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Research paper

Evaluation of land use change on an andosol through physicochemical and biological indicators

Evaluación del cambio de uso del suelo sobre un andosol mediante indicadores fisicoquímicos y biológicos

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Abstract

The conversion of forests to agricultural land can dramatically alter soil properties, but soil resistance, which is the ability of soil properties or processes to remain unchanged in the face of a specific disturbance or stress, remains unclear. We evaluated the impact of land use change and agricultural management on changes on an andosol in the Cauca department, Colombia, through the analysis of physicochemical variables and biological indicators (dimensionless resistance index, where +1 is the highest resistance and -1 is the lowest resistance) that allowed the assessment of soil resistance. The land uses analyzed included (1st) forest, which was approximately 100 years of age, plus areas of the same forest (70% of the area), which had been replaced by (2nd) natural pastures and (3rd) forage crops in the year 1985, i.e. 30 years before the observations. All physicochemical variables except soil clay content were significantly affected by the change from forest to natural pasture. Similarly, the change from forest to forage cropping affected all physicochemical variables as well as resulting in a decrease in soil microbial biomass but an increase in microbial activity. We found that the metabolic quotient (-0.32) had the lowest resistance, followed by the microbial coefficient (0.19), microbial biomass (0.32) and microbial activity (0.39), suggesting that soil stress caused by disturbance has a marked impact on the number and activity of the soil microflora. By contrast the change from forest to natural pastures was not associated with any effect on microbial biomass and its activity, suggesting that the continuous input of organic matter to the soil through the supply of organic residues from diversified root systems and nutrients from livestock urine and manure favored the preservation and resistance of microbial processes in the soil. These findings suggest that deforestation to establish natural pasture has less impact on soil stability and health than cultivating the soil following clearing.

Keywords: Cropping, forest removal, microbial biomass, pastures, resistance index, soil management.

Resumen

La conversión de bosques en tierras agrícolas puede alterar drásticamente las propiedades del suelo, pero la resistencia del suelo, que es la capacidad de las propiedades o procesos del suelo para permanecer sin cambios frente a una perturbación o estrés específico, sigue sin estar clara. Evaluamos el impacto del cambio de uso de suelo y manejo agronómico sobre cambios en un andosol en el departamento del Cauca, Colombia, mediante el análisis de variables fisicoquímicas e indicadores biológicos (índice de resistencia adimensional, donde +1 es la resistencia más alta y -1 es la resistencia más baja) que permitió evaluar la resistencia del suelo. Los usos de la tierra analizados incluyeron (1ro) bosque, de aproximadamente 100 años de antigüedad, mas áreas del mismo bosque (70% del área), que había sido reemplazado por (2do) pasturas naturales y (3ro) cultivos forrajeros 30 años antes de las observaciones. Todas las variables fisicoquímicas, excepto el contenido de arcilla del suelo, se vieron significativamente afectadas por el cambio

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de bosque a pasto natural. De manera similar, el cambio de bosque a cultivos forrajeros afectó todas las variables fisicoquímicas y resultó en una disminución de la biomasa microbiana, pero un aumento en la actividad microbiana. Encontramos que el cociente metabólico (-0.32) tuvo la resistencia más baja, seguido por el coeficiente microbiano (0.19), la biomasa microbiana (0.32) y la actividad microbiana (0.39), lo que sugiere que el estrés del suelo causado por la perturbación tiene un marcado impacto en el número y actividad de la microflora del suelo. Por el contrario, el cambio de bosques a pastos naturales no se asoció con ningún efecto sobre la biomasa microbiana y su actividad, lo que sugiere que el aporte continuo de materia orgánica al suelo a través del suministro de residuos orgánicos de sistemas de raíces diversificados y nutrientes de la orina y el estiércol del ganado favoreció la conservación y resistencia de los procesos microbianos en el suelo. Estos hallazgos sugieren que la deforestación para establecer pastos naturales tiene menos impacto en la estabilidad y salud del suelo que cultivar el suelo después del desmonte.

