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Soil quality/health indicators in a disturbed ecosystem in southern Ecuador

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Abstract

Tropical ecosystems are under increasing pressure from changes in land use (Ch-LUs). These changes significantly alter the quality/health of the soil, thus minimizing the possibilities for further development and human well-being. This occurs in the buffer zone of the Podocarpus National Park (PNP), where the majority of the population has recently been affected by food insecurity. As a means of subsistence, peasant producers have implemented changes in land use to produce food that will improve their living conditions. In this context, the objectives of the study were: (i) to evaluate the effect of Ch-LUs on the main edaphic physical-chemical properties in a buffer zone of the Podocarpus National Park in Ecuador (PNP) and, (ii) to compare whether there is concordance between scientific knowledge and local knowledge with regards to soil fertility management indicators and practices. Soils were analyzed in the laboratory (bulk density (g cm^{-3}), texture, pH, and total carbon (%) and then compared with local knowledge through semi-structured interviews administered to farmers. The results revealed greater similarity between the uses of crops and pastures, compared to the use of forest, due to a greater alteration in the cultivated and pasture areas, presenting as changes within the soil quality indicators. By integrating the knowledge of the farmer with the scientist, it was shown that they do indeed identify with local indicators of soil quality visible in the field.

1. Introduction

Changes in land use (Ch-LUs) have become one of the causes of climate change at a regional and global level (Brovkin et al., 2004; Verburg et al., 2011). Ch-LUs are the main causes for the loss of soil quality/health, since they are directly related to biogeochemical processes (Foley et al., 2005) and decrease the capacity of biological systems to support and satisfy human needs (Vitousek et al., 1997; Foley et al., 2005). The main impacts of Ch-LUs are the reduction in recharge of aquifers, which produces an imbalance of surface runoff and causes for the loss of nutrients (Trucíos et al., 2011). They also modify some of the hydraulic properties (Aoki and Sereno, 2005), change the structure and bulk density (Jaiyeoba, 1995), alter the concentrations of organic matter (Guimarães et al., 2013), while the contents of nitrogen, phosphorus, and soil microorganism populations decrease and/or increase (Wang et al., 2019).

Historically in Latin America, the main causes of Ch-LUs are human interests driven by the expansion of economic activity and in the construction of infrastructure. For example, in the Amazon basin, CH-LUs are mainly driven by illegal logging, the expansion of agricultural activities, the use of uncontrolled fire for the conversion of natural forests into pastures and crop areas (Armenteras et al., 2019), road construction (Perazzoni et al., 2020) as well as due to the protection of livestock (*Bos taurus*) and other domestic animals from predators (de Lima et al., 2020). These activities cause disturbances in natural forests and protected areas that can lead to the collapse of these ecosystems (Mohd-Azlan et al., 2020). South America has one of the highest average erosion rates (3.53 Mg ha^{-1} year^{-1}) compared to other regions such as Africa (3.51 Mg ha^{-1} year^{-1}) and Asia (3.47 Mg ha^{-1} year^{-1}) (Borrelli et al., 2017). The main countries affected by these anthropic processes are Argentina (41.6%), Bolivia (37.8%), Brazil (19.8%), and Peru (5.9%) (Modernel et al., 2016). In Ecuador, Ch-LUs affect the Amazonian, coastal and Andean forests. These forests are threatened by conversion to pasture for livestock purposes and by the increase and intensification of conventional and/or ecological agriculture (Tapia-Armijos et al., 2015; Carrión-Paladines and García-Ruiz, 2016). Conventional agriculture causes soils to lose their ability to sequester carbon, along with a loss of vital nutrients (N, P, and K), and, subsequently, floristic diversity is lost over time (Reyna-Bowen et al., 2018).

Ch-LUs accelerate the migration of the rural population, and when the population does not migrate due to socioeconomic conditions, people are known to cut down forests to expand the agricultural frontier, since the assumption is made that with larger areas, they will achieve greater production and greater economic profitability (Gray and Bilsborrow, 2014; Gaglio et al., 2016). Although Ch-LU is due to the direct action of humans, in Ecuador few studies based on ancestral knowledge have been developed combining these activities (Ch-LUs) with studies of the physical-chemical properties of soils (e.g. Quichimbo et al., 2012). This type of research has been developed in other countries, such as Mexico (Barrera-Bassols and Zinck, 2003), Kenya (Barrios and Trejo, 2003), South Africa (Buthelezi-Dube et al., 2018), and Madagascar (Brinkmann et al., 2018). Therefore, it is important to start with this type of study since according to Danilo and Céspedes (2016), obtaining scientific data and data from local knowledge will help to determine the degree of soil degradation easily and practically and with an accurate assessment of its quality.

