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Rediscovering the edaphic knowledge of smallholder farmers in southern Ecuador

Leticia Jiménez [a,*], Wilmer Jiménez [b,e], Diego Felicito [c], Natacha Fierro [a], Pablo Quichimbo [d], Darwin Sánchez [b], Daniel Capa-Mora [a]

[a] Facultad de Ciencias Exactas y Naturales, Universidad Técnica Particular de Loja, Loja, Ecuador
[b] Ministerio de Agricultura y Ganadería, Dirección de Generación de Geoinformación Agropecuaria, Quito, Ecuador
[c] Titulación de Ingeniería Agropecuaria, Facultad de Ciencias Exactas y Naturales, Universidad Técnica Particular de Loja, Loja, Ecuador
[d] Carrera de Ingeniería Agronómica, Facultad de Ciencias Agropecuarias, Universidad de Cuenca, Cuenca, Ecuador
[e] Punto Focal del Pilar 4 de la Alianza Mundial por el Suelo en Ecuador, Quito, Ecuador

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ABSTRACT

Understanding farmer local knowledge of soil management practices and their fertility is vital to maintaining soil fertility in agricultural areas, which contributes to maintaining sustainable agro-ecosystems. In this study, soil fertility indicators and the farmer's management practices were investigated, while local knowledge was contrasted with scientific understanding. For this, 610 surveys were conducted with dichotomous and open questions that were applied in the 16 localities of the province of Loja in southern Ecuador; for their comparison, carbon and texture maps were generated utilizing the respondents' main indicators. Farmers visibly identify various soil parameters such as texture (53.9% sandy soils), color (64.3% black soils), workability (81.3% workable soils), and stoniness (64.6% soils do not have stoniness), as indicators of soil productivity, while applying soil management practices inherited mainly from their parents and grandparents. As such, there are many concordances such as some of the practices that respondents use that pollute the soil and others that conserve the soil; also some disagreements in certain study places between soil color according to local knowledge and carbon stocks, other disagreements were between the texture according to the perception of the respondents and the textural classes. The findings demonstrate respondents identify soil fertility through their experience using visible indicators; some practices to soil management can contribute to soil conservation, which is very important for future management practices and soil fertility conservation that can significantly influence the techniques that farmers implement.

1. Introduction

The importance of the ancestral, local and traditional knowledge of farmers is increasingly recognized, which contributes to scientific knowledge in agricultural practices (WinklerPrins and Sandor, 2003). This perception is based on their points of view, concepts, experiences, time spent laboring on their farms, as well as their ability to relate to the environment (Jarvis et al., 2006). However, this knowledge is being lost due to multiple cultural, socioeconomic and political changes, which are damaging natural resources and, therefore, affect food security (Grenier, 1998; Thierfelder et al., 2015).

Laekemariam et al. (2017) point out that the experience of farmers has led to a new field called Ethnopedology which presents local knowledge and allows for the formulation of sustainable soil management with a socially acceptable, ecologically sustainable and economically viable scientific approach.

Some researchers have investigated the local knowledge of farmers in rural areas of certain countries in Africa (Brinkmann et al., 2018; Buthelezi-Dube et al., 2018), Asia (Nath et al., 2015); Europe (Capra et al., 2016) and Latin America (Sánchez-Cortés and Lazos, 2011; Pauli et al., 2012), and determined that the experience and knowledge of farmers is of utmost importance and necessary to complement with scientific knowledge for the greater benefit of agricultural sustainability (Barrios and Trejo, 2003; Omari et al., 2018); however, the work is still insufficient and requires more research on this topic, especially in countries like Ecuador where there is very little information.

* Corresponding author.
E-mail address: lsjimenez@utpl.edu.ec (L. Jiménez).

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Investigating knowledge at the farm level is essential since small farms consisting of a few hectares or even a fraction of an hectare are characteristic of family production systems. Therefore, they constitute the key to contributing to the world's food security since they are more productive and conserve biodiversity (Altieri and Nicholls, 2008).

The use and management practices of soils can alter the edaphic properties and therefore the fertility of the soil. In this context, farmers can identify visual changes in their soils, for instance, when the color changes are associated to low crop yields or due to the presence or absence of organic matter and organisms in the soil (Buthelezi-Dube et al., 2018; Pauli et al., 2012).