Palabras clave: Biomasa microbiana, cultivo, índice de resistencia, manejo del suelo, pastos, remoción de bosques.

Introduction

Approximately 38% of the Earth's ice-free land area is currently used for grazing and cultivation (Foley et al. 2011). More than 80% of agricultural expansion since the 1980s has been at the expense of tropical forests (Gibbs et al. 2010). These land use changes are associated with the expansion or contraction of the area of land used for different purposes, e.g. pasture and cropland, and the change in the type of management on existing land cover (Davis et al. 2019). Land use change is associated with progressive and continuous management, which may increase erosion and reduce soil quality, and can lead to a 30–50% loss of organic carbon (Reicosky et al. 1997), plus decrease in soil microbial biomass and activity (Ordoñez et al. 2015). The responses of soil functions or soil quality to land use change can be evaluated through 2 components of ecological stability: resistance (the ability of a soil property or process to remain unchanged in the face of a specific disturbance); and soil resilience (the ability of a soil property or process to recover after a specific disturbance) (Allison and Martiny 2008; De Vries and Shade 2013). Accordingly, agricultural sustainability and soil ecology introduced the terms 'soil resilience' and 'soil resistance' to describe the ability of soils to preserve their quality and maintain productivity (Seybold et al. 1999; Orwin and Wardle 2004). In this way, it is important to understand how to determine the impact of land use change on the factors that grant soil resistance in order to avoid soil degradation.

Microbial biomass and soil microbial activity, metabolic and microbial coefficients, are indicators of soil resistance because they allow early identification of the effects of disturbance on soil properties or functions (Chaer et al. 2009; Griffiths and Philippot 2013; Bloor et al. 2018). Additionally, land use change could modify the physicochemical properties of soil such as pH, moisture, bulk density, texture and availability of carbon and nitrogen in the long term (Kirschbaum 2000).

Andean soils occupy 1% of the world's land surface (Dahlgren et al. 2004). They occur in the Andes mountain range, which occupies the western part of South America bordering its entire Pacific Ocean coast from western Venezuela through Colombia, Ecuador, Peru and Bolivia. Andosols are volcanic soils and have the capacity to store several-fold greater amounts of organic carbon than other soils (Panichini et al. 2012). Some unique properties of andosols include variable charge, high water retention, high phosphate retention, low bulk density, high friability, highly stable soil aggregates and excellent tilth (Shoji et al. 1993). Andosols play a vital role in Colombia's natural landscape, helping to provide essential nutrients and regulate the water cycle. Nonetheless, Colombian Andean ecosystems are being transformed with the introduction of agricultural activities, such as intensified use of agrochemicals and certain types of tillage, among other factors, all aimed at increasing agricultural productivity (Mujuru et al. 2013). Traditionally, current studies on andosols have focused primarily on the responses of physical properties (Fujino et al. 2008; Dörner et al. 2012; Vásquez et al. 2012; Ivelic-Sáez et al. 2015); however, impacts on the biological functions of the soil have received less attention.

The maintenance of soil functions in ecosystems, that have been extremely poorly managed, is crucial, as in the case of the Colombian Andean soils. We hypothesized that conversion of forests to natural pastures or cropping would alter the physicochemical characters of Andean soils leading to possible deterioration of soils. The objective of this study was to evaluate the impacts of land use change from forest to natural pastures and forage crops on characteristics of andosols based on the analysis of physicochemical properties and biological indicators that grant resistance to soils. This information is crucial for adaptive management, to correct or improve soils and their contribution to the ecosystem services of carbon storage and nutrient cycling in these ecosystems that are so widely distributed in the Colombian Andes.

