aparente.

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INTRODUCTION

The páramo is an ecosystem with great environmental and socioeconomical importance, which is threatened by man activities, reducing its capacity to offer environmental services to the region and World. The mountain regions in the Andean region have been identified as vulnerable to climate change (Büchler *et al*., 2004). Otero *et al*. (2011) argued that Andean páramo and cloud forest ecosystems in South America are changing to agricultural activities such as potato farming and cattle grazing.

The páramo provides invaluable ecosystem services as constant supply of water and storage of soil organic carbon (SOC), that are dependent of soil behavior (Hofstede and Mena, 2011).The soils in páramo ecosystem have a high content of organic matter and can store, by a long period, organic carbon in this component, due to low temperature decreases mineralization rates (Hofstede and Mena, 2011). However, soil land activities, such as grazing and fires, can accelerate organic matter decomposition and decrease storage of SOC (Maia *et al*., 2009; Román-Cuesta *et al*., 2011). On the other hand, several studies in high Andean mountains of Colombia and Venezuela have not shown an increase in the total soil carbon during the fallow period (Sarmiento and Bottner, 2002). Some authors have found a negative impact of livestock activities in SOC storage (Han *et al.,* 2008; Luan *et al.,* 2014; Silva *et al.,* 2014); while others have argued that a good management can contribute to increase carbon sinks (De Camargo *et al*., 1999; Fisher *et al.,* 2004; Andrade *et al.,* 2008; Maia *et al.,* 2009; Wang *et al.,* 2014).

The government of Colombia has supported the research in high land ecosystems to understand the impacts of climate change and land use on cycles of water and carbon (Brown *et al*., 2007). The relevance of these terrestrial ecosystems is obvious, given the importance of these carbon reservoirs in páramo soils, thus the objective of this study was to estimate the impact of grazing on storage of SOC and its potential emission of carbon dioxide towards the atmosphere in this region.

MATERIALS AND METHODS

Study area

This study was conducted in the *Reserva Natural Semillas de Agua* and adjacent grasslands, located on east face of Central Mountain Range of Colombia, in the municipalities of Cajamarca, Rovira and Roncesvalles, Tolima, Colombia. This reserve, which covers 979 ha, is composed by páramo ecosystems, páramo native forests, Andean high land forests and grasslands and is dedicated to conservation and research (Birdlife, 2011).

The mean annual temperature is 7.3^{o}C, with a minimal and maximal temperature of -3 and 25^{o}C, respectively. The mean annual evapotranspiration is 680 mm and a vertical rainfall of 2141 mm/year. The rainfall shows a bimodal behavior with a dry season in January, February, March, September and December; whilst rainy season covers April, May, July, October and November. Strong winds are presented in August, September and January, with predominant direction southeast to northeast (Asociación Red Colombiana de Reservas Naturales de la Sociedad Civil, 2011).

The soils in the study area are derived from volcanic ashes, slags and vitreous pyroclastics with a thick layer of organic matter little weathered, which is typical of páramos. Experimental plots were located in two cartographic units: MDBf and MGCe (IGAC, 2004). The unit MDBf is dominated by pyroclastics, andesite and the metamorphic rocks (shale). This soil association is composed by soils Lithic Cryorthentsen in a 60% and Rocky outcrops in 40% of area. These soils have the following characteristics: a low evolution shallow due to hard rock, high content of organic matter, highly acid, high cationic exchangeable capacity, poor in changeable bases, low in available phosphorus and very low fertility. Steep slopes (50-75%), low temperatures and low soil effective depth are the main limiting characteristics for use.

The unit MGCe has volcanic ashes as parental material, which is deposited on andesite. Soils of this consociation are represented by Typic Haplundands in a 90% and inclusions of Humic Udivitrands in a 10% of area. These soils are characterized by high depth, with black color due to accumulation of organic matter, medium to moderately gross textures, well-structured and well-drained. These soils have a high cationic exchangeable capacity, high phosphorus content in top layers and moderate fertility. Slopes range between 25 and 50% in the area.

Selection of systems to evaluate

An unbalanced completely randomized design was used, selecting three treatments: 1) pastures with 20 years in conservation (PC); 2) pastures currently in use (PU); and 3) Andean high-land native forests (F). Selection of pastures was carried out with the advisory of local personal with knowledge of this zone. Producers were asked about time of use of pastures, mean stocking rate and periods of resting and occupation.

A total of 18 experimental units were evaluated: four PC in the conservation area of this natural reserve, 11 PU in adjacent farms and three F. This last system was considered as control to estimate the impact of land use change in storage of SOC. Each experimental unit was geographically located to identify the type of soil. Statistical analyses were carried out to define a significant effect of soil unit in results.

