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Traditional knowledge on soil management and conservation in the inter-Andean region, northern Ecuador

Conocimiento tradicional sobre manejo y conservación del suelo en la región interandina, norte del Ecuador
Conhecimento tradicional sobre gestão e conservação do solo na região inter-Andina, norte do Equador

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ABSTRACT

Local farmers' knowledge of edaphic fertility indicators is a decisive factor for decision making and sustainable soil management. Thus, the purpose of this study was to determine soil fertility indicators according to the criteria of small farmers and contrast it with scientific knowledge. A field study was developed in northern Ecuador, where 95 semi-structured surveys were applied to farm owners in the Andean and Subtropical zones. Each questionnaire grouped several questions with topics such as plant indicators of soil fertility, physical indicators of soil fertility, forms of soil degradation and conservation strategies, as well as the acquisition of knowledge over time according to farmers' perception. Farmers consider that crops are indicators of soil fertility, while the presence of "weeds" indicate poor soils. Additionally, characteristics like color, texture, stoniness, depth, the presence of macrofauna and crop yield indicated soil fertility. Also, farmers are aware of the soil's contamination and of conservation strategies available to avoid this; however, since their main objective is to improve crop yield and not precisely soil conservation, they do not always apply these strategies. Some of these practices are transmitted from one generation to the next and are at risk of being lost, hence the importance of integrating farmers' perception and scientific knowledge to generate guidelines for sustainable soil management.

RESUMEN

El conocimiento local de los agricultores sobre los indicadores edáficos de fertilidad es un factor decisivo para el manejo sostenible del suelo. Por lo tanto, el propósito de este estudio fue determinar los indicadores de fertilidad del suelo según los criterios de los pequeños agricultores y contrastarlos con el conocimiento científico. Se desarrolló un estudio de campo en el norte de Ecuador, donde se aplicaron 95 encuestas semiestructuradas a propietarios de fincas en las zonas andinas y subtropicales. Cada cuestionario agrupó varias preguntas con temas tales como: plantas indicadoras de la fertilidad del suelo, indicadores físicos de la fertilidad edáfica, formas de degradación y estrategias de conservación, así como la adquisición de conocimientos a lo largo del tiempo según la percepción de los agricultores. Los productores consideran que los cultivos son indicadores de la fertilidad del suelo, mientras que la presencia de "malezas" indica suelos pobres. Adicionalmente, las características como el color, la textura, la pedregosidad, la profundidad, la presencia de macrofauna y el rendimiento del cultivo indican la fertilidad del suelo. Los agricultores son conscientes de la contaminación del suelo y de las estrategias de conservación disponibles para evitar esto; sin embargo, dado que su objetivo principal es mejorar el rendimiento de los cultivos y no precisamente la conservación del suelo, no siempre aplican estas estrategias. Algunas de estas prácticas se transmiten de generación en generación y corren el riesgo de perderse, de ahí la importancia de integrar la percepción de los agricultores y el conocimiento científico para generar pautas para la gestión sostenible del suelo.

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RESUMO

O conhecimento local dos agricultores acerca dos indicadores de fertilidade do solo é um fator decisivo para a gestão sustentável do solo. Assim, o objetivo deste estudo foi determinar indicadores de fertilidade do solo de acordo com os critérios de pequenos agricultores e compará-los com o conhecimento científico. Foi realizado um estudo de campo no norte do Equador, onde se fizeram 95 inquéritos semi-estruturados a proprietários de quintas nas zonas Andinas e subtropicais. Cada questionário agrupou várias perguntas com temas como: plantas indicadoras da fertilidade do solo, indicadores físicos de fertilidade do solo, formas de degradação e estratégias de conservação do solo, assim como a aquisição de conhecimentos ao longo do tempo de acordo com a perceção dos agricultores. Os agricultores consideram que as culturas são indicadores da fertilidade do solo, enquanto a presença de infestantes indica solos pobres. Além disso, características como cor, textura, pedregosidade, profundidade, presença de macrofauna e o rendimento da cultura indicam a fertilidade do solo. Os agricultores estão conscientes da contaminação do solo e das estratégias de conservação disponíveis para a evitar; contudo, uma vez que o seu principal objetivo é o de melhorar a produtividade das culturas e não apenas a conservação do solo, estas estratégias nem sempre são aplicadas. Algumas destas práticas são transmitidas de geração em geração e estão em risco de se perder, daí a importância de integrar a perceção dos agricultores e o conhecimento científico para criar diretrizes para a gestão sustentável do solo.

KEYS WORDS
Andosols, farmer's perception, ethnopedology, soil conservation, plant indicators, soil fertility.

PALABRAS CLAVE
Andosoles, percepción de los agricultores, etnopedología, conservación de suelos, plantas indicadoras, fertilidad del suelo.

PALAVRAS-CHAVE
Andossolos, perceção dos agricultores, etnopedologia, conservação do solo, plantas indicadoras, fertilidade do solo.

1. Introduction

The goal of ethnopedology is to rescue the ancestral knowledge that allows the evaluation, classification and understanding of the management of soil resources, according to the perception of local farmers (WinklerPrins and Sandor 2003). This type of knowledge has been developed for centuries mainly in places closely associated with the major centers of plant domestication in the world (e.g. China, Egypt, India and Mexico) (Barrera-Bassols and Zinck 2003). Ethnopedology, the product of farmers' observation and experimentation, is transmitted from generation to generation. It is subject to continuous changes by different factors such as climate, latitude and soil type. Over time, this ancestral knowledge becomes local knowledge (Barrera-Bassols and Zink 2003; Barrios and Trejo 2003). For example, for indigenous people, local knowledge is the basis for making daily decisions; this empirical knowledge is part of their cultural system, resource management practices and their interaction with the natural surroundings, and is the baseline for sustainable development in the rural and local environment (Lambi and Lindemann 2012). Ethnopedology is also subject to the pressures of globalization and modernity (Vencill et al. 2012; Cheshire and Woods 2013); in most regions, ethnic groups have been affected by the erosion of their culture (Sujarwo et al. 2014) or, at worst, their culture has disappeared, having opted for a dominant culture's knowledge (Fentiman and Zabbey 2015). Andean culture is an example of such cultural erosion, hence, it is important to verify and value the knowledge of Andean peoples (Sandor and Furbee 1996).