Usually, soil changes cause negative impacts in plant productivity and to mitigate them, farmers use soil-conserving practices such as the implementation of terraces, the incorporation of organic matter into the soil, tree planting, crop rotation and agrosilvopastoral systems (Tarfasa et al., 2018; Kuria et al., 2018), these practices have been inherited from or acquired from their ancestors or have learned through experience or training. The study of farmers' perceptions is important to include in soil management at the local level and integrate it with scientific knowledge. In this research, we aimed to evaluate soil fertility according to the perception of farmers in southern Ecuador. The specific objectives were: (a) to identify the soil fertility indicators defined by the farmers; (b) to determine the soil conservation and management practices of local farmers; and (c) to compare the information issued by the farmers with the technical-scientific information given the Ministry of Agriculture of Ecuador. Our results will contribute to revalue and enhance local knowledge that can serve as a basis for responding to and managing projects for the management and restoration of soil fertility, and as a reference for decision-making by the respective authorities for plans and projects at the national level. level. Our results will contribute to revalue and enhance local knowledge that can serve as the basis for developing future projects for the management and restoration of soil fertility that are more inclusive with the knowledge of farmers.

2. Materials and methods

2.1. Study area

The research was conducted in the province of Loja, in southern Ecuador at 80°0'0'' W, 4°0'0'' S and 79° 6'36" W, 4°12'2" S (Fig. 1). The province has 16 cantons (canton is an unit of administrative and territorial division of the province) cantons named localities hereinafter. The topography of this area is diverse. The elevation varies from 115 to 3895 m above sea level (asl), and with an average annual temperature between 13 to 26 °C the climate is considered diverse as well (tropical, subtropical, and temperate) (IGM, 2020). The highest values are found in the Zapotillo canton with a temperature of 24.61 °C, followed by Macará, Catamayo, Paltas, Celica (Sabanilla, Tnte. Maximiliano Rodríguez parishes), and Puyango (El Limo and Alamor parishes) at 24.32 °C. Likewise, the lowest temperature values are located in Saraguro and Loja (Gualel and Santiago parishes) with 8.34 °C and Espíndola (Amaluza, Santa Teresita and El Ingenio parishes) 12 °C (GPL, 2011).

According to the geopedological map of Ecuador there are nine taxonomic orders of soils: Alfisols, Andisols, Aridisols, Entisols, Histosols, Inceptisols, Mollisols, Ultisols and Vertisols (MAG, 2019; USDA - Soil Survery Staff, 2006). Inceptisols are the most representative with 49%, distributed mainly on the slopes and upper reliefs of the inter-Andean basins, internal massifs of the southern highlands, and the southern Andean slope areas without pyroclastic coverage, but with mountainous reliefs (Fig. 2). This results in soils of low to moderate depth, and with zero to low stony, loamy clay or loamy textures (MAG, 2019).