In some countries, it has been shown that the knowledge of local populations can influence soil quality. For example, farmers from Veracruz in Mexico know how to identify the main changes that occur due to anthropogenic alteration in the hydrophysical, chemical and biological properties of the soil (Pauli et al., 2016). Likewise, the farmers also know that Ch-LU causes sedimentation in rivers and reservoirs, deteriorates the quality of the water and they also recognize changes in hydrological patterns (Geissert et al., 2017). These indicators are measurable attributes that reveal the response of soil productivity or functionality to the environment and indicate whether soil quality improves, remains constant or decreases (Marinari et al., 2006). Likewise, Nezomba et al. (2017) suggest that it is currently essential to determine soil fertility indicators, not only at a scientific level (laboratory analysis) but also through local knowledge, which includes the participation of farmers. This will guarantee the sustainability of programs and projects that seek an improvement in the quality of the ecosystem, especially if anthropogenic pressures occur in priority areas such as the buffer zones (BZ) of national parks (Silori, 2008). Unfortunately, few studies of this type have been conducted in the BZs of Ecuador's national parks; such is the case with the Podocarpus National Park (PNP), where one of the few investigations carried out in the BZ is the work of Lozano and Bussmann (2005), who studied landslides caused by anthropic activities. Therefore, it is necessary to develop these investigations in Ecuador where the local population is involved, in order to identify problems or needs and thus make the best decisions for the sustainable management of natural resources in the BZs (Pauli et al., 2012).

The objective of this particular study consisted in evaluating the effects of Ch-LUs on some physical-chemical properties of the soil, in sectors located next to the buffer zone of the Podocarpus National Park (PNP) (Southern Ecuador). Also, a comparison was made between local knowledge and scientific knowledge, on the indicators and management practices of edaphic fertility, whose information could be used to develop soil management and conservation strategies.

2. Materials and methods

2.1. Study area

The research was carried out in the province of Loja, in the north-western BZ of the Podocarpus National Park (PNP), in southwestern Ecuador (4°05´07.38˝ south and 79°12´26.45˝ west and between 4°05´32.5˝ south and 79°12´25.39˝; Fig. 1). The area has a complex topography, due to the orogenic processes in progress, which created abrupt changes between valleys and mountain ranges (Fries et al., 2020) and belongs to the taxonomic classification of the Dystrudepts and Hapludolls soils, with subgroups within the Andic Dystrudepts and Andic Hapludolls which are characterized by having a sandy loam texture (Soil Survey Staff, 2014). The altitude varies from 2130 to 2378 m a.s.l.

The climate in the study area is temperate-equatorial sub humid (Ochoa-Jiménez et al., 2015), with an average annual rainfall of 1123.8 mm and an average temperature of 16.4°C (INAMHI, 2004–2013). Precipitation shows inter-annual variability (with a minimum of 752.7 mm and a maximum of 1848.1 mm; period 2004–2013) and a clear annual cycle with a main rainy season from October to April (austral summer) which registers more than 75% of the total amounts of annual rainfall, and a dry season from May to September (austral winter) (Fries et al., 2020) (Fig. 2a, 2b). The area is part of the tropical montane cloud forest (TM-cf) (Lozano, 2002). The composition of the tropical cloud forests in this part of Ecuador is very particular and different from the formations in the north of the country (Lozano et al., 2007). The study area contains a wide variety of land-use classes: forest areas (Aliso [*Alnus acuminata* Kunth], eucalyptus [*Eucalyptus globulus*], pine [*Pinus radiata*]), grazing areas (Kikuyu [*Pennisetum clandestinum* Hoechst Ex Chiov.] and ryegrass [*Lolium perenne* L.]), as well as agricultural polyculture areas (chard [*Beta vulgaris* L. var. cicla], tomato [*Solanum lycopersicum* L.], broccoli [*Brassica oleracea* L. var. italica], potato [*Solanum phureja* Juz. Et Buk.], among others). The economy of the local population is based mainly on agriculture and livestock, in which subsistence products predominate (Raes et al., 2017). The Ch-LU classes chosen as sampling sites have different uses and have steep slope characteristics (15% to 30%) (Kindu et al., 2013). These zones include disturbed forest (Df) by anthropogenic activities, mainly related to migratory logging or selective logging for the implementation of grasslands (Gl) and crops areas (Ca) (Tapia-Armijos et al., 2015).

2.2. Soil sampling and laboratory analysis

For each land use type, four 20 x 20 m sample plots (SP) were randomly installed (400 m^2 each, 4800 m^2 in total). From each SP, 5 soil samples were taken at two depths (5 samples at