For many years, indigenous people and later mestizo people have preserved these practices, however, this local knowledge has not been historically reflected in the investigation of soil science (Yaalon and Berkowicz 1997). Nevertheless, in the last decades traditional knowledge has been recognized for its practical value and its contribution to the rational and sustainable management of soil (Nath et al. 2015). Barrera-Bassols et al. (2009) demonstrated that the integration of ethnopedology, in many countries and ethnic groups, helps address practical issues and provides culturally acceptable solutions appropriate within local contexts. In ethnic groups that preserve their traditional knowledge in soil management, like in South Africa, Madagascar (Buthelezi-Dube et al. 2018) and India (Nath et al. 2015), research on ethnopedology has evidenced the importance of such knowledge in the development of sustainable agricultural practices (Fairhead et al. 2017). The use of polycultures, aquatic plants, faique (*Vachellia macracantha*) and other legumes, alders (*Alnus acuminata)* and other trees, for instance, improve the contribution of organic matter and nutrients to the soil (Crews and Gliessman 1991; Avendaño-Yáñez et al. 2017), maintaining healthy soils for a longer time. Many studies have found positive correlations between traditional and scientific knowledge; for example, Buthelezi-Dube et al. (2018) demonstrated with laboratory analysis (chemicals) that the soils had a red color due to the presence of iron, however, this coincides with the comprehensive understanding of the farmers who also associated the color with the good drainage they have. On the other hand, there are also studies in which the results differ and there are knowledge gaps, in particular on the use of indicator plants (Omari et al. 2018).

In Latin America, some examples of case studies in ethnopedology have been conducted in Venezuela, Colombia and Honduras (Barrios and Trejo 2003). However, as far as we know, for the inter-Andean region of Ecuador, there are no studies that take traditional knowledge into account for soil management and conservation, hence, research on this topic is needed. Understanding the complex knowledge system of the local people with regards to their land and soil resources will help to effectively address local needs of resource use (Barrera-Bassols and Zinck 2003; Brinkmann et al. 2018). Furthermore, since there is a tendency towards an increase in the rates of deforestation, as well as forest fires and the indiscriminate use of pesticides, it is important to analyze subsistence agriculture that is based on ethnopedology, since it is the common denominator in many local economies (Pan et al. 2007; Armenteras et al. 2017). Therefore, the objective of this study was to determine soil fertility according to smallholder farmers' criteria and contrast them with scientific knowledge. For this purpose, farmers' criteria were obtained by applying a survey and semi-structured interviews. In addition, geo-referenced information on the main physical and chemical properties of the soils was used to contrast whether there is a similarity or difference between local and scientific knowledge. This information is especially important when it refers to soil management and conservation in agricultural systems with limited resources, which are progressively expanding.

2. Materials and Methods

2.1. Study area

The study was carried out in the two climatic zones, Andean zone (Quiroga) and subtropical zone (Peñaherrera and Plaza Gutiérrez), province of Imbabura in north-central Ecuador (**Figure 1**). Inhabitants are predominantly mestizos, with a low proportion of Quechua and Afro-Ecuadorian indigenous people.

In general, the soils of the study area are predominant Andisols, Mollisols and Inceptisols with poorly developed horizons (**Figure 1**). Most of these soils are covered by a thick layer of volcanic ash, which is characterized by low bulk density, high moisture retention, being rich in organic matter and having high phosphate retention (Zebrowski et al. 1997; Moreno et al. 2018).

Quiroga, considered a high Andean zone, is located in the foothills of the northern Andes of Ecuador, between 2480 and 3440 m a.s.l. (791860.63 E and 32824.82 N). Rainfall varies from 1100 to 1300 mm/year and temperature from 9 ºC to 15 ºC (Autonomous Decentralized Government of Quiroga - GAD of Quiroga 2015). The geology is characterized by volcanic tuff rocks, basaltic lavas and breccias (from the Piñan formation), pyroclastic rocks, lahars and lava flows (Cotacachi volcano formation, Cuicocha volcano formation, Cotopaxi volcano formation), shale, limestone and volcanoclastic rocks (Yunguilla formation) (Autonomous Decentralized Government of Quiroga - GAD of Quiroga 2015). The area is classified as very a)

b)