Estimation of storage of soil organic carbon

Estimation of SOC was done to a depth of 0-30 cm, employing bulk density (BD), concentration of SOC and portion of gross fragments (rocks; Don *et al*., 2007; Maia *et al*., 2009). To avoid over-estimations of SOC, it was applied a correction of the soil weight according to BD following the approach recommended by Ellert *et al*. (2002) and Buurman *et al*. (2004). The treatment with lowest BD was taken as reference, assuming this variable was similar in all experimental plots before land use change.

One combined soil sample per plot was obtained by mixing ten sub-samples collected with a manual auger in each experimental plot. Concentration of SOC was estimated by method of Walkley and Black (1934) in the *Laboratorio Laserex* of the *Universidad del Tolima*. BD was estimated using the cylinder approach (Andrade and Ibrahim, 2003), taking three samples by experimental unit with a cylinder of 100.13 cm^3. In case of soils with a high content of rocks, gross-fragment content was calculated doing a soil pit of 50 x 50 x 50 cm and estimating volume of rocks by water displacement.

Estimation of herbaceous biomass

Aboveground biomass of grasses was estimated using the methodology proposed by Andrade and Ibrahim (2003), taking 10 quadrats of 50 x 50 cm, which were randomly located in each experimental plot. In these quadrats, all aboveground biomass of grasses was cut and weighted in fresh, taking a subsample of around 200 g to estimate dry matter content (65ºC until constant weight). Biomass was transformed to carbon multiplying by a carbon fraction of 0.5, which is recommended by IPCC (2007).

Statistical analyses

An analysis of variance was carried out to those normal variables. Variable with no normality, such as concentration of SOC (%), were transformed. In case of found statistical differences among treatments, a comparison test of Tukey was executed. Analysis of correlation and lineal regression, with logarithmic transformation and untransformed variables, between storage of SOC and BD, and management factors such as annual stocking rate, occupation period and time of use were carried out. To evaluate the effect of soils in response variables, it was developed an analyses of variance taking soil units as classification variables. All statistical analyses were carried out using the software InfoStat.

RESULTS AND DISCUSSION

Concentration of soil organic carbon

No significant difference ($P>0.05$) was found in concentration of SOC in the top 30 cm among land use systems. However, the lowest concentration of SOC was registered in native forests (2.9%), which was statistically similar ($P>0.05$) to those in conserved pastures, but a 37% lower ($P<0.05$) than in pastures in use (Figure 1a).

Bulk density

BD was not significantly affected ($P>0.05$) by type of soil, ranging between 0.46 and 0.63 g/cm^3. It was found that soils in native forests had a lower BD (0.46 g/cm^3), followed by conserved

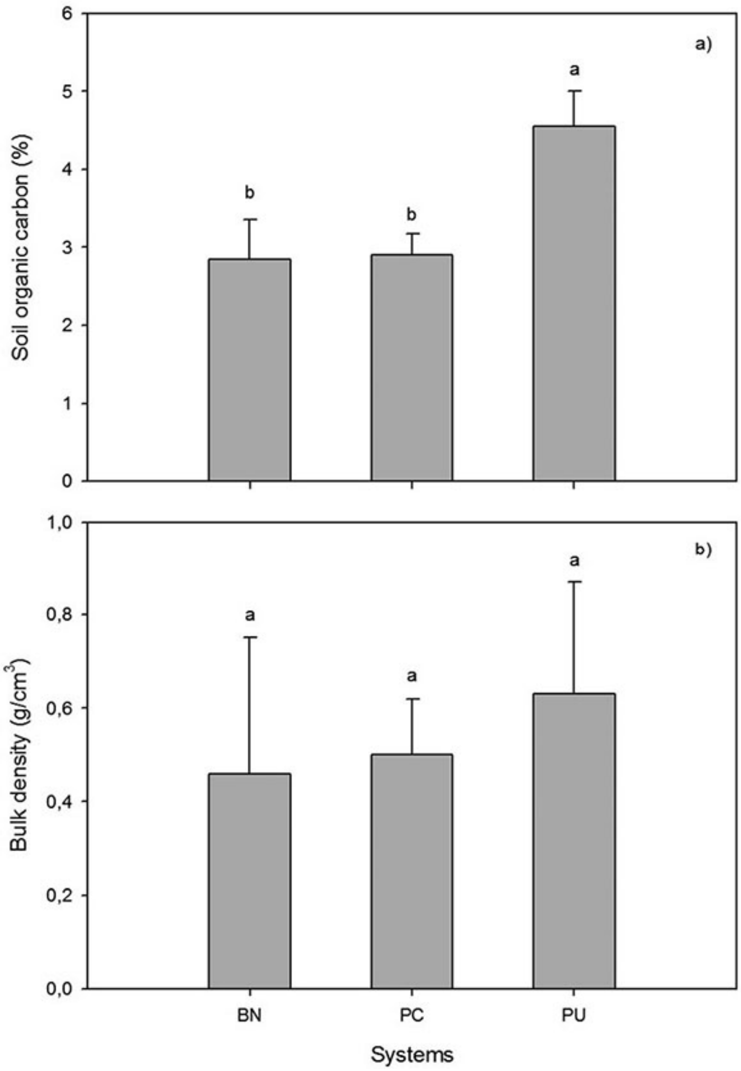

Figure 1. Concentration of soil organic carbon (a) and soil bulk density (b) at a depth of 0-30 cm in areas with andean highland forests and pastures in the Páramo of Anaime, Cajamarca, Tolima. BN: andean highland forests PC: conserved pastures; PU: pastures in use. Different letters indicate statistical differences (P<0.05).