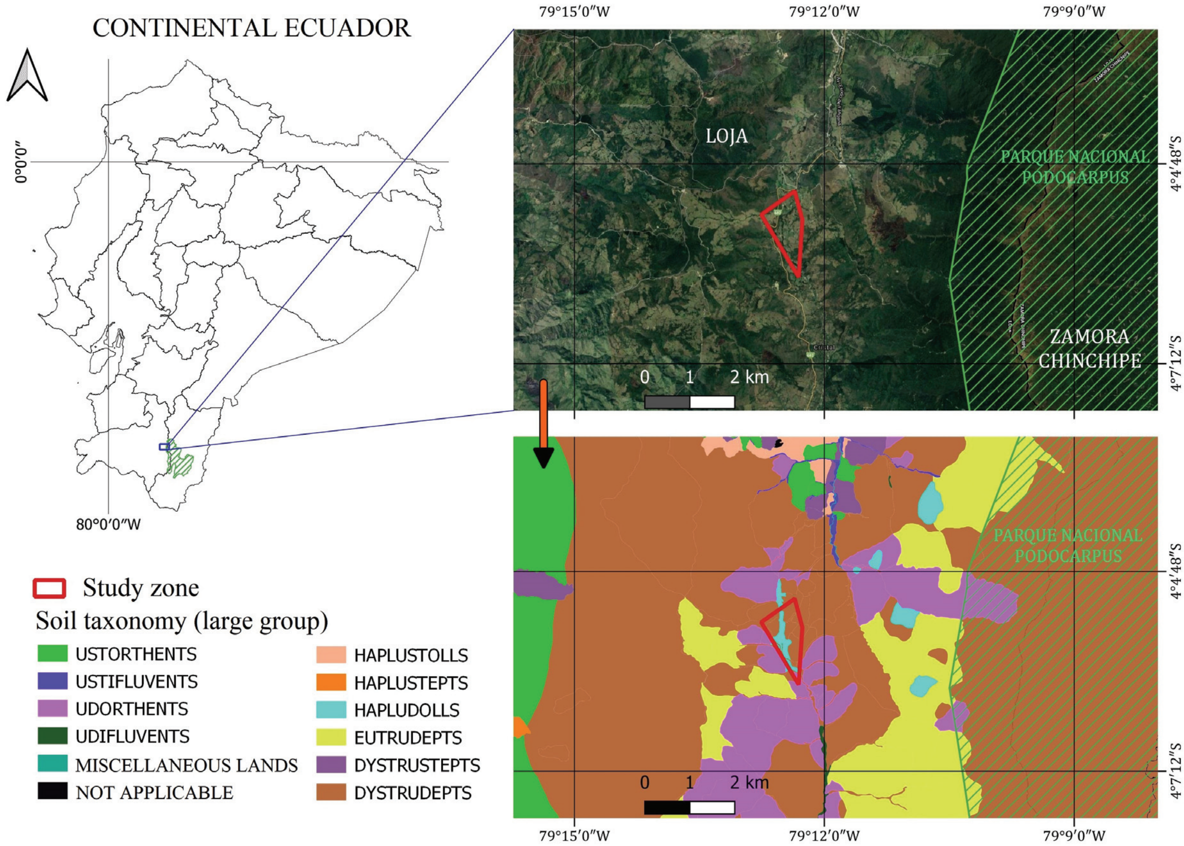

Fig. 1. Location of the study area in the BZ of the Podocarpus National Park (PNP) in continental Ecuador (left area painted blue). PNP and BZ enlarged (the area on the right painted in green corresponds to the PNP). The red polygon indicates the location of the study area in the BZ and on the soil taxonomy map

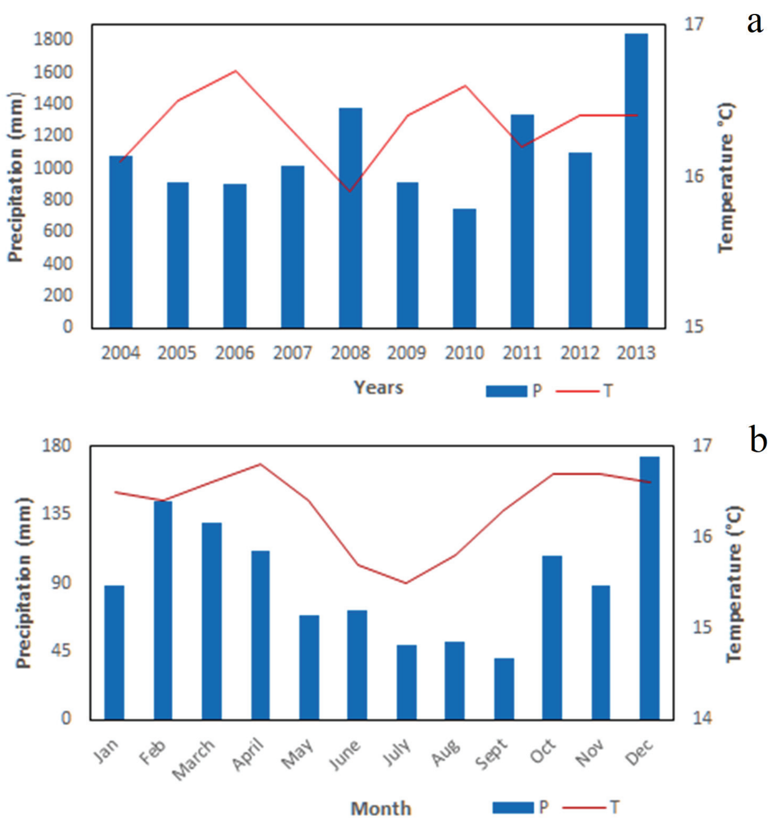

Fig. 2. Climograph of La Argelia station (M0033), province Loja – Ecuador (period: 2004–2013). a. Interannual climate graph; b. Monthly climograph

a depth of 0–10 cm and 5 samples at 10–20 cm). The samples were duly labeled and a total of 120 soil samples were obtained. For the analysis of the samples, the visible residues of the roots of the plants were eliminated and each one was sieved through a 2 mm mesh. The bulk density (Bd) was calculated utilizing the method of Sandoval et al. (2011) and the particle size distribution was determined by the hydrometer method (Bouyoucos, 1951). The color was determined in dry and wet soil using the Munsell Notation System proposed by Lin et al. (1999). The pH (soil/water ratio 1:2.5) was determined following standard methods. The total carbon content (TC) was determined by the ignition method that is based on determining the weight loss (g) of a soil sample when subjected to a high temperature in a muffle at 400°C, achieving the complete oxidation of organic matter (Dawis, 1974; La Manna et al., 2007).