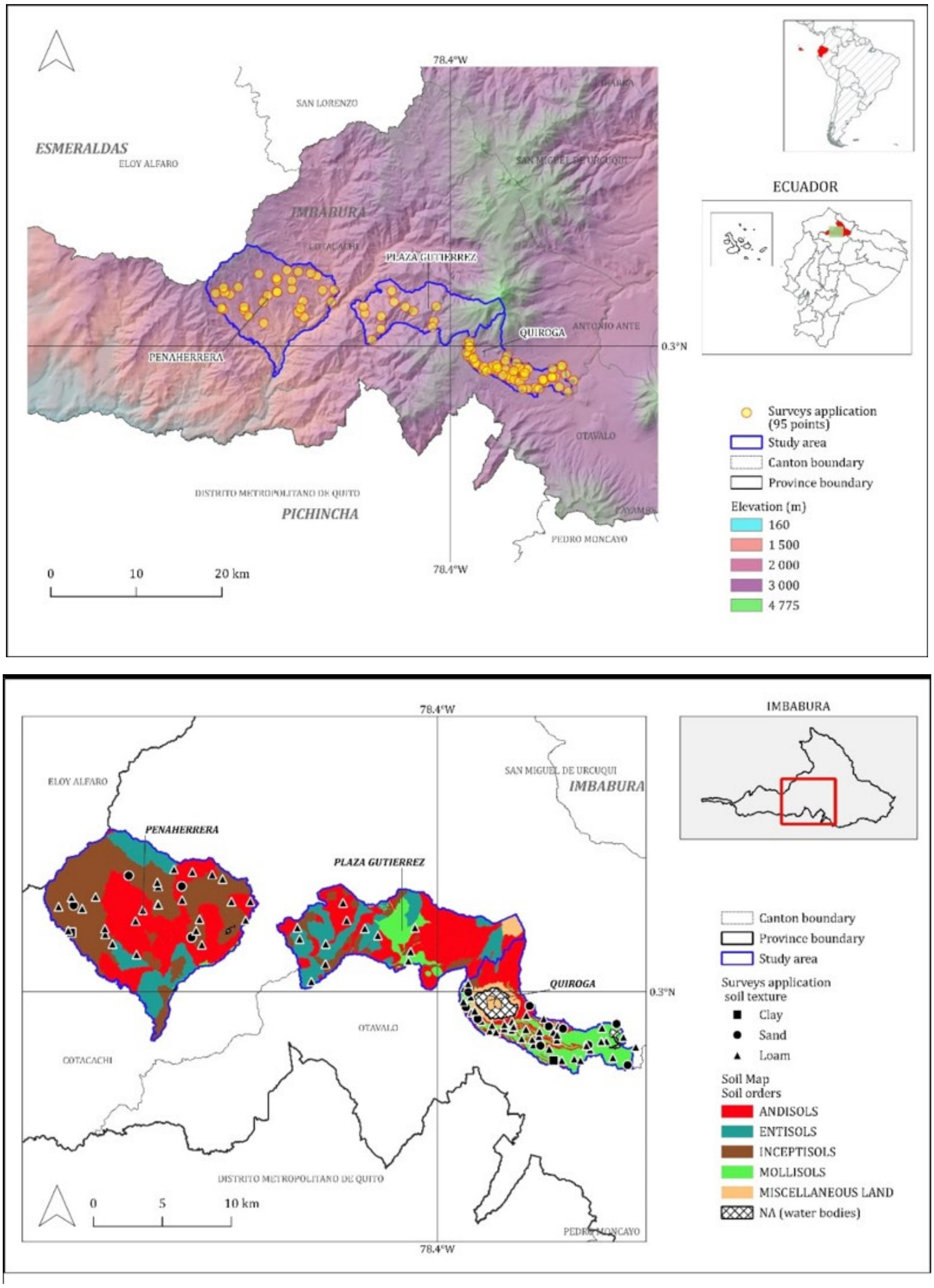


Figure 1. Location of the study area in the north-central inter-Andean region of Ecuador. a. Digital Elevation Model (DEM) of Cotacachi canton where the study areas Quiroga, Peñaherra, and Plaza Gutiérrez are located with blue boundaries. The yellow circles correspond to the place where the surveys were carried out. b. Soil taxonomy map of the contrasting zones (MAG 2019; Soil Survey Staff 2006).

humid montane forest (bmh-M). This vegetation partly belongs to the upper limit of the so-called mountain brow, which is characterized by a high incidence of fog and humidity (Cañadas 1983). The study area is mainly occupied by small farmers who manage mainly short-cycle crops.

Peñaherrera (775834.18 E and 40816.83 N) and Plaza Gutiérrez (779413.29 E and 38111.89 N) are located in the Toisán mountain range, in the foothills of the Ecuadorian Andes, at an altitude between 1181 and 3490 meters above sea level. Annual precipitation ranges from 500 mm to 1000 mm/year. It is characterized by humid mesothermal subtropical and humid mesothermal equatorial climates with annual average temperatures of 25 ºC. In general, the soils are of volcanic origin, with silty and sandy deposits, as well as being rich in organic matter with slightly acidic pH, well drained and of medium fertility, with moisture retention of 20-50%. The dominant vegetation types are primary and disturbed secondary forest (Autonomous Decentralized Government of Peñaherrera 2015; Autonomous Decentralized Government of Plaza Gutiérrez 2015). Small-scale agricultural production, grazing and conservation are the main land uses in the area.

2.2. Collection of local knowledge

In the two climatic zones (Andean zone [Quiroga] and subtropical zone [Peñaherrera and Plaza Gutiérrez]), ethnographic and ethnopedological research was conducted to acquire local information about soils. Different techniques were used, including a semi-structured survey of 35 question and semi-structured interviews to explore local soil knowledge about soils. They were applied to 95 participants who are legal landowners. The questions were grouped into five themes following the methodology described in Barrios et al. (2006) and Dawoe et al. (2012). The main questions of the survey are presented in **Table 1**.

Table 1. Main questions of the survey applied to farmers in the study areas

Topics	Questions of survey
General information	Province, zone (Andean or subtropical), geographical coordinates, gender, age, level of education, economic activity. What animals do you own on the farm? Are the soils of your farm intended for? What do you consider to be the main problems to produce?
Soil fertility indicators	Do you consider your soil to be: clay, sandy, neither very sandy nor very clayey? Are the soils of your farm: deep, shallow? Are your soils very stony? Yes, no Are your soils easy to work with? Yes, no Is your soil colored? Black, brown, yellows, red, others How do you recognize soils with high organic matter? Do your soils have worms or other types of living organisms? Which? Do your soils give good yields? What plants grow on poor soils? What plants grow in fertile soils?
Soil contamination and conservation strategies	What do you consider to be the main sources of soil contamination? Chemical fertilizers, organic fertilizers, pesticides, garbage, other. What strategies do you use to conserve the soil? Fallow, tree planting, incorporate crop residues, associated crops, incorporate animal manure, terraces, weeding, gabion wall, others. Why do you use (describe) them?
The acquisition of knowledge over time	How did you learn about soil management? Did your relatives (parents, grandparents) manage the farm in a way: Similar to you, Different from you? Do you consider that the soils of your farm used to be more fertile than now? Why?

2.3. Comparison with the main physical-chemical properties of the soil

Surveys were georeferenced to shape file points using the Spreadsheet Layers plugin (Camptocamp 2020) in the open-source software QGIS 3.12.2-București (QGIS Development Team 2020) (**Figure 1**). With this information, a comparison was made between local knowledge and scientific knowledge as has been done in previous research (Brinkmann et al. 2018; Dawoe et al. 2012). The comparison consisted of analyzing the taxonomy, texture, color and soil organic carbon content (T ha^{-1}), which allowed the respective discussion maps to be produced.

2.4. Data analysis

Data collected was subjected to descriptive analysis of simple proportions using the SPSS Version 24.0 statistics software. The frequency distribution for all variables was calculated and the two-way Chi-square test (χ^2) was used to see the uniformity among the respondents from the evaluated areas (Andean and subtropical zone), with difference level $p < 0.05$. In the case of the forms of contamination and soil conservation strategies, descriptive statistics were performed, tabulating the data in percentage, because they had 2, 3 or more options that respondents selected.

3. Results and Discussion

3.1. Characteristics of the farmers

Of the 95 farmers interviewed, 53.7% were men and 46.3% were women (**Table 2**). The age of the respondents ranged from 35 to 70 years, with an average of 43 years. A significant proportion of 48.8% had at least primary education and 35.7% had formal secondary education. In the study area, only 2% had a university education. This reality is repeated in the rural populations of most South American countries, as is the case in Colombia, where only 2.1% of people residing in rural areas have university or postgraduate education (Ministerio de Educación Nacional de Colombia 2018). The majority of the rural population is engaged in agriculture (72.6%). These data are relatively similar to those recorded for the country as a whole, which shows that 62% of the adult rural population works in agriculture (Ferreira et al. 2014; Requelme and Bonifaz 2012). Agricultural and livestock production constitutes the main source of income for the population living in the study area. The data from the two zones (Andean and subtropical) coincide with that reported by Berdegué and Fuentealba (2011), where they indicated that in Ecuador family farming comprises 88% of all farms and 41% of agricultural land. Furthermore, in the two study sites, men spend more time on these activities than women (27.4% and 6.3%, respectively); however, 63.2% of agricultural activity is shared among all family members. Again, this trend is similar at the national level where 88 % of the Ecuadorian population is engaged in agricultural activities.