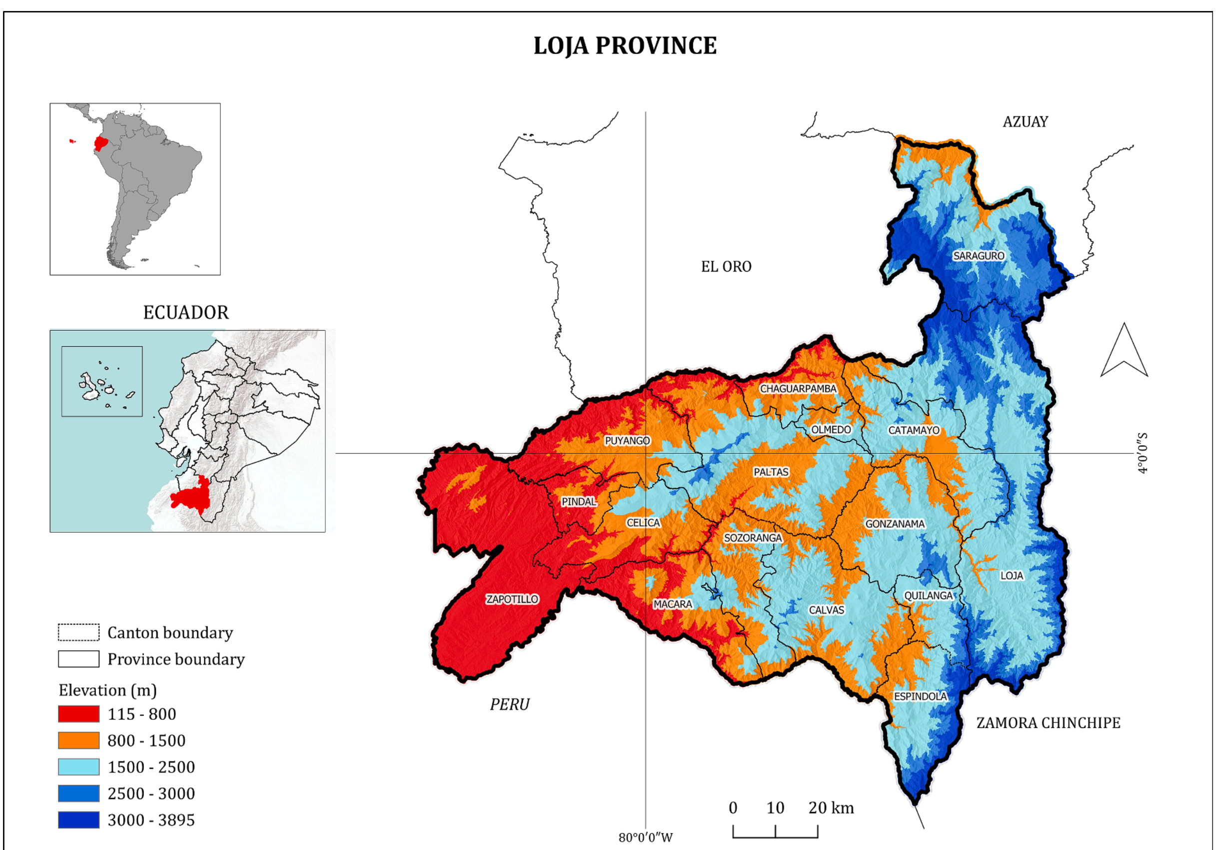

Fig. 1. Representation of the study area, province of Loja, in the south of Ecuador. Black lines indicate canton boundary (canton is an unit of administrative and territorial division of the province of Loja).