pastures and those in use where this variable has increased in 9 and 37%, respectively (Figure 1b).

It was found a decreasing lineal relationship between BD and concentration of SOC in pastures in use, indicating an increase of SOC decreases of this first variable. In spite this relationship is just explained in a 0.5% (Figure 2a). On the contrary, an increasing lineal relationship between BD and concentration of SOC, when all land use systems were included, was found with an explication of 12% (Figure 2b).

Impact of grazing on soil bulk density

Stocking rate had a positive impact on BD (Figure 3a), in the studied range (0 – 0.19 animals/ha/year), which are so low due to own characteristics in the zone. In the same way, an increase in stocking rate of 1 animal/ha/year causes an increase of BD in an average of 1.1 g/cm^3 (Figure 3a). The period of occupation affected in a very

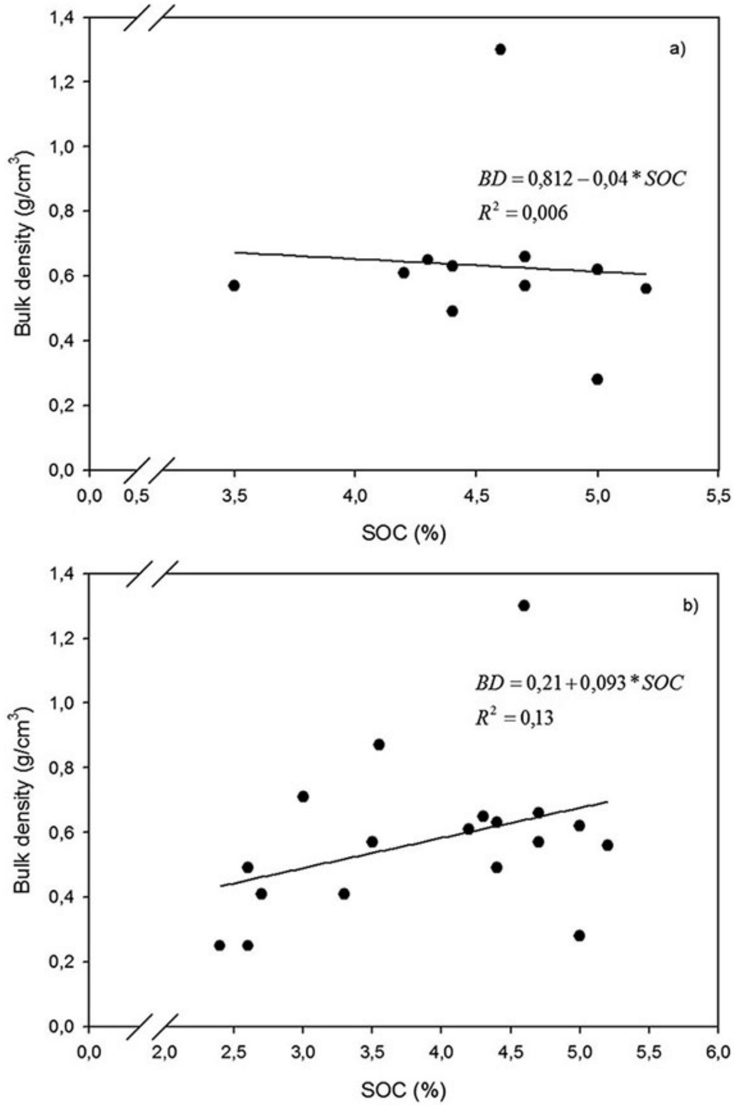

Figure 2. Relationship between the bulk density (BD) and concentration of soil organic carbon (SOC) at depth of 0-30 cm in pastures in use (a) and in andean highland forests, conserved pastures and pastures in use (b) of the Páramo of Anaime, Cajamarca, Tolima.

similar way than stocking rate, to BD (Figure 3b), increasing it a mean of 0.1 g/cm^3 every 100 days of grazing. Similarly, the time of use of pastures increases BD in 0.03 g/cm^3 every 10 years of use (Figure 3c). These predictive models explain a total of 21-23% the variation of BD.