Materials and Methods

Study area

The study area is located in the basin of the Las Piedras River, Cauca department, Colombia, between 2°25'42"–2°27'40" N and 76°23'53"–76°26'14" W (Figure 1) with an average elevation of 2,495 masl. Its physiographic features are representative of the South American tropical Andes. The terrain is mountainous, with slopes of 16 to 50%. The soils, andosols derived from volcanic ash, have a medium clay-loam texture that is loosely structured and well drained, acidic (pH 4.6–5.0) with high aluminum saturation and low calcium, magnesium and phosphorus concentrations (Martínez Burgos 2009). The annual average temperature ranges between 10.4 and 18.4 °C (CRC 2006), while the region has orographic precipitation (Poveda 2004; Guzmán et al. 2014), with an average monthly rainfall of 136 mm. The 3 land uses studied correspond to the Andean forest formations (Cuatrecasas 1958) and according to the Holdridge classification (Holdridge 1967), these formations belong to the lower montane wet forest.

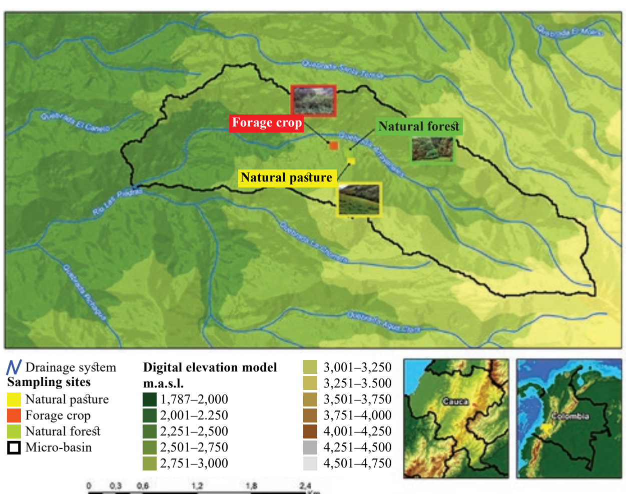

Figure 1. Study area in the basin of the Las Piedras River, Cauca department, Colombia.

In the area, approximately 50% of the land supports livestock (pasture), 35% is protected areas (forest) and 15% is used for forage cropping (Ordoñez et al. 2020). All plots occur on a similar landform unit, are derived from similar parent material and experience similar climatic conditions. Hence, we assumed that soils used had similar soil properties prior to land use change. The site under study had been under forest for about 100 years. In 1985, 70% of the area had been cleared and replaced by natural pastures and forage crops (Figure 2). The history of land use and management practices was identified through interviews with the local population. The forest is characterized by *Quercus humboldtii* Bonpl., *Guarea kunthiana* A. Juss, *Myrcianthes* sp., *Nectandra reticulata* Mez, *Chrysochlamys* sp. and *Croton* sp. Land use change was based primarily on the establishment of the following systems: natural pasture (*Holcus lanatus* L., a perennial naturalized species), managed by rotating livestock, with each field being grazed for one month and then allowed to rest for 2 months in order to recover. It is considered that this grazing system is not intensive as stocking rates are not high and adequate recovery times are allowed. The only input to the system is cattle urine and manure.

The forage grown is Elephant grass [*Cenchrus purpureus* (Schumach.) Morrone (syn. *Pennisetum purpureum* Schumach.)], a perennial crop with a duration of 5 productive years. Once cultivation begins, the crop is ready for harvesting after 4 months and repeat harvests are carried out every 2–4 months. The ground is tilled with draft animals prior to row-planting the grass, and weeds are controlled in a similar way. Following harvesting, work is carried out to eliminate weeds from the field and compost is added, about every 4 months.