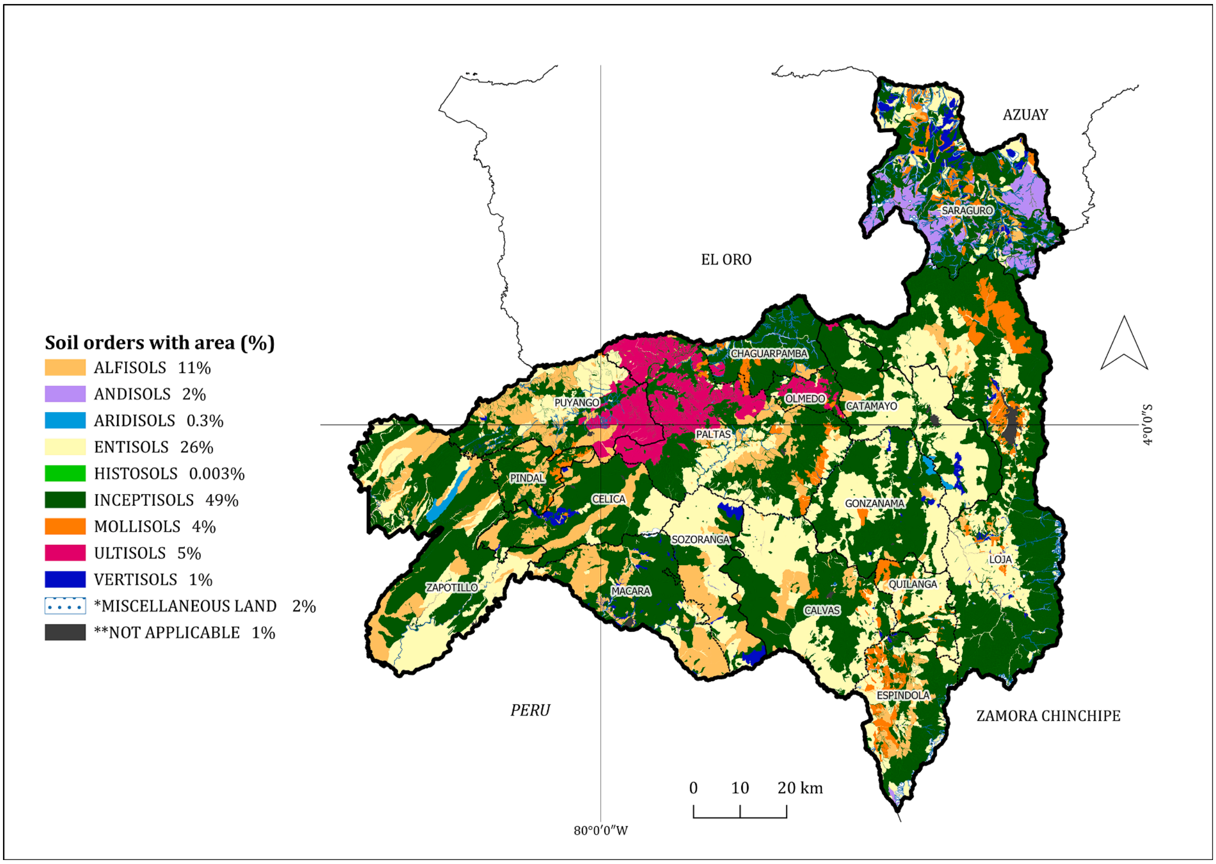

Fig. 2. Map of soil orders within the province of Loja with their percentage of the surface, according to the geopedological map of continental Ecuador 2009-2015 (http://geoportal.agricultura.gob.ec). * Lands that are not characterized as land units or taxonomic units. ** Corresponds to populated areas, bodies of water, wastelands without vegetation cover, and anthropic infrastructure.

2.2. Information gathering

The farmers' information was obtained by the application of a semi-structured survey (Barrios et al., 2006; Dawoe et al., 2012). It consisted of a total of 35 questions that addressed aspects such as: 1) general information about the farm and the respondents, 2) visible indicators of soil fertility, 3) management practices and soil conservation strategies, and 4) knowledge acquired over time. Most of the questions were dichotomous (yes or no) and multiple choice with 3 to 7 options; the rest of the questions were open-ended. For example: How do you describe good soil? How did you gain knowledge about soil management? (see details in Jiménez et al., 2021).Out of a total farmers population of 137848 producers and/or relatives in the province of Loja (INEC, 2014), it was necessary a sample of approximately 400 farmers – computed with a precision of 5% and an α level of 0.05, assuming a population proportion of 50% (Israel, 1992), however 610 farmers were surveyed in total to cover the study area's sociocultural, climatic, and edaphic diversity. The surveys were aimed at people engaged in agriculture, mining, forest or other related land uses.

The technical-scientific soil information came from the database of the Project "Generation of Geoinformation for the Management of the Territory at the National Level", this information is the one that the national government promotes through the distribution and management of geoinformation for the use of citizens or institutions in an open and free way through the platform GEOPORTAL (http://geoportal.agricultura.gob.ec). The mentioned database contains data from soil profiles described during the period 2009-2016 and also showed soil information in form of digital maps. In particular, soil color, soil texture, soil organic matter content, soil organic carbon stocks, and stoniness from that database were used to compared with the information from farmers.

Table 1
Relationship of the categorical variables gender and age with characteristics of farmers 173 and indicators of soil fertility using Chi-square test of independence (α = 0.05, n = 610).

Parameters	Value	df	Pearson's Chi-square. Asymptotic significance (bilateral)
Gender-soil color	5.893	4	0.207
Gender-soil depth	0.455	2	0.796
Gender-soil workability	1.211	2	0.546
Gender-education	5.366	4	0.252
Gender-ethnicity	23.440	3	0.000
Age-soil depth	5.280	8	0.727
Age-soil color	37.348	16	0.002
Age-stoniness	8.805	8	0.359
Age-soil workability	12.326	8	0.137

2.3. Data analysis

Data collected through the surveys was harmonized in an Excel spreadsheet and subjected to a descriptive analysis, calculating the frequency distribution for all the variables while the two-way Chi-square test ($\chi 2$) was used to demonstrate the uniformity among the respondents from the different localities. Statistical software SPSS Version 24.0 was used for the analysis. The comparison between the farmers information and that of the technical-scientific was carried out using maps. A map was made from farmers information by the "point method", which consists of assigning the georeferenced points from the coordinates of the farms (a centroid point) of the surveyed farmers (Wieczorek et al.,

Table 2
Analysis of main soil fertility indicators according to respondents per localities in the province of Loja, (*n*= 610), DS indicates significant differences among localities as a result of chi-square test (P<0.05).