Storage of soil organic carbon

Pastures in use had a significantly highest ($P<0.05$) SOC in top 30 cm than that in conserved grasslands and high land native forests (34.4 ± 3.4 *vs* 22.0 ± 2.1 *vs* 21.6 ± 3.8 tC/ha, respectively; Figure 4).

Impact of grazing on storage of soil organic carbon

A quadratic relationship between storage of SOC and animal stocking rate and period of occupation (Figures 5a and 5b) was detected. Accumulation of SOC is maximized when annual stocking rate

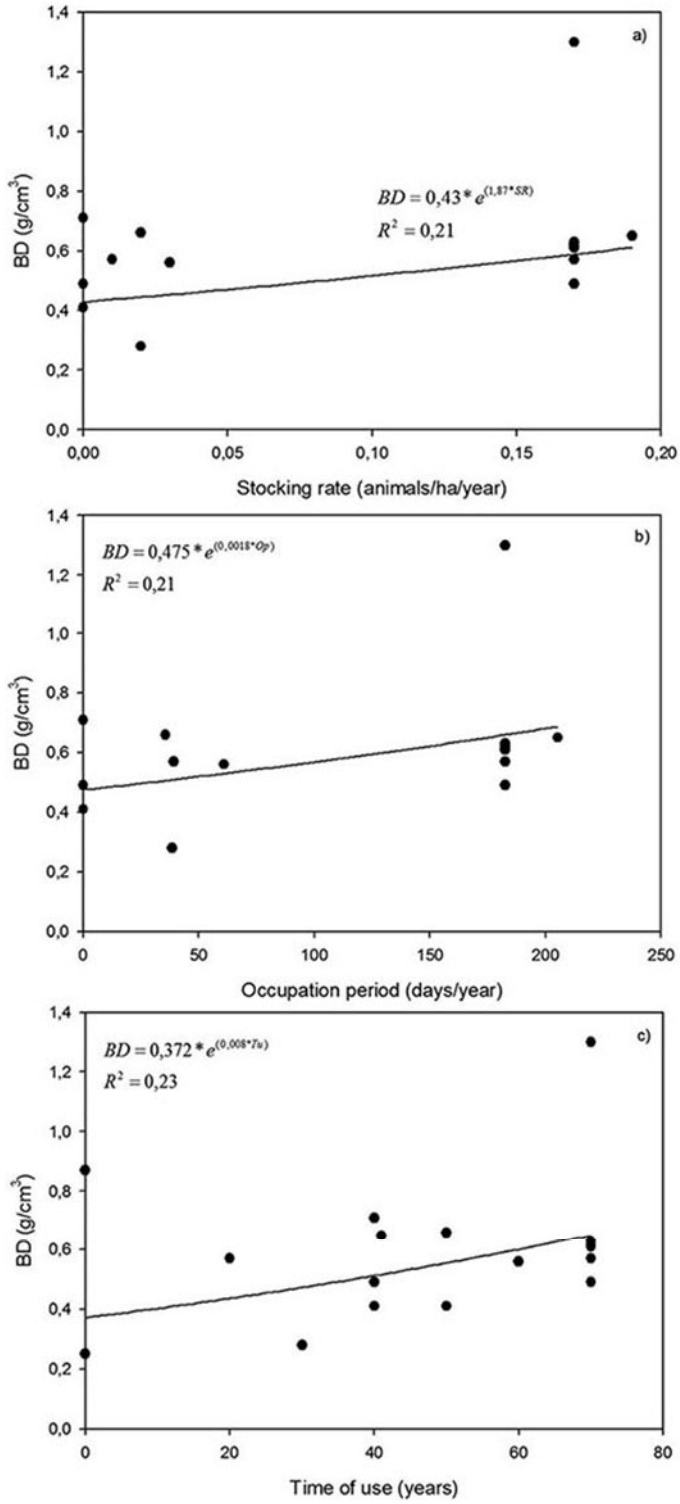

Figure 3. Relationship between bulk density (BD) at a depth of 0-30 cm and (a) annual animal stocking rate (SR), (b) occupation period (Op) and (a) time of use (Tu) in pastures of the Páramo of Anaime, Cajamarca, Tolima.