2.3. Analysis of local and scientific knowledge

To determine local knowledge about soil quality/health and its relationship with scientific knowledge, information was collected through semi-structured individual interviews (Barrios et al., 2006; Dawoe et al., 2012) that were contrasted with the results of the physical-chemical analysis of soils (Table 1) (e.g. Carrión-Paladines et al., 2016; Buthelezi-Dube et al., 2018; Dollinger and José, 2018). The interviews consisted of 35 questions that were directed to two key groups; the first made up of workers from agroecological farms and farmers (46%) and the second group made up of soil science teachers and students (54%). The questions were multiple choice and open, to determine the general characteristics of the respondents, characteristics of the farm, and physical indicators and bioindicators of soil quality/health.

Table 1
Main questions and physical-chemical parameters of the soil used to compare the local knowledge to scientific knowledge.

Survey topics	Local Knowledge (Questions)	Scientific Knowledge (Physical chemical analysis of soils)	References
General characteristics of the respondents.	Name, age, gender, ethnicity, level of education, productive activity		Raes et al. (2017)
Characteristics of the peasant farm.	Type of farm activity		Cerdŕ et al. (2018); Raes et al. (2017)
	Native and exotic animals included in the system		
Soil quality/health indicators.	What kind of texture do you think your soils have?	Texture, color, bulk density, soil carbon, pH	Buthelezi-Dube et al. (2018)
	What color of soils is the best to determine its quality?		
	What color of the soil do we need to do agriculture?		
	How do you describe good soil?		
	Do you consider that the soils of your farm were previously more fertile than now?		
	Does stoniness influence soil quality?		
	Do you use the ease of workability of the soils as an indicator of its quality?		
	Do you consider that the depth of the soil is used to determine if it is of good quality?		
	Do you use the productive yield of crops as an indicator of soil quality?		
Bioindicators of soil quality/health.	Do you know plants on your farm that indicate that the soil is fertile?	Texture, color, bulk density, soil carbon, pH	Dollinger and José (2018); Kim et al., (2018); Kuria et al. (2018); Bezabih (2016); Tobita et al. (2015); Bizoza, (2012); Urgilés et al. (2014); Desbiez et al. (2004); Barrios and Trejo (2003)
	Do you know plants on your farm that indicate that the soil is infertile?	Texture, color, bulk density, soil carbon, pH	
Soil management.	Do you produce organic fertilizers on your farm?		Carrión-Paladines et al. (2016)
	Do you apply organic fertilizers on grassland and crops?		Carrión-Paladines et al. (2016)
	Do you use the traditional plow in the crop areas of your farm?		Cerdŕ et al. (2018); Raes et al. (2017)

2.4. Statistical data analysis

The data from the analysis of the physicochemical properties of the soil were subjected to an analysis of variance (ANOVA, F test, $p < 0.05$). The ANOVA test was performed separately for each soil depth (0–10 cm and 10–20 cm deep) (de Moraes et al., 2016). When the statistical analysis was significant, the means were compared using Tukey's post hoc test ($p < 0.05$). The categorical data referring to local knowledge of soil fertility were analyzed with descriptive statistics and, with the remaining information, tables, counting diagrams, and percentages were produced. Information on the physical and chemical properties of soils, as well as local knowledge, was calculated with the statistical software SPSS version 15.0 (SPSS Inc, Chicago).

3. Results and discussion

3.1. Physical-chemical properties of the different land uses

In Table 2 it can be observed that in the Bd between Ca and Gl there are no statistically significant differences (depth of 10–20 cm), however, these two land uses do have statistical differences concerning the Df at a depth of 0–10 cm; the latter presents the highest values. De Koning et al. (2003) found values relatively equal to this study (values between 0.77–1.3 g cm^{-3}) for the grasslands of northwestern Ecuador, which cover the entire province of Esmeraldas along with the most northwestern portion of the province of Pichincha. However, Hribljan et al. (2016) reported that in the paramos of Ecuador, the mean dry bulk density of mineral soil was 0.58 g cm^{-3} on average, values lower than those of this study; this may be because the degradation of organic matter is slower in high altitude areas (Gutiérrez-Salazar and Medrano-Viscaíno, 2019). These results indicate that the contributions of organic matter as well as the sustainable practices applied in the area such as crop rotation and the application of organic fertilizers (vermicompost, compost, among others) in the Gl and Ca in the study area, are contributing to a reduction in Bd at the soil surface.

The soils presented a texture of clay-sandy loam to sandy loam in the three land uses, which is generally good for agriculture (Table 2). However, it was observed that the percentage of sand has a small decrease in the Ca and Gl zones at the two depths studied, compared to Df. At a depth of 0–10 cm between Df and Gl there are statistically significant differences, but there are no statistical differences between Df and Ca; on the other hand, at the depth of 10–20 cm there are no statistical differences between Ca and Gl, but these two Ch-LUs differ with Df. Concerning the other fractions, the clay percentages in the three land uses and at a depth of 0–10 cm do not show statistical significance, while at a depth of 10 to 20 cm, the uses of Ca and Gl are similar where these two do show a statistically significant difference with the use of Df. Regarding the silt fractions, the three land uses in both depths (0–10 and 10–20 cm) are similar, showing no statistical differences between them (Table 2). These changes in soil texture (loss of sand) are probably due to the soil being exposed to the weather, activities such as plowing the land on slopes of up to 30% where there is much rain in the rainy months (Fig. 2) while due to wind speed, the soil may lose a fraction of sand as an effect of intensive erosion as demonstrated by previous studies (Giertz et al., 2005; Tellen et al., 2018). The land uses Ca and Gl have a lower content of sand and an increase in the content of clays (Table 2). Under these conditions, the soil structure is favored since it has been proven that clay and organic matter (SOM) are fundamental pillars of the structure; the clays that flocculate form stable domains and together with the SOM act as a bonding material between the mineral particles in the formation of the structure (Alvarado et al., 2015). Therefore, our results are consistent with those reported by Ochoa et al. (2017) who found that in agroforestry coffee crops located in the mountainous sectors of Vilcabamba, Malacatos, and Solanda (areas adjacent to those of this study) the soil textures are loamy-clay-sandy like those found in classes Ca and Gl. The soil in the three types of use presented mainly dark colors; wet 4/3 YR, wet 3/2 and 10YR very dark grayish brown.