	Calvas (%)	Catamayo (%)	Celica (%)	Chaguarpamba (%)	Espíndola (%)	Gonzanamá (%)	Loja (%)	Macará (%)	Olmedo (%)	Paltas (%)	Pindal (%)	Puyango (%)	Quilanga (%)	Saraguro (%)	Sozoranga (%)	Zapotillo (%)	**Total (%)**	**X2 value**	**Significance**
Color																			
Black	52.9	75.0	20.0	42.9	71.4	81.6	61.3	47.6	18.2	52.2	75.0	25.0	88.5	71.2	25.0	16.7	64.3	189.1	0.000
Brown	47.1	13.8	40.0	35.7	21.4	6.1	32.3	33.3	63.6	34.8	25.0	75.0	3.8	27.6	50.0	50.0	26.4		DS
Red and yellow	0.0	10.3	40.0	21.4	0.0	4.1	1.6	19.0	18.2	13.0	0.0	0.0	3.8	0.6	25.0	33.3	7.4		
White and gray	0.0	0.9	0.0	0.0	0.0	6.1	1.6	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	1.0		
Others	0.0	0.0	0.0	0.0	7.1	2.0	3.2	0.0	0.0	0.0	0.0	0.0	1.9	0.6	0.0	0.0	1.0		
Texture																			
Sandy	47.1	37.1	10.0	60.7	57.1	53.1	51.6	66.7	68.2	52.2	25.0	0.0	76.9	66.0	50.0	41.7	53.9	128.6	0.000
Clay	35.3	46.6	80.0	32.1	14.3	22.4	32.3	23.8	0.0	39.1	75.0	100.0	19.2	16.7	25.0	8.3	29.8		DS
Loam	17.6	16.4	10.0	7.1	28.6	24.5	16.1	9.5	31.8	8.7	0.0	0.0	3.8	17.3	25.0	50.0	16.2		
Soil stoniness																			
Yes	35.3	41.4	10.0	21.4	7.1	49.0	35.5	23.8	18.2	39.1	0.0	12.5	44.2	36.5	12.5	16.7	34.6	40.51	0.095
No	64.7	58.6	90.0	78.6	92.9	49.0	62.9	76.2	81.8	56.5	100.0	87.5	55.8	62.2	87.5	83.3	64.6		NS
None	0.0	0.0	0.0	0.0	0.0	2.0	1.6	0.0	0.0	4.3	0.0	0.0	0.0	1.3	0.0	0.0	0.8		
Workability																			
Yes	64.7	88.8	90.0	71.4	71.4	77.6	82.3	90.5	86.4	69.6	100.0	87.5	82.7	78.2	75.0	91.7	81.3		
No	35.3	11.2	10.0	28.6	28.6	20.4	17.7	9.5	13.6	30.4	0.0	12.5	17.3	21.2	25.0	8.3	18.4		
None	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.3		
Soil depth																			
Deeper soils	5.9	18.1	40.0	21.4	35.7	42.9	45.2	19.0	4.5	43.5	50.0	87.5	44.2	30.1	25.0	50.0	32.0	80.3	0.000 DS
Surface soils	94.1	81.9	60.0	78.6	64.3	55.1	51.6	81.0	95.5	56.5	50.0	12.5	55.8	69.9	75.0	50.0	67.5		
Other	0.0	0.0	0.0	0.0	0.0	2.0	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5		
Do your soils give good yields?																			
Yes	82.4	74.1	70.0	3.6	78.6	87.8	85.5	100.0	0.0	73.9	75.0	87.5	78.8	82.7	87.5	83.3	74.9	278.9	0.000
No	17.6	25.9	30.0	50.0	21.4	10.2	12.9	0.0	59.1	26.1	25.0	6.3	21.2	16.0	12.5	16.7	20.7		
Other	0.0	0.0	0.0	46.4	0.0	2.0	1.6	0.0	40.9	0.0	0.0	6.3	0.0	1.3	0.0	0.0	4.4		DS