On the other hand, there were no significant differences among farmers in terms of economic activity and knowledge of soil quality (texture, soil depth, presence of soil organisms, and workability). However, with the soil color parameter and on past soil quality there were significant differences. Therefore, the research communities were considered to be demographically quite similar in terms of household characteristics and certain soil quality identification parameters, except for soil color, which differed among all respondents (**Table 1**).

3.2. Plant species as fertility and infertility indicator

Figure 2 describes annual and perennial crops that are used by farmers as bio indicators of soil health. These results coincide with other research where the use of Andean plants as indicators of soil quality has been reported (Barrios and Trejo 2003). In the Andes, native plants are a means by which farmers classify the soils of their farms (Barrios and Escobar 1998). According to farmers, fertile soils of Andean zone are characterized mainly by the cultivation of *Zea mays, Phaseolus vulgaris* and *Vicia faba*; according to the GAD of Quiroga (2015), 61.7% of this parish grow crops such as *Zea mays, Solanum tuberosum, Phaseolus vulgaris, Hordeum vulgare* and vegetables, destined for self-consumption (40%) and for selling (60%). A smaller percentage cultivate medicinal plants, used mostly by midwives and "Yachac", who are people or spiritual guides that use these plants for curative purposes. In contrast, in Plaza Gutierrez and Peñaherrera the main

Table 2. Chi-square analysis of differences between surveyed farmers in the study area

Characteristic	Andean zone %	Subtropical zone %	X^2 value	Significance
Gender				
M	26.3	27.4	1.453	0.228
F	28.4	17.9		NS
Age of respondents				
17-35 years	2.1	0	3.383	0.496
35-55 years	23.2	25.3		NS
55-70 years	16.8	10.5		
> 70 years	4.2	2.1		
Education level				
Primary	24.2	24.2	7.564	0.56
Secondary	18.9	16.8		NS
Superior	1.1	0.9		
None	11.6	2.1		
Economic activity				
Agriculture	36.8	35.8	2.491	0.288
Livestock	7.4	2.1		NS
Fishing	0	0		
Mining	0	0		
Others	10.5	7.4		
Who spends more time in agriculture or livestock farming?				
F	2.1	4.2	2.57	0.463
M	13.7	13.7		NS
The whole family	37.9	25.3		
Time of cultivation				
< 5 years	6.3	1.1	5.695	0.127
5-10 years	14.7	10.5		NS
10-20 years	12.6	18.9		
> 20 years	21.1	14.7		
Texture				
Sandy	10.5	4.2	1.849	0.397
Loam	43.2	35.8		
Clay	1.1	0.9		
Soil depth				
Surface soils	21.1	15.8	0.129	0.719
Deeper soils	33.7	29.5		NS
Soil stoniness				
Yes	14.7	11.6	0.22	0.882
No	40	33.7		NS
Workability				
Yes	33.7	29.5	0.129	0.719
No	21.1	15.8		NS

Color				
Black	11.7	6.4	10.391	0.016
Brown	28.7	33		S
Reddish	0	3.2		
Yellow	0	0		
White	13.8	3.2		
Presence of soil organisms				
Yes	48.4	44.2	2.927	0.87
No	6.3	1.1		NS
Do your soils give good yields?				
Yes	43.2	41.1	2.48	0.115
No	11.6	4.2		NS
Knowledge acquisition				
Relatives (parents, grandpa-rents, siblings)	48.4	41.1	0.125	0.724
Other (training, self-learning)	6.3	4.2		NS
Were the soils more fertile in the past or are they more fertile today?				
Yes	31.6	36.8	6.12	0.013
No	23.2	8.4		S

NS = not significance; S = significance.

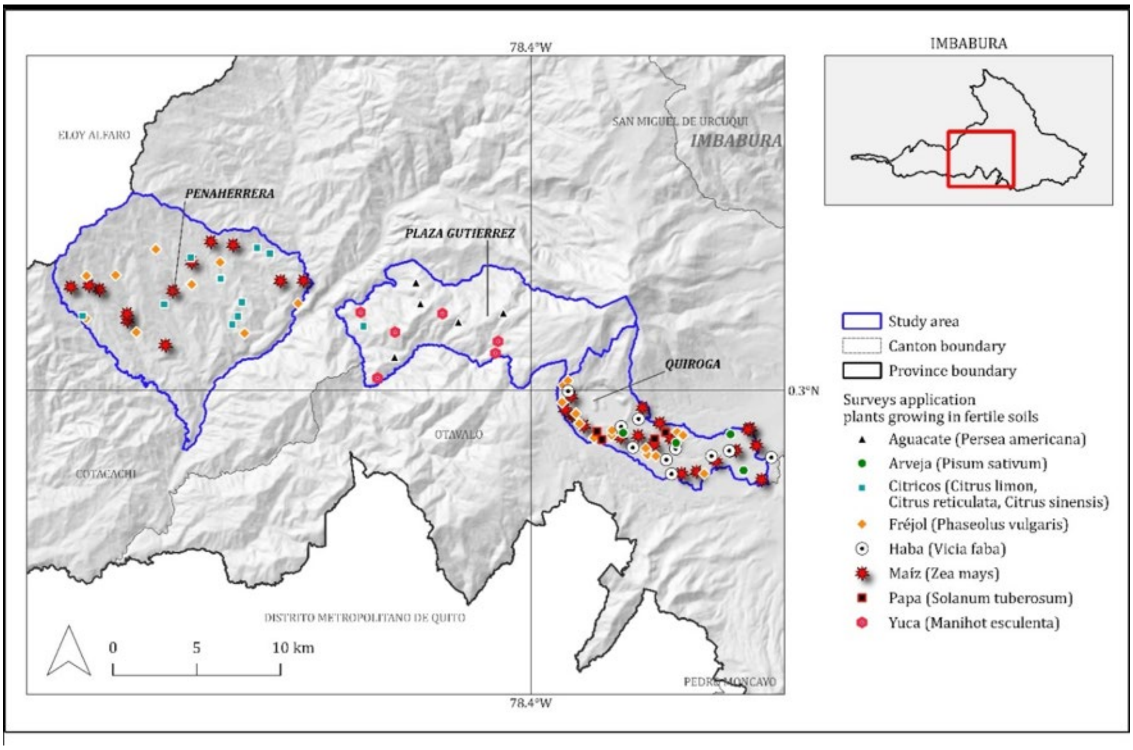
plant indicators of soil fertility are crops like *Zea mays, Phaseolus vulgaris, Citrus limon, Citrus reticulata, Citrus sinensis, Persea americana* and *Manihot esculenta*. Both areas, due to the soils' fertility, are suitable for agricultural and livestock production (Autonomous Decentralized Government of Plaza Gutiérrez-GAD of Plaza Gutiérrez 2015).