Another edaphic property of the soil evaluated was pH, presenting moderately acidic values, with averages between 5.4 and 5.7 (Table 3). The depth of 0 to 10 cm did not present statistically significant differences, but there were statistical differences between the land uses at a depth of 10 to 20 cm. The lower pH values in the Ca and Gl in front of the Df may be due to the depletion of basic cations from crop harvesting and the continuous use of acid-forming fertilizers (Nega and Heluf, 2013). Additionally, changes in land use have been shown to cause pH values

Table 2
Main physical properties of the different land uses

Land use pattern	Bulk density (gcm^{-3})		Sand (%)		Clay (%)		Silt (%)		Textural class 0–10 cm	Textural class 10–20 cm
	0–10 cm	10–20 cm	0–10 cm	10–20 cm	0–10 cm	10–20 cm	0–10 cm	10–20 cm		
Crops (Ca)	0.9 ±0.2 ^{a}	0.7 ±0.1 ^{a}	55.4 ±10.1 ^{ab}	56.5 ±7.6 ^{a}	23.5 ±6.4 ^{a}	24.0 ±7 ^{b}	20.9 ±6.9 ^{a}	19.4 ±6.4 ^{a}	Sandy clay loam	Sandy clay loam
Grasslands (GL)	0.9 ±0.2 ^{a}	0.7 ±0.2 ^{a}	52.0 ±5.9 ^{a}	50.5 ±7.0 ^{a}	22.3 ±4.5 ^{a}	29.5 ±11.9 ^{b}	25.6 ±3.9 ^{a}	20.0 ±8.5 ^{a}	Sandy clay loam	Sandy clay loam
Disturbed forest (Df)	1.1 ±0.2 ^{b}	0.6 ±0.1 ^{a}	64.8 ±4.9 ^{b}	67.5 ±1.3 ^{b}	16.8 ±7.7 ^{a}	12.7 ±1.8 ^{a}	18.4 ±8.0 ^{a}	19.8 ±2.1 ^{a}	Sandy - loam	Sandy - loam

Explanation: Different letters mean significant differences (One way ANOVA; $P < 0.05$).

Table 3
Chemical properties of the different land uses

Land use pattern	pH		TC (%)	
	0–10 cm	10–20 cm	0–10 cm	10–20 cm
Crops (Ca)	5.4 ±0.5 [a]	5.3 ±0.6 [a]	1.2 ±0.2 [b]	0.8 ±0.2 [b]
Grasslans (Gl)	5.4 ±0.6 [a]	5.4 ±0.6 [a]	0.59 ±0.3 [a]	0.7 ±0.3 [b]
Disturbed forest (Df)	5.7 ±0,3 [a]	5.9 ±0.4 [b]	0.57 ±0.3 [a]	0.2 ±0.2 [a]

Explanation: Different letters mean significant differences (One way ANOVA; $P < 0.05$). C – soils carbon

to vary; for example, according to Thomson et al. (2015), due to anthropic activities such as the conversion of forests to crops or pastures, excessive logging, and management practices (use of fertilizers, burning, etc.), the pH generally changes as a result of these conversion processes. However, the pH ranges found in the study may be ideal for most crops to develop properly since it has been shown that at high acidity or alkalinity, nutrient supplies are not available to plants (Läuchli and Grattan, 2012).

The total carbon (TC) in the first 10 cm of soil is also affected by Ch-LUs. At this depth, there are statistically significant differences between the Ca (higher TC) versus the areas of Gl and Df (lower TC) (Table 3). The depth of 10 to 20 cm did not show significant differences between the Ca and Gl, but there were differences between these two compared to the Df. This higher concentration of TC in crops may be because agricultural soils are an important sink for this element, through the formation of organic matter (SOM) and the implementation of sustainable strategies for land management (Jarecki and Lal, 2003; Yang et al., 2003). One strategy that is carried out in the growing area is the implementation of organic farming. This system in recent decades has shown that by applying its strategies, C concentrations in surface soils increase (Gattinger et al., 2012; Han et al., 2018). A strategy implemented in the study area is the preparation and application of vermicompost in the crops. An example is the use of vermicompost based on the residues of the palo santo tree (*Bursera graveolens*) that have recently been produced in the area and that contain a proportion of up to 40.8% of TC, which could increase the organic matter content and C (Carrión-Paladines et al., 2016). Also, the biomass of crops (stubble) is incorporated in the first 10 cm of the soil, which according to previous studies, allows for an increase in the content levels of organic carbon, phosphorus, magnesium, and micronutrients (Clocchiatti et al., 2019; Kwiatkowski et al., 2020). On the other hand, the rotation of short-cycle crops such as potato (*Solanum phureja*), corn (*Zea mays*), beans (*Phaseolus vulgaris*), chard (*Beta vulgaris*), etc., together with the application of composted manure from cattle (*Bos taurus*), guinea pigs (*Cavia porcellus*) and chicken manure (*Gallus gallus domesticus*), double the organic carbon content of the soil (Stepien and Kobialka, 2019). There are other strategies to increase C in the soil, such as those mentioned by Henke et al. (2019), who demonstrated that the use of cover crops, such as the incorporation of green manure, leads to a significant increase in the C content in the soil. This has also been demonstrated with other horticultural crops such as those planted in the study area, as in the case of the tree tomato (*Solanum lycopersicum*), which significantly increases the presence of C in the soil (Carvajal et al., 2011).