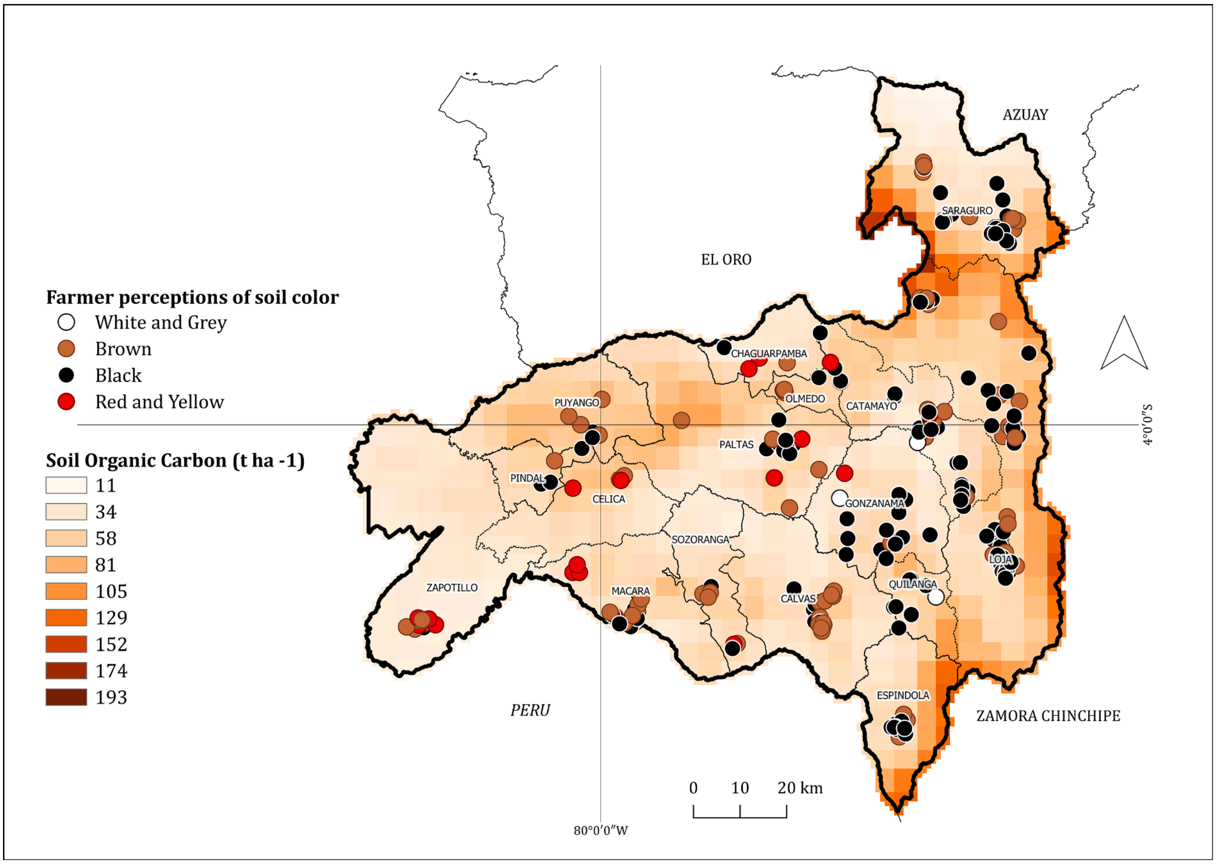

Fig. 3. Comparison between soil organic carbon (SOC) stocks according to the stocks carbon map of continental Ecuador 2019 (MAG, 2019) versus the farmer's perception of soil color in the province of Loja.

2004). The georeferentiation of the surveys to shapefile points was made using the Spreadsheet Layers plugin (Camptocamp, 2020), in the open-source software QGIS 3.12.2-Bucureşti (QGIS Development Team, 2020). Then a spatial analysis by means of intersection tools of QGIS was done between the maps of farmers for different indicators of soil fertility and the maps of the main soil properties of the technical-scientific information available with a spatial resolution of 1 km (MAG and FAO, 2018). From the information of those maps intersections the comparisons was done, for instance, the information obtained from the respondents on the color of the soil as an indicator of fertility (black, brown, red, yellow and white) was compared with the carbon stocks of the soil; the local knowledge about the textural classes of the soil was contrasted with their respective technical-scientific texture class; soil organic matter contents was contrasted with the perception of soil fertility, determined in three categories: high, medium and low; and finally, the soil conservation strategies were contrasted with that of the soil carbon stocks.