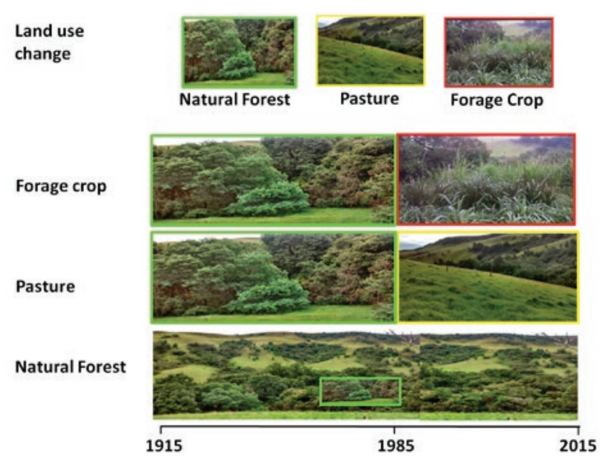

Figure 2. Description of the changes in land use over time in the Las Piedras River basin, Cauca, Colombia. Natural forest (1915–2015); land use change from forest to pasture and forage crop was in 1985.

Experimental and sampling design

Soil resistance was evaluated in terms of 11 soil properties: 4 physical parameters (bulk density, clay, silt and sand); 3 chemical parameters (C, pH and N); and 4 biological indicators (microbial biomass, soil microbial activity, metabolic quotient and microbial coefficient). It was considered a randomized unifactorial design, where a factor corresponds to a type of land use management with 3 levels (forest, natural pasture and forage cropping). Each land use was divided into plots. In natural pastures, cattle were rotated, while forage was harvested from cropped areas. Each land use type had 2 replicates situated 20 m apart. The replicates were established in different plots for each land use. In each replicate (200 m^2), 8 subplots (25 m^2) were established. We collected 8 soil samples (0–0.20 m) each month. Samples were randomly taken from the established subplots for 11 months (n = 88), making it possible to obtain an independent sample each month, thus creating a temporal replicate (Casler 2015). All soil samples were immediately transported to the laboratory and stored in polyethylene bags at 4 °C before analysis. Biological analysis was carried out on the same day as the sample collection.

Laboratory analysis

The soil texture was measured by the Bouyoucos method, using the American Society for Testing and Materials (ASTM) HYDR Fisher Brand D2487-06. Bulk density was determined by the cylinder method (Soil Survey Staff 2004) and soil pH (H_2O) potentiometrically by method 9045D (EPA 2004). Soil organic carbon was measured by oxidation with chromic acid (Walkley and Black method) (Schumacher 2002) and soil nitrogen by the Kjeldahl method (Gomez-Taylor 2001).

Soil microbial biomass was estimated by fumigation - extraction: samples were fumigated with ethanol-free chloroform, whereas Control samples were left unsprayed; after 3 days, the microbial carbon was extracted (Vance et al. 1987). To determine soil microbial activity, the CO_2 output was measured by the respirometry method (C-CO_2): the soil sample was incubated for 5 days in a closed system, then 1 N sodium hydroxide was added and precipitated with barium chloride, followed by the addition of 2 drops of phenolphthalein. Finally, the soil sample was titrated with 0.5 N hydrochloric acid to quantify the amount of hydroxide that had not reacted with CO_2; a Control or blank sample was always included. Based on the biological and carbon measurements, the following microbial indices were calculated: metabolic quotient qCO_2 = basal respiration (μg C-CO_2/g soil)/ microbial biomass (μg C-mic/g soil); and microbial coefficient qM = microbial biomass (μg C-mic/g soil)/C content (mg C/g soil).

The indicators qCO_2 and qM can be used for bio-indication of adverse processes in soils. Both indicators evaluate the efficiency of soil microbial populations in utilizing organic C compounds. The qCO_2 has been proposed as an indicator of stress in soils, because there is a reduction in microbial efficiency in energy use in disturbed ecosystems (Anderson and Domsch 1993). qCO_2 decreases in stable systems and increases with the incorporation of easily degraded waste (Dinesh et al. 2003). qM may be related to organic matter formation and efficiency of conversion of recalcitrant C pools into microbial biomass (Sparling 1992). Generally, if a soil is intensively disturbed, microbial biomass will decline faster than organic matter and qM will decrease (Sparling 1992).