Furthermore, these increases in the C reserve in the first centimeters of the soil could be associated with climatic factors such as precipitation and environmental humidity (Lal, 2005; Solano et al., 2018) (see Fig. 2). Generally, in Ecuador, high elevation areas such as those in the study area have lower temperatures and greater precipitation, so the decomposition of organic matter is slower (Fries et al., 2009) and therefore the C content remains longer in the soil. In this context, Solano et al. (2018) found that the C content increases along an altitudinal gradient, which shows that at higher altitudes the C contents are higher than at areas of low elevation. These findings could explain why there is a greater amount of C in the Ca, where precisely the strategies utilized in organic farming are applied. By contrast, in Df the C content was lower, possibly due to the anthropic activities that are being carried out in the area such as deforestation, creating roads, and cattle grazing. These activities alter the quality of the soil by promoting erosion and the loss of some macro and micronutrients in the surface horizons of the soil (Xiangbin et al., 2006; Sharma et al., 2010). Furthermore, the lower C reserve values in Df could also be due to edaphic factors such as texture (Table 2). Df contain greater amounts of sands and fewer amounts of clay, so they tend to contain less organic matter than clay (Solano et al., 2018). Jobbágy and Jackson (2000) showed that when clay content increases, there is better adsorption and stability of organic matter, which may be another reason for higher C content in crops.

3.2. Indicators of soil quality according to the perception of respondents

In Figure 3 you can see the main indicators of soil fertility according to the perception of the different respondents, both at the level of teachers and university students, as well as farmers. The informants mentioned that an important indicator to qualify a good soil is the texture (Fig. 3a). These results are consistent with the work of Buthelezi-Dube et al. (2018), who indicated that in Zalaze (a province of South Africa), in the Keiskamma alluvial plain, villagers and especially farmers also use soil texture as a quality indicator throughout the basin where they live. Likewise, Rogé et al. (2014), in their work showed that according to the farmers' knowledge, clay soils are the most productive in periods of drought, while sandy soils are the easiest to cultivate in wet years, but they are not very productive. However, in the buffer zone of the Podocarpus National Park, the soils presented textures ranging from sandy loam to clay loam, which, according to the respondents, are suitable for cultivation in both periods or seasons of the year (winter from October to April, when the weather is hot and rainy and summer from May to September, known as the dry season with little rain and cooler temperatures).

Another indicator is crop yield because for respondents this is an indicator that is directly related to their livelihoods since many of them market their products in the local market. Respondents in the study area reserve the most fertile land for cultivation, mainly using the land for vegetable crops and for pasture as well. With this local knowledge, farmers and teachers along with students contribute to landscape management where their conservation and production priorities overlap; in this way they ensure the success of the subsistence of this area, as happens in other regions of the world (Harvey, 2008). Likewise, our results coincide with those of Barrera-Bassols et al. (2006) who suggest that to determine soil quality, greater attention should be paid to local knowledge and understanding of the logic of local agricultural practices, since many farmers and agricultural technicians consider crop yields and the presence of macro soil organisms as a determinant of their quality/health (Fig. 3b). In this study, color was the other important indicator (dry, 4/3 10YR brown; and wet, 3/2 10YR very dark grayish brown). They identify black soils as "fertile soils" because of their organic matter content, and because they provide adequate conditions for the development of plant roots. Barrios and Trejo (2003) support these results since they indicate that generally, farmers and specialist technicians use color for the classification and evaluation of soil quality (Fig. 3c). Finally, both farmers, teachers, and students consider that stoniness is a key indicator of soil quality/health, as it can limit workability, especially when there are very large stones in the soil (Fig. 3c). However, according to their criteria, the soils in the study area are not very stony, which favors tillage and crop development as shown by previous studies (Buthelezi-Dube et al., 2018).

3.3. Local knowledge of farmers who use bioindicators of soil health

Farmers know some plants that use them as bioindicators of the quality/health of the soil. They know and use the best soils for planting crops that are produced in the area such as chard (*Beta vulgaris* var. Cicla), beans (*Phaseolus vulgaris* L.), carrots (*Daucus carota* L.), passion fruit (*Passiflora ligularis* L.), orange (*Citrus* X *sinensis*), and also some medicinal species such as chamomile (*Chamaemelum nobile* L.), rue (*Ruta graveolens* L.) and mint (*Mentha piperita* L.), and pastures for livestock feeding such as kikuyo (*Pennisetum clandestinum*).