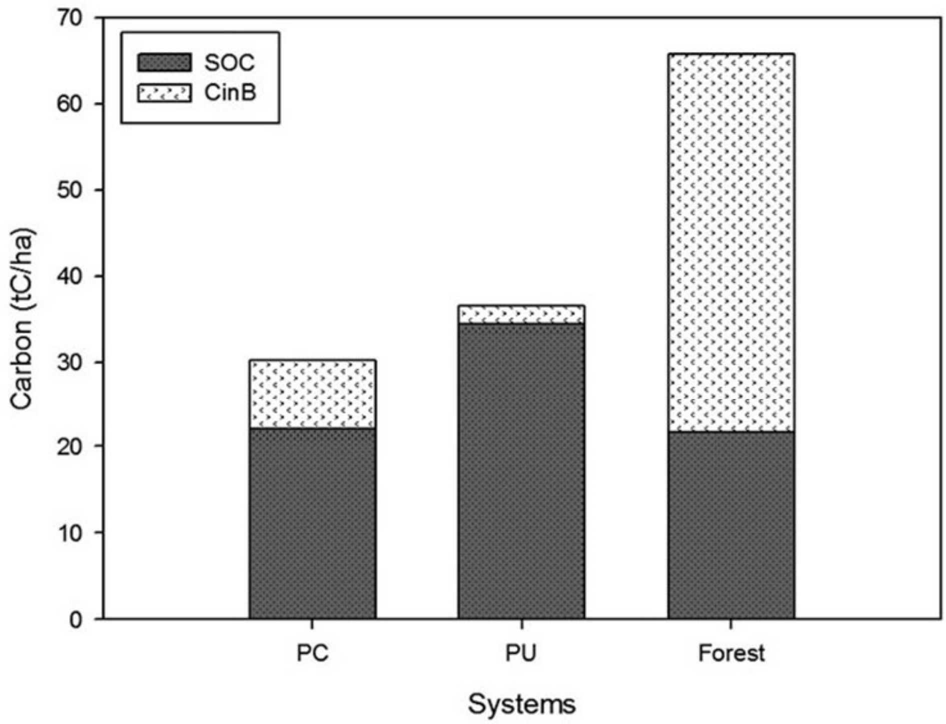

Figure 4. Storage of soil organic carbon (COS) at a depth of 0-30 cm and in aboveground biomass (CinB) in pastures and andean highland forests in the Páramo of Anaime, Cajamarca, Tolima. PC: conserved pastures; PU: pastures in use. Different letters indicate significant differences (P<0.05). Above ground carbon stored in forest and high Andean montane wet Northern Andes (Source: Gálmez and Kómetter, 2009).

is 0.1 animals/ha and 115 days of occupation/ year (Figures 5a and 5b). These models have a high explanation of storage of SOC in these ecosystems (77-78%). In contrast, time of use of pastures always increased SOC storage at a mean rate of 0.18 tC/ha/year (Figure 5c).

Carbon storage in aboveground biomass

Statistical differences (P<0.05) in accumulation of aboveground biomass of herbaceous species between conserved and in-use pastures (8.3 ± 0.3 *vs* 2.1 ± 0.9 tC/ha, respectively). This can be seen in Figure 4, with an estimation of aboveground biomass of high-land native forests reported by other authors.

Total carbon storage in pastures and native high-land forests

Taking information about carbon storage in aboveground biomass in high-land forests (Gálmez and Kómetter, 2009), it is possible to show a tendency in finding more carbon accumulation, as expected, in native forests than in in-use and conserved pastures (65.8, 36.6 and 30.3 tC/ha, respectively; Figure 4). In native forests, most of this carbon is located in aboveground biomass; whereas in pastures this is stored in soils (Figure 4).

Concentration of soil organic carbon

The SOC concentration in pastures in conservation (2.9%) was lower than that reported by Farley *et al*. (2004), who found a value of