3. Results

Of the total number of respondents in the study area, 63% corresponded to men and 37% women. Most respondents were between 35 and 55 years old, which represented 38% of those surveyed. 68% were dedicated to agriculture and 26% to livestock. Those surveyed mentioned that 42% engaged in the agricultural practices are men alone, 10% are just the women, while 48% include all members of the family (mother, father, children). Ethnic groups represented in the survey were the following, as self-reported: 77.9% of the people belong to the mestizo ethnic group, distributed throughout the province, 19.7% considered themselves indigenous, particularly amongst the Saraguro zone, Celica and the city of Loja, 1.5% Afro-Ecuadorians, distributed amongst different localities, especially in Catamayo and Paltas, while the remaining percentage was for those not responding. Regarding education level, 45% of the respondents attended the initial or primary level, 28% had a secondary level, and only 10% had higher education. The remaining 16% did not have any formal education. With reference to land use, the majority of the respondents (92%) use their soils for crops, followed by 6% for pastures, and a small percentage for forests and other activities (either for exploitation or for conservation of their soils).

3.1. *Soil fertility indicators*

According to the results obtained from the respondents, a primary indicator was soil color. Black was the predominant color in the soils of their farms (64% of the respondents). In the sectors of Celica, Olmedo, Puyango, Sozoranga, and Zapotillo, 26% reported having soils of brown color. Meanwhile, 7% had soils of reddish and yellow color and the remaining percentage had white, gray or another color soil. Between all the localities in the study area statistically significant differences were detected (Table 2, Fig. 3).

The chi-square analysis indicated that the gender variable is related to the ethnic variable when taking into consideration the respondents' perception (Table 1). The group of female respondents was identified more as mestizo, while men were more likely to identify as indigenous. However, Table 1 indicates that the perception of the respondents was divergent in terms of how the different genders perceive the indicators of soil fertility and also education.

Regarding the relationships between age and the different indicators of soil fertility and farmers characteristics, only the age and soil color were significant (Table 1). However, the perception of soil color was not the same in all ages, most farmers between 36 and 55 years old consider soil fertility to be mainly related to brown, red, and yellow, followed by