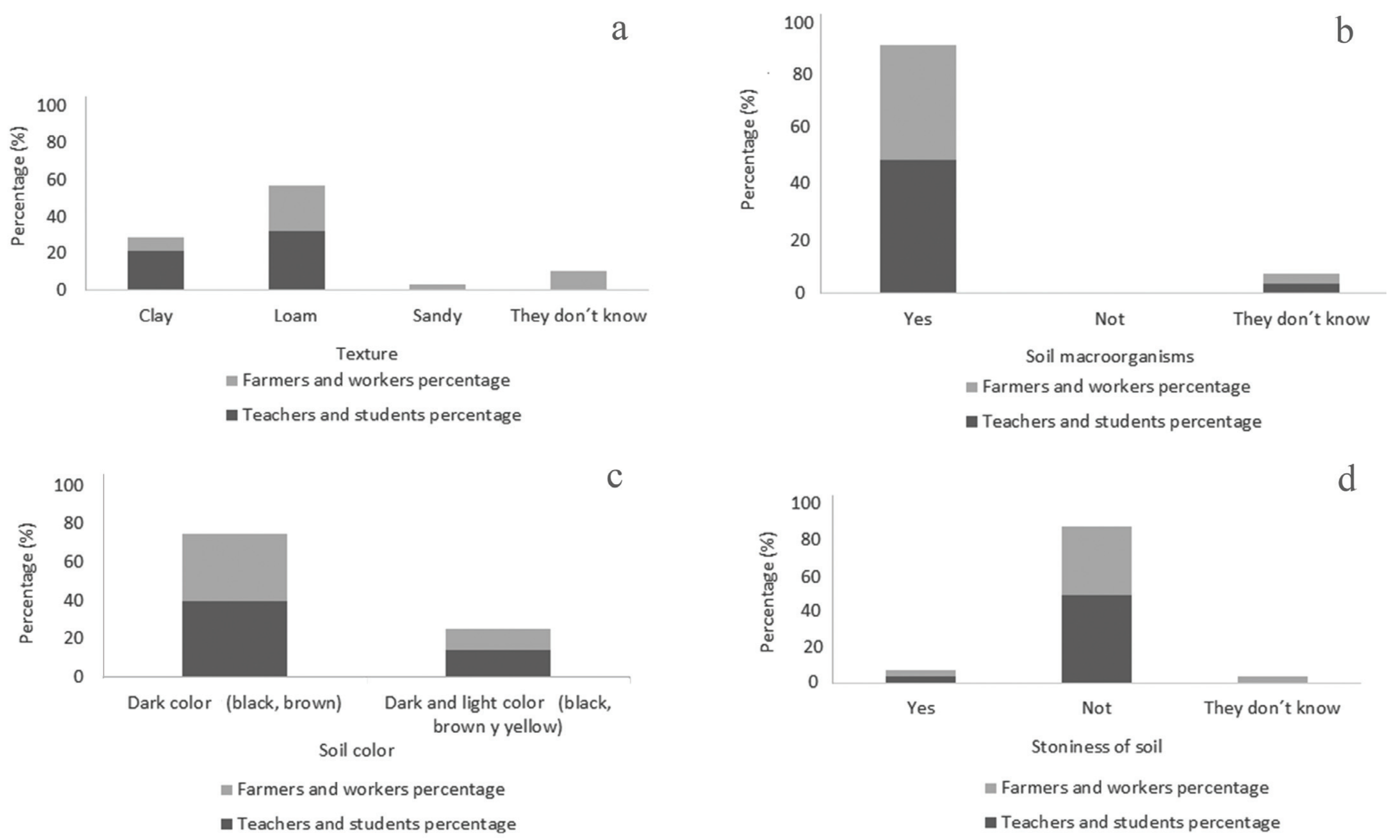

Fig. 3. Main indicators of soil fertility according to the perception of the respondents. a – texture; b – soil macroorganism; c – color; and d – stoniness of soil

The aliso tree (*Alnus acuminata*) was on the list of species that grow in good soils; these results coincide with that reported by Kuria et al. (2018) who indicated that in Uganda, farmers use this tree as a restorative species of soil quality/health. Besides, in other regions, it is widely used for the establishment of progressive benches and terraces on steep slopes (Bizoza, 2012), since this tree is also an excellent nitrogen fixer. According to Urgilés et al. (2014) and Tobita et al. (2015), this species is also used by subsistence farmers for the afforestation of degraded areas.

On the other hand, these results indicate that farmers also know that medicinal plants, fruit trees, and vegetables when implemented in agroforestry systems are beneficial to improve soil quality/health (Table 4). For example, Dollinger and José (2018), demonstrated that agroforestry has the ability to: i) enrich soil organic carbon unlike monoculture systems, ii) improve soil nutrients and fertility due to the presence of trees in the system, and iii) improve microbial dynamics in the soil, which would positively influence health and quality.