Statistical analysis

The impact of the change in land use on soil resistance was evaluated based on the change in its physicochemical properties by applying the comparison of means by a Student's t-test (Ayala-Orozco et al. 2018). A property was considered sensitive when the 95% confidence interval for the difference between the means included zero. The results were complemented with the calculation of the size of Cohen's d effect, which allows us to know if the effects of the differences between treatments are significant. Statistical power depends on the sample size of the study, the magnitude of the effect and the significance criterion (typically α = 0.05). Magnitude of the effect allows researchers to present the magnitude of the reported effects in a standardized metric, which can be understood regardless of the scale that was used to measure the dependent variable. A commonly used interpretation is to refer to magnitude of effects as small (d = 0.2), medium (d = 0.5) and large (d = 0.8) based on benchmarks suggested by Cohen (1988). The resistance of the biological properties of the soil was analyzed through the resistance index (RS) (Equation 1) proposed by Orwin and Wardle (2004) (+1 maximum resistance, -1 minimum resistance), evaluating the change in resistance of the microbial indicators caused by land use change from forest to natural pasture or forage crops:

$$RS = 1 - \frac{2\,|\,D_0\,|}{(C_0 + |\,D_0\,|\,)} \quad \text{(Equation 1)}$$

where:

D_0 = the difference between the Control C_0 and the disturbed soil P_0 at the end of the disturbance. This index is standardized by the Control soil, that of the forest.

Results

Resistance of the soil to land use change

There was no change in soil clay content from forest to natural pasture, but the other variables were significantly different between these types of land use ($P<0.05$) (Tables 1 and 2). Sand percentage, soil C and N concentrations and soil pH increased under natural pastures ($P<0.05$); in contrast, bulk density and silt percentage decreased ($P<0.05$). Similar behavior was found in the conversion from forest to forage cropping with sand percentage, soil C and N concentrations and soil pH increasing and silt percentage decreasing ($P<0.05$); in contrast, bulk density did not change ($P>0.05$) (Table 2). Calculation of the magnitude of the effects confirmed that the significant differences found in the physicochemical variables of the conversion from forest to natural pasture were derived from the land use change factor ($d>0.8$) (Table 2). Similarly, those differences found in the variables during the conversion from forest to forage cropping were explained by the change in land use.

In the change from forest to natural pasture, microbial coefficient (qM) had the lowest resistance (0.37), while soil microbial biomass (0.98), metabolic quotient (qCO_2) (0.63) and microbial activity (0.61) were more resistant to land use change. In the change from forest to forage crop, metabolic quotient (-0.32) had the lowest resistance, followed by qM (0.19), microbial biomass (0.32) and microbial activity (0.39) (Figure 3).

Table 1. Mean and standard deviation of the mean of physicochemical and biological properties of soil under 3 land uses in the 0–20 cm soil horizon.

Soil characteristic	Natural forest		Natural pasture		Forage crop	
	Mean	SD	Mean	SD	Mean	SD
Bulk density (g/cm^3)	0.71	0.07	0.66	0.04	0.70	0.04
Sand (%)	51.3	2.76	56.9	1.36	64.8	2.11
Clay (%)	10.3	0.26	10.4	0.38	10.8	1.16
Silt (%)	38.4	2.69	32.7	1.21	24.4	2.50
Soil organic carbon (%)	5.20	0.86	9.65	1.05	7.63	0.87
pH (H_2O)	4.68	0.20	5.38	0.20	5.21	0.28
Nitrogen (%)	0.59	0.10	0.99	0.12	0.77	0.15
Microbial activity (μg $C\text{-}CO_2$/g/d)	120.8	23.00	149.9	28.08	173.4	36.49
Microbial biomass carbon (μg C/g)	206.4	83.29	208.7	54.33	100.4	79.70
qCO_2	0.75		0.78		2.50	
qM	3.74		2.19		1.02	

Table 2. Soil resistance measured as the difference between the mean values for the natural forest, natural pasture and forage crop in the 0–20 cm soil horizon. Asterisks mark significant differences at $P\leq0.05$. Negative values in mean difference indicate that the parameters in changing from natural forest to natural pasture and forage cropping have been increasing and positive values indicate that the values have been decreasing.