Although the Andean and subtropical zones differ climatically and even edaphologically (**Figure 1**), according to local knowledge there are plant species that are shared in these zones and are used as bio indicators of soil fertility (**Table 2**). This is because many species have a high ecological value; such is the case of maize (*Zea mays*), which adapts to a wide range of climates and diverse soils, resisting ecological factors such as light, temperature, humidity, pH, and nutrient concentration (e.g. phosphorus, nitrogen, among others) (Bonea et al. 2001). This is consistent with those reported by some researchers since this species is distributed, cultivated, and is the most consumed on the planet (García-Lara and Serna-Saldívar 2019). In colder areas, soft corn is grown, which is harvested after 6 months, and in areas with higher temperatures, hard corn is sown, which is harvested after approximately three months (GAD of Quiroga 2015; GAD of Peñaherrera 2015). Likewise, beans (*Phaseolus vulgaris*) have a wide distribution in America (Ariani et al. 2018); therefore, these two species can be found in a wide range of distribution. These results are consistent with the work of Astier et al. (2010) who, for example, using the maize crop as a bio indicator, contrasted some biophysical factors and thus determined the distribution and diversity of this crop in a regional mosaic (2015).

Soil infertility indicator plant species were similar in both areas. *Desmodium adscendens*, despite being considered by the farmers of this area as a species that grows on poor soils, is a legume plant that supplies nitrogen to the soil. Pardomuan-Tambunan et al. (2017) evaluated this plant as a potential species for post-mined land rehabilitation in South Kalimantan and they found that *Desmodium adscendens* had a positive effect on erosion control. In the same way, *Bidens pilosa* was selected as a sign of infertility, though other authors such as Mairura et al. (2007), indicated that this species grows in fertile soils; however, in this region farmers remove the plant as it is considered a "weed".

Other species related to soil infertility are *Pennisetum clandestinum* and *Pennisetum*

a)



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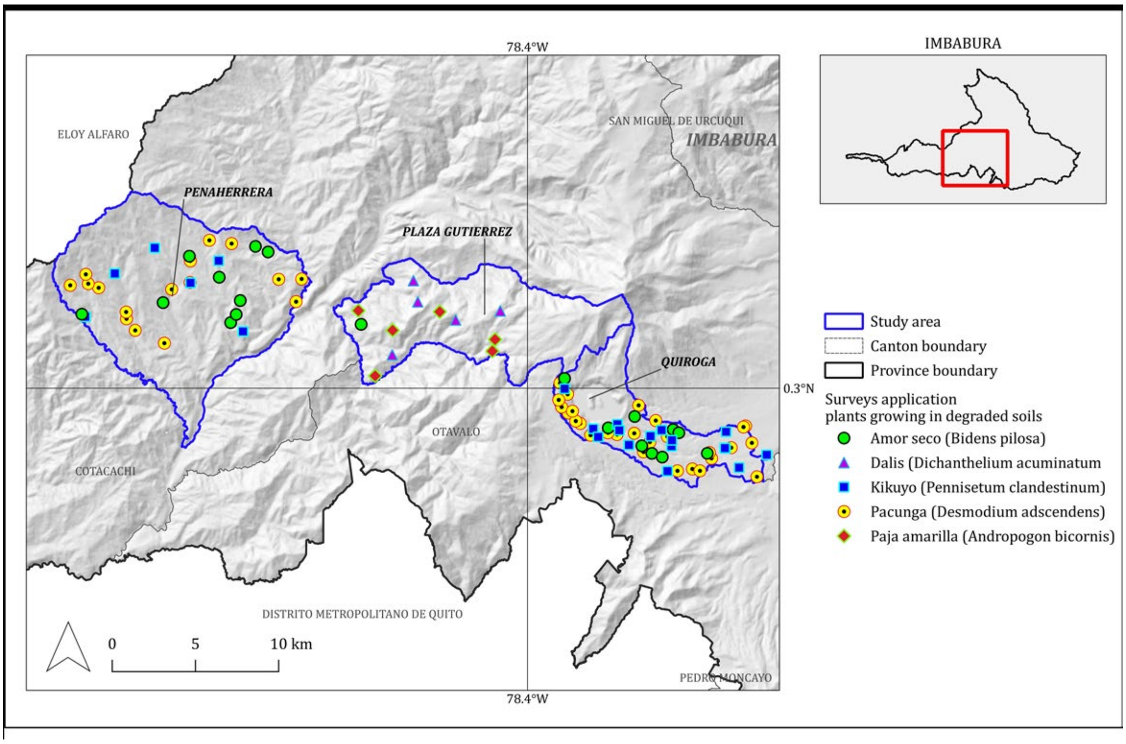

Figure 2. Plant species indicators of soil fertility and infertility in the two contracting areas. a. Soil fertility indicator species and b. Soil infertility indicator species.

sp. when the soil has low fertility, the stem is usually dry, yellowish, and thin. In another study, de Kogge-Kome et al. (2018), *Pennisetum purpureum* is reported to be found in both nutrient-rich and nutrient-poor soils. Murage et al. (2000) also mentioned that infertile soils are used for feeding livestock, so it is necessary to restore the fertility of these soils. Most poor soil indicator plants are highly undesirable because they easily colonize croplands, lowering crop yields through competition. However, and although *Pennisetum clandestinum* is considered as an indicator of poor soils, it also serves for the production of methane (biogas) (Ramírez et al. 2015), it is used for the restoration of saline and cadmium-contaminated soils due to its high resistance to the contents of these chemical elements (Muscolo et al. 2013; Okem et al. 2015) and protect the soil from erosion processes (Kamau et al. 2020).