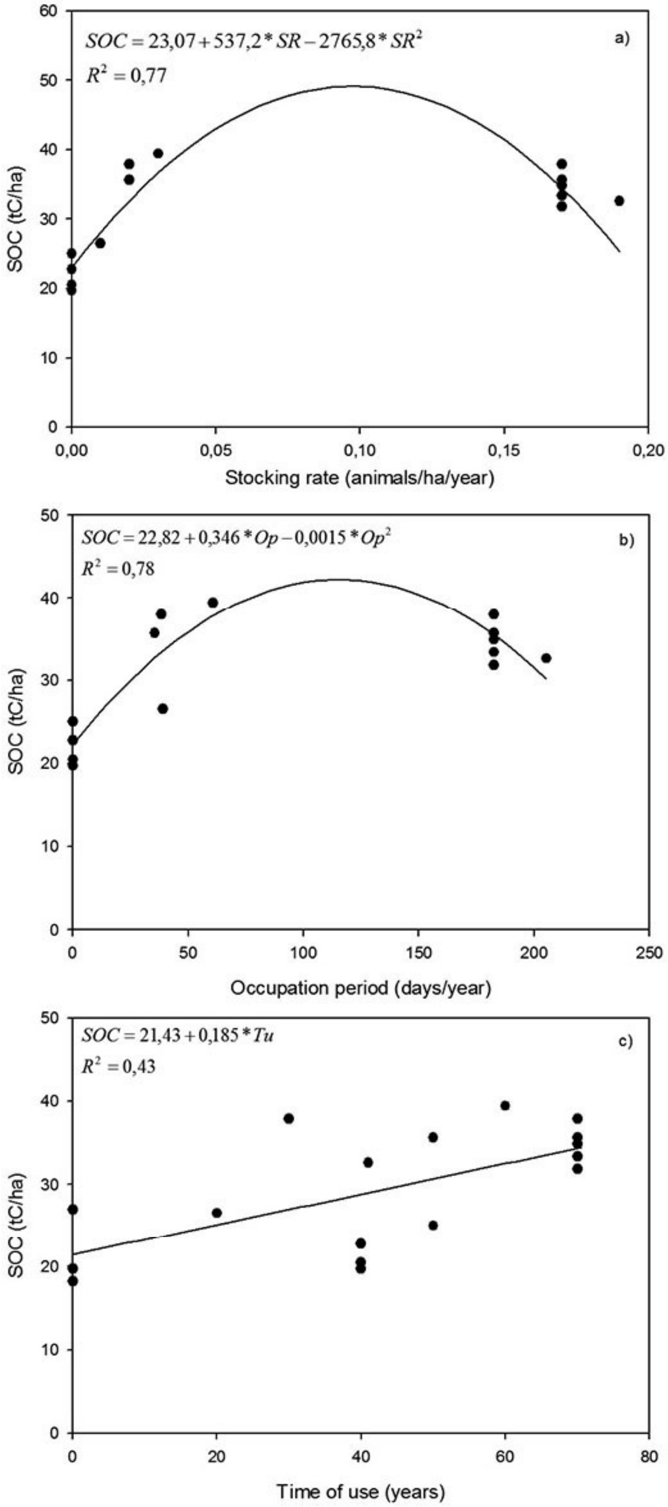

Figure 5. Relation between soil carbon storage (SOC) at a depth of 0-30 cm (COS) and (a) annual animal stocking rate (SR), (b) annual occupation period (Op) and (c) time of use in pastures (Tu) in the Páramo of Anaime, Cajamarca, Tolima.

4.2% in páramo soils in the equadorian Andean region at a depth of 0-10 cm. The results of this study and quoted one are coinciding when in-use pastures are considered, despite of slight differences in the studied soil depth. However, Han *et al.* (2008) found that SOC decreased with grazing intensity at the same depth of this study.

The positive impact of extensive livestock in the páramo on concentration of SOC may be explained by an increase of biomass of fine roots which at death and decomposition supply carbon at soil (FAO, 2007; Andrade *et al*., 2008; Maia *et al*., 2009). It is considered that in forests and conserved pastures (with no grazing for more than 20 years) there is not an important contribution of carbon by fine root senescence. Similarly, necromass due to fine roots can be maintained by a relative long time due to low temperatures in the zone, which decline decomposition rate and mineralization of organic matter. According to Pansu *et al.* (2009), rhizodeposition provides a force for microbial-mediated process, including soil carbon sequestration. This analysis is important to understand the dynamics of SOC in Latin America, due to the change from forests to pastures is one of the most important tendencies in the region (Harvey *et al*., 2005).

Bulk density

The BD found in this study (0.46 – 0.63 g/cm^3) were much lower than those reported by Farley *et al.* (2004) in top 10 cm in pastures in ecuadorian Andean region (1.17 g/cm^3). This clearly indicates an effect of soil genesis in BD and show the importance of considering the soil type when studying the impact of land use and management practices in this soil physical variable.

The increment of BD in soils is a clear and widely studied process. Pressure of cattle hooves causes compaction, mainly when previous land use was native forests. These changes were not significant in this study, due to the nature of soil, mainly by its origin from volcanic ashes. In a research developed by Sadeghian *et al.* (1999), it is reported that in spite of finding significant changes in soil compaction by animal trampling, the values of BD were not so great due to its parental material of volcanic nature (andisols with low bulk and real densities), its textural classes, dominated by sand and high content of organic matter. Similar results were found by Medina-Roldán *et al*., 2012, who reported an increase of soil BD by grazing effect in comparison to grazing exclusion (0.18 vs 0.14 g/cm^3, respectively). In contrast, Larreguy *et al.* (2014) found the lowest BD in moderate grazing disturbance in comparison to low and high grazing disturbance (1,08 vs 1,15 vs 1,23 g/cm^3, respectively) in arid soils of Argentinian Patagonia.

BD in currently in-use pastures is being affected by two simultaneous, but opposite factors: grazing and addition of organic matter. The last one is derived from the senescence of fine roots caused by grass defoliation (FAO, 2007; Andrade *et al*., 2008; Maia *et al*., 2009). Pressure of hooves of animals has a negative impact on soil due to an increase of BD as a consequence of reduction of porosity. This is confirmed by the study of Alegre and Lara (1991), who found a rise in soil BD by the effect of animals grazing. In the same way, in the Páramo of Chontales (Boyacá), Avellaneda (2006) claimed that grazing caused a hardening and impermeability of soils, affecting water movement and, therefore, altering the hydrologic cycle.