Land use change	Soil parameter	t	Significance (2-tailed)	Mean difference	Cohen's d[1]
Natural forest to natural pasture	Bulk density (g/cm^3)	5.79	0.00*	0.06	1.36
	Sand (%)	-15.53	0.00*	-5.63	2.59
	Clay (%)	-0.78	0.44	-0.04	0.13
	Silt (%)	16.33	0.00*	5.67	2.72
	Soil organic carbon (%)	-27.75	0.00*	-4.45	5.58
	pH (H_2O)	-21.14	0.00*	-0.70	4.00
	Nitrogen (%)	-21.49	0.00*	-0.40	1.78
Natural forest to forage crop	Bulk density (g/cm^3)	1.21	0.23	0.01	0.2
	Sand (%)	-33.02	0.00*	-13.51	5.5
	Clay (%)	-3.28	0.00*	-0.46	0.5
	Silt (%)	32.31	0.00*	13.97	5.3
	Soil organic carbon (%)	-16.80	0.00*	-2.43	2.79
	pH (H_2O)	-12.98	0.00*	-0.53	2.16

[1]The size of Cohen's d effect (Cohen 1988). The significance criterion is $\alpha = 0.05$. The magnitudes of effects are taken as small ($d = 0.2$), medium ($d = 0.5$) and large ($d = 0.8$).

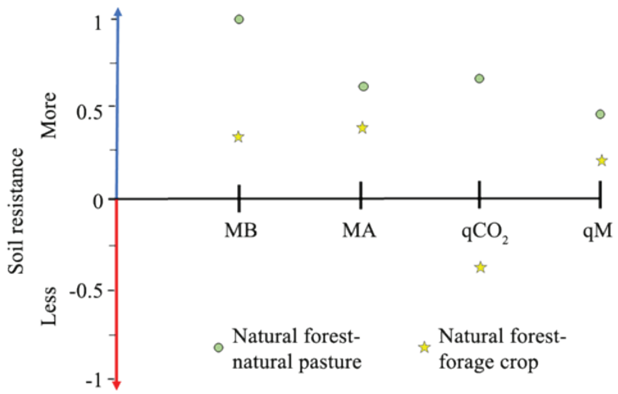

Figure 3. Comparison of soil resistance indicators according to land use change (+1 more resistance, -1 less resistance). MB (microbial biomass), MA (microbial activity), qCO_2 (metabolic quotient) and qM (microbial coefficient).

Discussion

While land use change from forest to natural pasture or forage crop changed many of the soil's physical, chemical and biological properties, the changes had no negative impact on bulk density. This is in contrast with other studies where tillage contributed to increasing bulk density under intensive cropping because of the potential destruction of soil aggregates due to physical mixing/abrasion by tillage operations (Anda and Dahlgren 2020). The same effect has also been documented in soils with overgrazing (Hofstede 1995). Soil bulk density values did not exceed 0.94 g/cm^3 in both pasture and tilled soils, which is considered a critical threshold for establishing crops on Andean soils, due to low bulk density being characteristic of Andean horizons (<0.9 g/cm^3), associated with the development of porous soils (IUSS Working Group WRB 2015). Values recorded in our study remain within the characteristic ranges for andosols, possibly because the practices conducted in forage cultivation and natural pasture were not intensive. However, sand percentage increased in both soils, and silt decreased by approx. 7%, with more pronounced changes in levels under forage cropping. Additionally, the proportion of clay in soils did not change with conversion from forest to natural pasture, but increased significantly with forage cropping. These results may imply the loss of soil components due to deflation, in which particles with the size of silt, when susceptible, are more easily suspended in the wind than sand particles, while clay particles, which have a high electrostatic charge and affinity with water, make it less susceptible to loss due to deflation (Li et al. 2009; Bettis III 2012; FAO 2019). The decrease in vegetation cover, as a consequence of grazing and clearing of land, and the possible alteration of the soil structure appear to have resulted in a preferential loss of silt particles, effectively increasing concentration of sand particles. These findings coincide with those of Neff et al. (2005), Ordoñez et al. (2015) and Zhang et al. (2019). Additionally, the increase in the clay fraction is associated with increased soil organic carbon (SOC) stabilization (Sollins et al. 1996). Organic matter is a major factor affecting aggregate stability because its abundance and characteristics can be modified by agricultural practices, like tillage methods, residue management and amendments. For example, the addition of organic matter such as manure to forage crops has been reported as a beneficial practice to maintain the stability of soil aggregates in the long term because of humified compounds (Abiven et al. 2009). At our study site, despite the fact that significant changes in physical properties were evidenced following changes from forest to natural pastures and forage crops, the magnitudes of these properties (bulk density, texture) remained within the characteristic ranges for andosols, possibly because the practices developed in the area are not intensive and because the ability to store carbon in andosols favors the structure and stability of aggregates, making the soil resistant to physical damage from agricultural practices (Watts and Dexter 1998).