Likewise, according to the information provided by the farmers, there are indicator species of soil infertility that are shared in the two contrasting zones. Such is the case of pacunga (*Desmodium adscendens*), amor seco (*Bidens pilosa*), and kikuyo (*Pennisetum clandestinum*). These species are adapted to diverse edaphic and climatic conditions. *D. ascendens* is distributed in all tropical regions of the world (Vanni 2001), *Bidens pilosa* is a cosmopolitan species (Arthur et al. 2012) and kikuyo (*Pennisetum clandestinum*) is a eurytopic and invasive species (Fernández-Murillo et al. 2015). Therefore, this agrees with what farmers say, that because these species are invasive they adapt or grow easily in soils with very low fertility.

3.3. Indicators of soil fertility

Based on farmers' perceptions, our results indicate that the soils have an intermediate texture (loam > 80%), with similar rates at both sites (Andean zone 78.8% and subtropical zone 88.3%). When comparing with the map of the Ministerio de Agricultura y Ganadería - MAG (2019), it is observed in **Figure 3** that the textural class that predominates in the two study areas is sandy loam and sandy-clay loam, observing agreement between the two types of knowledge. As expected, there were also few discrepancies between the perception of farmers who believed that there are sandy and clayey soils (less than 5%) and the textural classes observed in **Figure 3**. do not present these two textural classes. Barrios and Trejo (2003) found that, according to farmers' perceptions, the texture is considered a local indicator, since they know that this physical property affects soil water-holding capacity and resistance to tillage. Less frequently, there are sandy or coarse-textured soils (**Table 2**), which are classified as infertile due to low water and nutrient retention (Kogge-Kome et al. 2018).

Another key characteristic used by farmers is color, because it can be an indicator of a soil's fertility (Murage et al. 2000; Barrera-Bassols and Zink 2003). The farmers identified their soils as fertile because of their dark color, being mostly black and brown (Andean zone 40.4% and Subtropical zone 39.4.0%), white (13.8% and 3.2% respectively). There were significant differences between color and zones (**Figures 4, 5**).

With regard to the relationship between the soil color given by farmers and the carbon stocks indicated in the soil map, it can be seen that this relationship is consistent, thus there is a higher percentage of farmers who affirm that their soils are darker in the areas with the highest stocks of C (zones of Peña Herrera and Plaza Gutiérrez) compared to the zone with the lowest stocks (Quiroga). This is also consistent with the types of soils, according to Lal (2004) the soils Andisols and Inceptisols (dominant soils in Peña Herrera and Plaza Gutierrez, **Figure 1b**) have higher stocks of organic carbon than the Mollisols (dominant soils in Quiroga, **Figure 5**).

According to Frausin et al. (2014), in Colombia farmers perceive that the colors black and brown are indicators for good harvests, unlike light colours (red, yellow and white) that are considered less fertile (scarce in organic matter). Some researchers report that farmers plant maize in "black soil" because they consider it the best type of soil for the growth of this crop (Pauli et al. 2012; Nath et al. 2015) where dark soils tend to have higher content of organic matter than yellow and red soils.

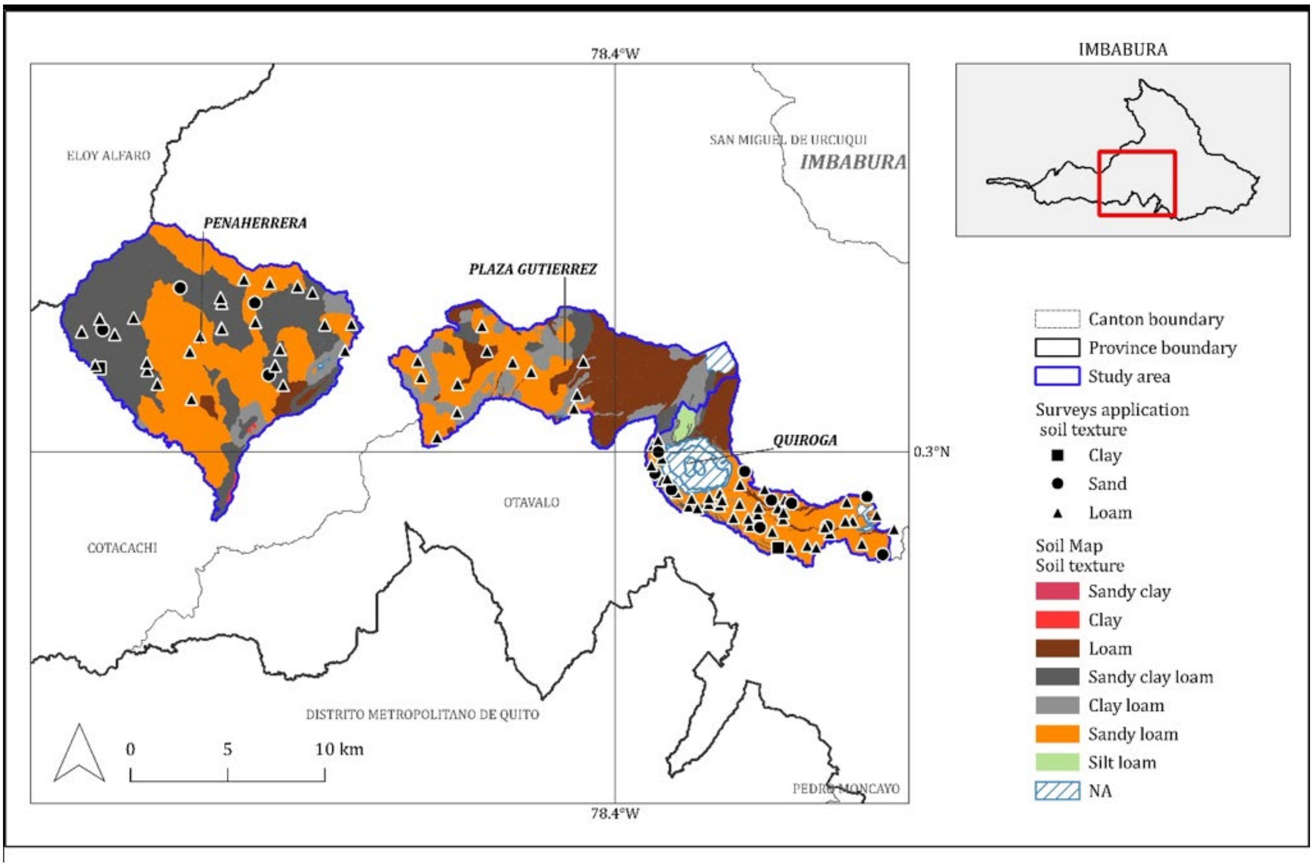

Figure 3. Comparison map between the texture soil (GIS) with the perception of farmers in the Andean and subtropical zones.