Grazing is contributing to improve the storage of organic matter (OM) in soil, which would improve the soil structure. According to Fassbender and Bornemisza (1987), OM favor the formation of individual aggregates, reduce soil global aggregation, improve water infiltration, intensify soil aeration, contributes to better water distribution in soil profile and augment water retention capacity. Civeira (2010) also found that soil physical properties improve with addition of compost: an increase of OM which reduces BD and rises infiltration. Sadeghian *et al*. (1999) found, in the Department of Quindío (Colombia), than organic matter has significantly contributed to reduce BD and helped to improve porosity and water retention, additionally to increase structural stability.

The low explication (0.5%) of SOC concentration by BD indicates that other factors, such as grazing are affecting carbon sequestration in soils. It was observed a non-expected relationship; in other words, when concentration of SOC is increased BD is also raised, with an explanation of 12%. This confirm that addition of organic matter is not having a positive effect on reducing BD, on the contrary, it was observed a tendency in rising BD by livestock activity. It must be clarify that stocking rates were low (0.01 – 0.19 animals/ha/year), due to extensive management of livestock in the study area. That is to say that the evaluated stocking rate is not enough to promote a change in BD. Growth rate of grasslands is so slow, as a consequence of low temperatures; consequently, resting periods are so long in order to allow the recovery of grasses (between 183 and 329 days/year). As a result of this, the occupation periods are relatively short, ranging between 36 and 205 days/year. This extensive use does not cause a significant impact on BD.

No variation in BD can also be explained by the addition of organic matter from grazing, which increases the capacity of soil to hold high stocking rates (Martínez *et al*., 2008). In other words, functional resilience of soil pores is closely related to presence of organic components (Dörner *et al*., 2009), that indicates that under the same management conditions a soil is enriched with organic matter this should increase its capacity to maintain stocking rates in comparison to soils with lower organic matter (Martínez *et al*., 2008). Results of this study coincides with findings of Alarcón *et al*. (2010), where it was found that BD and total porosity of soil were not significantly affected by increase of grazing intensity, demonstrating the soil capacity to endure animal transit and trampling with no a significant deformation of soil volume.

A significant change in BD would have to be the result of intensification of livestock activity, such as reports by Sadeghian *et al*. (1999), who found that magnitude of diminishing of pore spaces found were greater with an increase of the number of animals by area. In the same way, it was reported that trampling of animals in 2 to 3 years in intensive systems of meat and milk production caused a similar compaction to that extensive systems during more than 15 years.

Soil organic carbon

The extensive livestock has a positive impact in storage of soil organic carbon in this zone, allowing the capture of 12.5 tC/ha in comparison with pastures in conservation by more than 20 years. In other words, the use of extensive cattle could be causing a SOC fixation of around 0.6 tC/ha/year. This response can be explained by a potential higher biomass and extension of grasses fine roots, mainly in top soil, than trees as found by Harden *et al.* (2013) in an Ecuadorian páramo. Stockmann *et al.* (2013) argued that improved grazing with best management practices could fix carbon at a rate of 0.4-0.8 tC/ha/year, mainly in the top 30 cm of soil, the zone with the highest root and microbial activity and plant inputs. The effect of grazing intensities is contrasting among different studies. For example, Silva *et al.* (2014) found that low and moderate grazing intensities had lower soil organic carbon losses than high grazing intensity in Southern Brazil. Luan *et al.* (2014) reported that grazing exclosures of five years significantly increased SOC stock in alpine ecosystems in east Qinghai–Tibet Plateau; which contrasts with Wang *et al*. (2014) who found a reduction in carbon content in the topsoil in Loess Plateau (China) after grazing exclusion.

These results agree with those reported by Fisher *et al*. (2004) in the Colombian Orinoquia and by Ibrahim *et al*. (2007) in Colombia and Costa Rica, who found that forests store lower carbon in soils than improved grasslands (*Brachiaria humidicola)*. De Camargo *et al*. (1999) found similar results on Brazilian Amazon, where land uses of improved pastures (*B. humidicola*) incorporate more carbon than forests of forestry plantations. Maia *et al*. (2009) found in oxisols in Rondônia and Mato Grosso, Brazil than degraded pastures caused a reduction of SOC in 0.27-0.28 tC/ha/year, contrasting with well-managed and improved pastures (0.61 – 0.72 tC/ha/year). In contrast, Zimmermann *et al.* (2010) did not find statistical differences in SOC stocks among forests, shrublands and grasslands in the Peruvian Andes (11.8 *vs* 14.7 *vs* 11.9 kgC/m^2, respectively).

The previous statement does not mean that the ideal situation is land use change, from native forests to grasslands, due to it is only taking into account the SOC storage. The global cycle of carbon must consider the carbon accumulation in biomass in the forest ecosystems. In the same way, any possible land use change must take into account the functions of protection and offer of environmental services, such as water regulation and soil conservation at protect it from erosive effects of water and air (FAO, 2010).