Soil pH and C and N concentrations were sensitive to land use changes, increasing in both natural pasture and forage cropped soils. Management practices imposed lowered the acidity of the soils under forage cropping through the supply of calcium compounds in the form of carbonates and oxides, the most common management practice for the correction of acidity and the elimination of toxicity in soils of volcanic origin (Dahlgren et al. 1991; Tonneijck et al. 2010). The neutralization in the soil pH of natural pastures may be due to the continuous supply of organic carbon by livestock, which gradually generates greater condensed molecules (humic substances) that produce strong aluminum retention (Tonneijck et al. 2010); organic amendments to soils can generally increase soil resistance (Griffiths and Philippot 2013). On the other hand, in our study, soil C and soil N increased with the land use change from forest to natural pastures and forage cropping, due to the supply of fresh manure to pastures and manure amendments to forage crops that increased carbon storage in this soil, avoiding an annual net loss; similar results were reported in andosols in Chile at 20 cm depth (Dörner et al. 2011). In the case of pastures, a large component of detritus is incorporated directly into the mineral soil horizons

(Shoji et al. 1990). These findings were consistent with those of Novara et al. (2019), who found a positive effect of manure application during organic farming on SOC concentration by 53% in the 17–18 cm soil horizon over 21 years. Koga et al. (2017) reported that fertilizing of soils with composted cattle manure increased carbon stocks to a lesser extent than when manure application was mixed with inputs from crop residue, as has been done for years in the pastures in our study. This pattern was also observed in andosols under pastures compared with andosols under forest stands, where greater amounts of organic C are found (Kov et al. 2018). This phenomenon has been commonly attributed to fertilizer application and liming practices in grasslands, as well as to grass species that have denser rooting systems. Therefore, the positive relationship between the amount of total C contribution and the change in soil C reserves can be attributed to the differing management methods (Koga 2017). Given that agricultural sustainability is dependent on maintaining levels of or incorporating organic matter into soil (Weiner et al. 2010), any increases in soil C will almost certainly improve soil functioning and soil quality (Poulton et al. 2018). In relation to C, the conversion of forest to natural pastures and forage crops led to increased C storage, which could produce beneficial effects on soil biological activities and physical properties, such as water infiltration, aggregate stability, ease of tillage, soil fertility and regulation of nutrients (Jackson et al. 2017). Thus, improving soil management practices should allow maintenance and possible increase of soil C, avoiding further land degradation (Keesstra et al. 2016).