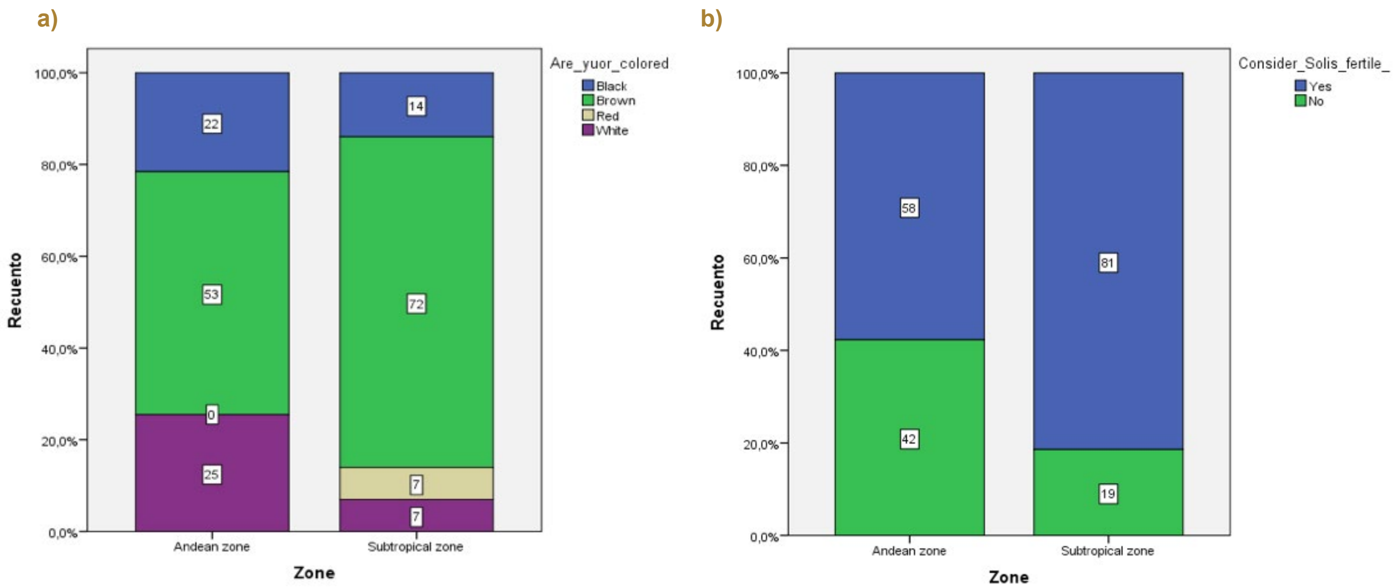

Figure 4. Main indicators of soil fertility have significant differences ($p < 0.05$) between study areas and colors and knowledge of soil fertility. a. Color and b. Historical knowledge of soil fertility.

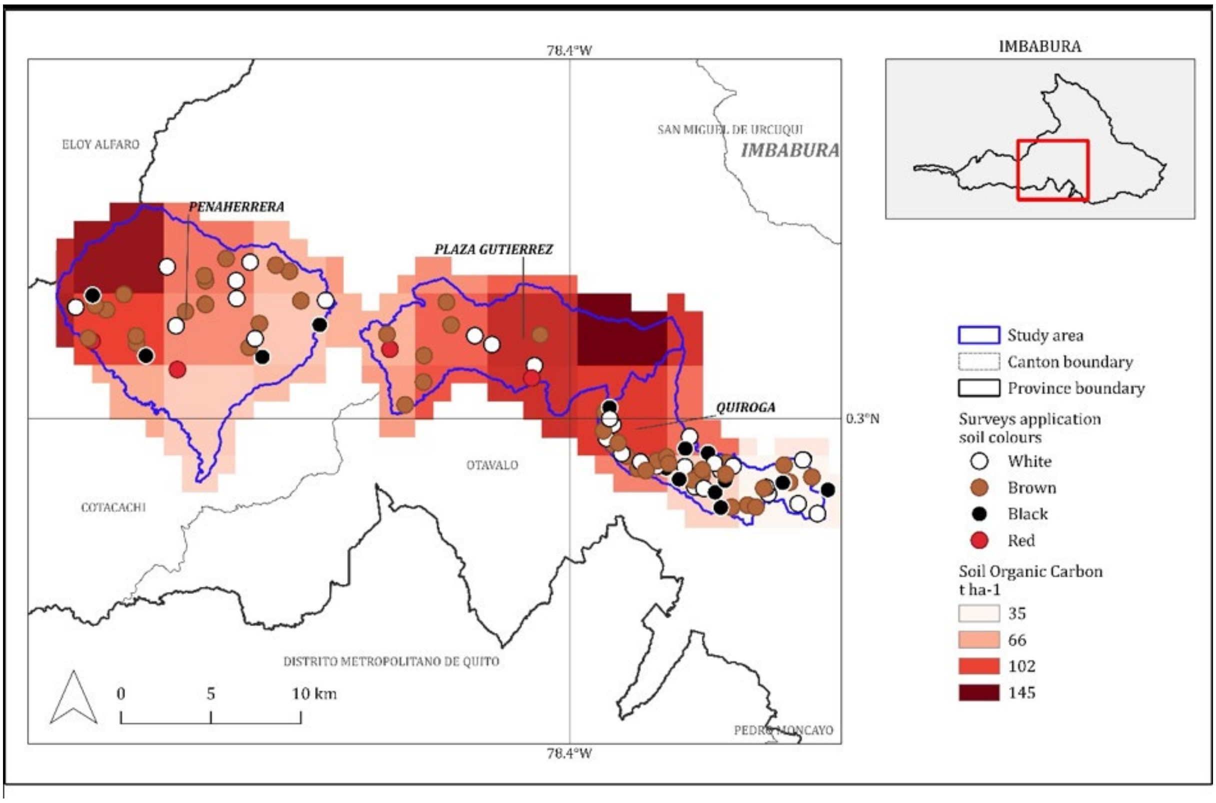

Figure 5. Comparison map between the carbon stock (MAG 2019) and soil color (GIS) with the perception of farmers in the Andean and subtropical zones.