According to the farmers, they also know the plants that indicate poor soil quality; for example, when they see the growth of dumarin (*Tibouchina laxa* [Desr.] Cogn.), llashipa (*Pteridium aquilinum* L. Kuhn), eucalyptus (*Eucalyptus* sp.), and cow tongue (*Dracaena trifasciata*) for them they are indicators of bad soil quality. However, only Barrios and Trejo (2003) have also reported that farmers associate llashipa (*Pteridium aquilinum*) with poor soils, therefore, it is important to deepen the study to include other plants reported by farmers as indicator species of degraded soils. In this context, other species were mentioned by Desbiez et al. (2004) and Bezabih (2016) who reported that farmers believe that some poaceae such as *Cyanodon dactylon* L., *Pennisetum clandestinum* and *Brachiaria ramose* L, are indicators of quality/health, and are used in degraded soils. According to Kuria et al. (2018) when these plants are used in degraded soils, they experience levels of water stability in the soil (when there is water stress) and also extract high amounts of the dehydrogenase enzyme, which facilitate oxidation-reduction reactions of various substrates in the soil, leading to its recovery. Other benefits of these plants have also been determined, since they have synergistic effects with organic amendments, for example, which indicates that after chemical stabilization, they could improve the physical and biological properties of the soil (Kim et al., 2018).

Finally, with these results, we maintain that the perceptions of the local population, combined with scientific knowledge, are important in the development of agroforestry programs since they allow for the adequate management of soil resources and with this, agricultural productivity could be increased while protecting the biodiversity of communities living near national parks. These strategies could reduce threats to the natural habitat, since they integrate the need of rural communities with the conservation of the soil and the environ-

Table 4
Most important plant species used as local indicators of soil quality.

Common name	Scientific name	Botanical family	Plant type	Soil type
Kikuyo	*Pennisetum clandestinum*	Poaceae	Herbaceous	Fertile
Chine	*Urtica urens*	Urticaceae	Herbaceous	Fertile
Aliso	*Alnus acuminata*	Betulaceae	Tree	Fertile
Menta	*Mentha piperita*	Lamiaceae	Herbaceous	Fertile
Ruda	*Ruta graveolens*	Rutaceae	Secondary shrub	Fertile
Manzanilla	*Chamaemelum nobile*	Asteraceae	Herbaceous (medicinal)	Fertile
Naranja	*Citrus X sinensis*	Rutaceae	Tree	Fertile
Granadilla	*Passiflora ligularis*	Passifloraceae	Climbing plant	Fertile
Higo	*Ficus carica*	Moraceae	Tree	Fertile
Poroto	*Phaseolus vulgaris*	Fabaceae	Climbing plant	Fertile
Acelga	*Beta vulgaris var. cicla*	Amaranthaceae	Leaves	Fertile
Zanahoria	*Daucus carota*	Apiaceae	Plant root	Fertile
Dumarin	*Tibouchina laxa*	Melastomataceae	Bush	Infertile
Llashipa	*Pteridium aquilinum*	Dennstaedtiaceae	Bush	Infertile
Eucalipto	*Eucalyptus globulus*	Myrtaceae	Tree	Infertile
Lengua de vaca	*Rumex crispus*	Polygonaceae	Herbaceous	Infertile
Mora	*Rubus rubutus*	Rosaceae	Bush	Infertile
Lagula	*Rumex tolimensis*	Polygonacae	Herbaceous	Infertile
Pedorrera	*Ageratum conyzoides*	Asteraceae	Herbaceous	Infertile

ment, to contribute to the sustainable management of the land while conserving traditional knowledge that may be lost over time (Harvey, 2008).

3.4. Soil evaluation with narratives of the interviewees

In particular, respondents noted a change in soil conditions, depending on its use and fertility management. For the inhabitants of the buffer zone of the PNP, to maintain the quality/health of the soil, the management is carried out mainly by plowing before sowing, providing SOM made with the waste of their animals and farm plants, taking advantage of kitchen waste and diversifying planting. For example, some ranchers and farmers close to the PNP mention:

"By keeping cattle in stables, manure is wasted and urea is lost from the cattle's urine. In the morning it is milked; it takes about 3 or 4 days according to the grass that there is and the soil is fertilized. This for me is more comfortable".

"*I grow different plants ... I have different types of potatoes, tree tomatoes to see which one produces the best for me… So, the plant that produces the best and develops here on this earth, this plant I will continue to sow*".

In the work area of the agricultural students, there are pasture areas for livestock feeding, alfalfa forage plots (*Medicago sativa*) for guinea pig feeding (*Cavia porcellus*), and short-cycle demonstration plots of legumes. Some of them mentioned:

"*We have a small tractor where we first plow the soil so that it is looser and allows greater aeration... and we proceed to place a fertilizer as a base as we always try to focus on organic use*" (Agricultural student).

"*We apply growth-promoting bacteria; fertilization of soils with organic manure; planting of plants in hydroponic forage system; we sow alders in fences, we delimit pastures; association of crops and drains*" (Professor of Agricultural).

4. Conclusions

The Ch-LUs evaluated here revealed greater similarity in their physicochemical properties between the uses of crops and pastures, when compared to the forest land use. This is due to a greater alteration in the cultivated and pasture areas, presenting significant statistical differences. By integrating the farmer's knowledge, it was possible to verify that they use local soil quality indicators which are visible to them in the field. Thanks to the ancestral knowledge acquired, they know the physical parameters such as texture and color and also identify the soil indicator plants based on the yield, thus managing to know which soils are suitable for cultivation and which plants will give good crops. This bi-directional knowledge, in which scientific knowledge is combined with local knowledge, could create a new approach that will become a basis for the development of local soil quality/health assessment systems. It is essential to maintain this new approach that combines agro-productive systems with the conservation of biodiversity in the buffer zones of the Podocarpus National Park so that the farmers of this protected area contribute directly to the conservation of the soil and other natural resources.

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