We found negative effects of change in land use in terms of biological indicators in the soil. In the conversion of forest to forage cropping, resistance of the soil microbial biomass, microbial activity and metabolic coefficient (qCO_2) were reduced in comparison with conversion of forest to natural pasture. The lower qCO_2 indicated the conversion to natural pasture promoted the formation of new microbial biomass and less C loss through respiration as compared with cropped soils; the higher input of C to the pasture system promotes an increase in soil microbial biomass, allowing greater efficiency in C utilization by the microorganisms (Kaschuk et al. 2011; Lopes et al. 2010). On the other hand, despite the fact that soil C increased with forage cultivation, it has been found that 30 years forage cultivation in andosols results in a decrease in the soil microbial biomass and affects its activity (Joergensen and Castillo 2001). The lower soil biological resistance with the change from forest to forage crop is related to the decrease or absence of mulch and the quantity and quality of organic material input to soils as well as the possible effects of ploughing every 5 years and weeding activities every 4 months. In this sense, less organic material input to soils promotes metabolic activity with greater energy costs for its maintenance and greater competition for nutrients (Kızılkaya et al. 2010; Royer-Tardif et al. 2010; Guillaume et al. 2016). To process added mature organic matter (compost) microorganisms consume a greater amount of energy (high microbial activity). Our results showed that conversion of forest to forage cropping reduced the soil resistance indicators related to the microbial community and its carbon assimilation process, as indicated by the decrease in the soil microbial coefficient and soil microbial biomass, results that have also been evident in other crops (Tilston et al. 2010).

The microbial coefficient (qM) was less resistant in the change from forest to forage cropping than in the change from forest to natural pasture; this change is associated with the effect of tillage and the type of agricultural inputs that affect the structure of the microbial community (Wakelin et al. 2009). When the microbial biomass is under stress with regular disturbance, this results in a reduced qM, which indicates a decrease in the efficiency of the heterotrophic microorganisms to convert organic carbon into microbial biomass. This ratio was found to be higher under an agroforestry system than under an organic and conventional system established on andosols (Paolini Gomez 2018). On the other hand, according to the results of Lopes et al. (2010) in native forests and pastures, the greater qM value may be due to the higher C content of the soil microbial biomass, suggesting appropriate conditions for microbial growth, facilitated by the input of organic matter of good quality (Sousa et al. 2015). Hence there was greater soil resistance by the biological indicators (microbial biomass, microbial activity, qM and qCO_2) in the change from forest to natural pasture because of the infrequent grazing periods, which allow enough time for the microbial community in the soil to re-establish after the intervention, thus recovering the activity and the diversity of microorganisms, reducing land degradation and achieving sustainable soil management (Griffiths et al. 2016). Additionally, in this soil, there is a higher concentration of organic carbon, because of the continuous supply of organic residues from diversified root systems and nutrients from urine and manure. These inputs may increase the resistance of the grassland soil microbial community, and therefore soil functions (Ng et al. 2015).

Conclusions

The evaluation of the sensitivity of the selected physicochemical and biological properties of the soil allowed us to understand the impact of the management practices associated with the use of the soil on its resistance. Even though significant changes in physical properties were evidenced, these remain within the characteristic ranges of the andosols, possibly due to the fact that the practices employed in forage cultivation and natural pasture are not intensive. For example, in natural pastures there is a low density of animals per hectare, agricultural practices are carried out by direct sowing and the dead material remains on the soil surface. In forage cultivation, planting was performed 6 times before evaluation, using ploughing and application of organic fertilizers. It appears that pH and soil C and N concentrations in soil were sensitive to land use changes, actually increasing following the change from forest to natural pasture and forage cropping; however, there was a reduction in microbial biomass and an increase in qCO_2 after conversion from forest to forage cropping, suggesting that the biological functions are less resistant than the physicochemical properties of andosols. Therefore, we suggest that evaluation of resistance of andosols to management change be carried out through the integration of physicochemical and biological properties, considering the variability in the degree of sensitivity that their properties present when faced with different management intensities.

In future studies a greater spatial coverage of soil samplings should be undertaken to take into account topographic factors that may influence changes in soil characteristics.

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Conflict of Interest

The authors have no conflict of interest to declare.

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