Low stoniness (Andean zone 40.0% and subtropical zone 33.7%) and the soil workability (33.7% and 29.5% respectively) of soils for ploughing are also considered as indicators of fertility. Although according to Kogge-Enang et al. (2016), the stoniness hinders the development of roots, in this case most farmers mentioned that there is little stoniness, reckoning it facilitates the use of hand tools commonly used in agriculture and benefits the tillage of the land. The depth, also mentioned as important, is a characteristic that indicates which type of crop to sow, where for instance, because of root type, fruit trees and/or perennial crops need deeper soils than vegetables like *Citrus limon, Citrus reticulate, Persea americana* and *Phaseolus vulgaris*.

Farmers' criteria is that the soils of this area are deep (Andean zone 33.7% and subtropical zone 29.5%), so they are destined for several perennial crops such as *Solanum betaceum, Saccharum officinarum*, and short-cycle crops such as *Phaseolus vulgaris, Zea mays, Pisum sativum, Hordeum vulgare* and *Capsicum annuum* (Ibarra and Chuquín 2016). In most cases, the crops selected depend on this indicator. In the parish of Quiroga, most respondents believe that they have deep soils, according to the GAD of Quiroga (2015), and currently, this population is settled into geophysical plains and are considered to be soils with good aptitude for agriculture.

Most farmers mentioned that the presence of macrofauna such as earthworms, spiders, ants and beetles (almost 100% in both zones) indicates that a soil is fertile, although it is not always easy to scientifically identify or relate to soil fertility (Murage et al. 2000; Gruver and Weil 2007), because other characteristics tend to predominate for several farmers. The positive effect of the macrofauna, especially of earthworms, lies in the transport of soil to the surface, the improvement in the structure and porosity of the soil and the fertilization of the soil as a result of the decomposition of organic matter (Birmingham 2003; Pauli et al. 2012) which adds benefits to the soil for the practice of agricultural activities. Earthworms are normally seen when farmers till the land or when the soil becomes saturated during the rainy season and earthworms emerge (Zúñiga et al. 2013).

Crop yield, considered by Gruver and Weil (2007) and Tarfasa et al. (2018) as the most important indicator of soil fertility, is also considered a crucial soil indicator by the small farmers, they answered affirmatively in Andean zone 43.2% and subtropical zone 41.1%, because it is a highly visible parameter (from a food security standpoint) (Mairura et al. 2007), reflected in productive harvests year after year. The edaphic fertility in the area may be due to the volcanic soils, which is characteristic that enhances the growth of crops (Moreno et al. 2018). According to the information from Autonomous Decentralized Government of Cotacahi (GAD of Cotacachi 2011), these soils are highly suitable for agricultural activities, which agrees with the perception of farmers.

3.4. Soil contamination and conservation strategies

According to farmers' criteria, the main soil pollutants in the two areas are in the following order: pesticides (Andean zone 38.94%, subtropical zone 42.10), garbage (Andean zone 34.73%, subtropical zone 35.78) and chemical fertilizers (Andean zone 26.31%, subtropical zone 29.47). On the one hand, organophosphorus insecticides have been widely used in practice to improve crop yields. The insecticide is released into surface waters or the soil, and is subject to volatilization, photolysis, hydrolysis and biodegradation (Cycoń et al. 2009). Therefore, it is necessary to consider the amounts to be applied, the composition, frequency and degree of danger of these products in order to reduce the effects they have on both soil's and people's health.

On the other hand, the garbage produced by domestic and/or agricultural activities generates waste that pollutes the soil, water and natural resources in general, so the farmers within the study area perceive the generation of this waste as the main source of soil contamination. Excessive nitrogen fertilization causes an increase in nitrate leaching into waterbodies (Ju et al. 2004). Therefore, it is important to make fertilization plans to provide the soil the right amount of nutrients required by each crop. In these areas, and even at the country level, it is not a widespread practice to perform a soil analysis, nor determine appropriate fertilizer quantities, based on particular crops.

In terms of conservation strategies, most farmers have adopted some strategies to maintain the natural fertility of the soil, such as mixed cropping (Andean zone 41.05%, subtropical zone 30.5%), letting the soil rest (Andean zone 21.05%, subtropical zone 15.78%, and the incorporation of crop residues and/or manure into the soil (Andean zone 28.42%, 29.47%, subtropical zone 42.10%, 36.84% respectively). However, it has also been reported that some farmers eliminate organic waste directly into nature, leading to pollution and decreased productivity (Murage et al. 2000). All the respondents use at least one conservation strategy, and 81% of these between 2 and 4 strategies. All the agricultural practices used contribute to soil conservation and reduce problems such as erosion, desertification, contamination and compaction.

3.5. Acquisition of knowledge

According to Ryder (2003), farmers can provide invaluable insights into soil's historical changes in use and management practices that have had a local impact, which is corroborated by our study, where most of the respondents have transmitted their knowledge from generation to generation (Andean zone 48.4% and 41.1% subtropical zone), where practices have been handed down from parent to child, and a smaller percentage from grandparents or some other relatives. Another small percentage (Andean zone 6.3% and 4.2% subtropical zone) claimed to have acquired knowledge on their own, implying that their parents had no land and therefore could not learn from them.

In the Andean zone (31.6%) and the subtropical zone (36.8%) the respondents indicated that their soils produce better yields and agree that this is partly due to the management of the soil, mainly as a result of the incorporation of organic matter, which provides for improved harvests (Bedada et al. 2014).

The processes of knowledge transmission play a crucial role in the maintenance and advancement of the essential knowledge that people require to carry out their land use activities (Fritz-Vietta et al. 2017). Therefore knowledge transmission, along with people's own perceptions and observations, facilitate the maintenance of local knowledge and its growth which is then transmitted from one generation to another, helping to satisfy the population's needs while preserving natural resources. In addition, this knowledge, transmitted as part of their culture, is disappearing because young people and children have no interest in the management of crops and livestock (GAD Quiroga 2015).

4. Conclusions

Indigenous and mestizo farmers preserve profound ancestral knowledge about the biological and physical indicators of soil fertility, as is found in other regions of Latin America. In the study area, with the exception of a small number of farmers who have learned from their own experience or studies, people have acquired their knowledge with regards to land use and management almost exclusively from their ancestors (grandparents and parents). These teachings have been maintained for generations and are still today passed on from parents to children. Ancestral wisdom also manifests itself in agricultural practices; the characteristics examined have provided qualitative information with several similarities to scientific knowledge, though there are still some disagreements between farmers and scientists. These preliminary results on soil indicators and the loss of fertility require further research and expansion with in situ physical-chemical analysis of the soil to achieve closer integration.

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