Similarly, it must be highlighted the negative and opposite impact of livestock in other non-evaluated issues, such as the loss of water sources and water quality, decrease in water regulation, loss of natural ecosystems, decrease of biological diversity, erosion and mass removals (Murgueitio, 2003).

The results suggest that extensive livestock in the zone is contributing to increase carbon reservoirs in soils; however, changes in management practices, such as an increase in livestock intensification, could cause a negative impact in carbon storage in the future, generating an CO_2 emission to atmosphere. Grazing intensity not affect COS, according to Medina-Roldán *et al.* (2012) in an upland grassland in England and Silveira *et al.* (2013) in perennial grass pastures in the southeastern USA. It means that if the resting periods, where grasses can recovery, are not taken and unsustainable practices are used in intensive livestock a negative impact could be caused, transforming these ecosystems from sinks to sources of carbon.

This study suggests that the management of these pastures be extensive, in a natural way without the use of chemical-synthesis fertilization; avoid seasonal fires and elimination of vegetal succession by chemical methods. Unsustainable practices, such as the use of concentrates, conduce to an intensification of cattle production which causes a negative environmental impact much higher than current systems. Murgueitio (2003) found that in intensive production systems of milk and fattening steers with high stocking rates, a reduction of diversity of plant species and soil fauna was produced.

The importance of páramo zones for water conservation and regulation must not be forgotten. Herrera (2011) argued that the "capacity of páramo in the storing and distribution of water from rains and cloud condensation is based on their special soil structure, safeguarded by vegetation".

Carbon storage in aboveground biomass

The reduction of plant cover, due to change from native forests to grasslands, and the current use of pastures does not have a negative effect in carbon storage in soil in the Páramo of Anaime. Medina-Roldán *et al.* (2012) found similar results in upland grasslands of England, no detecting the impact of seven years of grazing exclusion on total carbon in soil surface. Moreover, soil loss from water erosion, with a consequent carbon loss, can be also caused. The highest carbon accumulation in forests is caused by its greatest carbon in aboveground biomass (44.2 tC/ha, Gálmez and Kómetter, 2009) counteracting the low SOC storage. In other words, despite of the use in pasture causes a higher SOC fixation, when a change in land use from forests to pastures is presented a loss of carbon which is not compensated by an increase in SOC. The land use change from forests to grasslands could cause an emission of 118 tCO_2/ha.

Although conserved pastures store more carbon in aboveground biomass, those in-use pastures contain around 6.3 tC/ha more than first ones due to a greater carbon accumulation in soils. That is to say that pastures currently in use have caused a total carbon fixation of 1.2 tCO_2/ha/year over than those in conservation.

Taking in consideration the importance of páramo ecosystems and theirs vulnerability to climate change and anthropogenic activities, impacts of livestock activities in the generation of environmental services and conservation of these ecosystems must be evaluated. With this information, it can be evaluated and recommended if it is better to conserve pasture, reducing SOC but increasing carbon in biomass in order to protect this ecosystem from degradation.

CONCLUSIONS

Conservation of pastures does not contribute positively to SOC storage. On the contrary, the extensive cattle activity, which is characteristic of this zone, has a positive impact in the carbon storage in soil in the Páramo of Anaime, fixing about 1.2 tCO_2/ha/year more than those in conservation. This is possible due to the higher dynamics of fine roots by defoliation in grazing lands, which conduces to incorporation of organic carbon to soil. This carbon can be stored by a long time due to low temperatures reduce considerably mineralization of organic matter. In contrast, conservation of grasslands increases carbon retention in aboveground biomass, resulting in similar total carbon in conserved and in-use grasslands. However, more research is needed to find more details about the SOC dynamics in tropical upland grasslands.

Land use change, from forests to pastures, has a positive impact in the SOC storage. However, in this change must be considered carbon capture in biomass and other environmental services, such as those derived from conservation of biodiversity, soil protection and water regulation. Moreover, it is widely known that conventional cattle activity has negative effects on offer of invaluable environmental services that are supplied by páramo zones.

Although a rising tendency in BD caused by cattle activity, this relationship was not significant. This can be caused by a higher effect of parental material, low stocking rate, long resting periods, short occupation periods and an increase of incorporation of organic matter due to grazing, which improves soil structure. An increase in stocking rate and occupation period has a negative effect in SOC storage; in contrast, a higher time of use increases SOC. This can be explained by soil parent material, low animal stocking rates, long resting periods, short occupation time and the organic matter of livestock activities at low level of intensification. An increase in annual stocking rate and occupation periods has a negative effect in SOC stocks; in contrast, an increase in time of use of grasslands causes that SOC stocks rises. According to this, it is needed to maintain sustainable and ecofriendly practices and avoid intensification of this activity.

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LITERATURE REVIEW

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