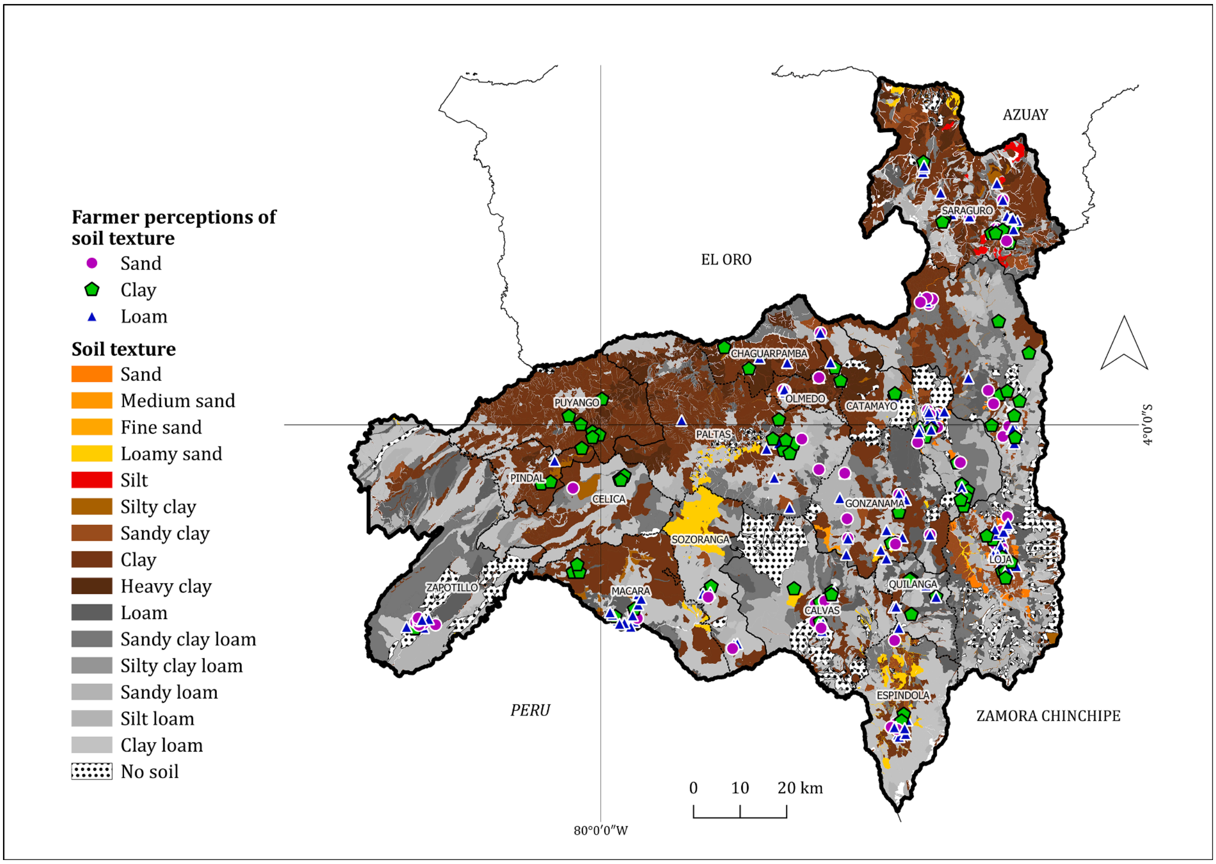

Fig. 4. Comparison between soil texture according the soil class-texture map of continental Ecuador 2019 (MAG, 2019) versus the farmer's perception of soil texture (clay, loam and sand) in the province of Loja.

black. On the other hand, for farmers between the ages of 56–70 years, light colors such as red and yellow were considered less fertile, followed by black and brown, which were considered to be more fertile soils.

The farmers in the different localities of the study area, from their perspective, mentioned they have different textural classes in the soils of their farms. In Saraguro, Chaguarpamba, Macará, Olmedo, and Quilanga, sandy soils predominated. This is contrasted with areas like Celica and Catamayo that registered more clay. These results presented statistically significant differences (Table 1, Fig. 4).

Regarding stoniness and workability, the results did not present statistical differences. All of the respondents claimed that their soils have low stoniness (65%) and are workable (92%). From their perspective, farmers mentioned soil depth as an important indicator of their farms' edaphic fertility, as it is a key characteristic for determining the plant species to be cultivated. Thus, in this study, most farmers (68%) mentioned that their soils are shallow, making it difficult for them to grow species with more developed roots, other than vegetables and medicinal plants (Fig. 5).

Farmers consider the soil to be fertile when they have good crop yields (75%) and do not need to fertilize constantly, indicating significantly statistical differences with respect to soils of low yield (Table 1). In 14 of the 16 localities it is common belief that their soils give good harvests.

3.2. Main sources of soil contamination

In the studied locations, farmers mentioned different sources of soil contamination (Fig. 6a), where 14 localities indicated that fertilizers are the main factor of contamination (82% of the respondets). Pesticides were the second most mentioned contaminant (14%), while garbage was the third source of soil contamination, mainly in the areas of Macará and Zapotillo.

3.3. Soil management and conservation practices

Farmers within the province of Loja indicated that the most common practice was manual tillage (57%). Sprinkler irrigation within the province of Loja was also common (37% of the respondents), particularly in Calvas, Espíndola, Loja, Olmedo, Saraguro and Sozoranga. Meanwhile in Catamayo, Macará and Zapotillo irrigation is by gravity (Fig. 7).

One of the strategies most mentioned and repeated was for allowing the soil to rest, also known by some farmers as fallowing (38%). Respondents also mentioned the importance of planting trees and the incorporation of crop residues as the second and third most mentioned option, respectively. Other options included the association of crops, the incorporation of animal manure and finally, terraces.

3.4. Acquisition of knowledge with regards to soil management

Farmers demonstrated familiarity and knowledge of their soils, with the majority (68.7%) claiming that their knowledge had been acquired from their parents, grandparents, siblings, or other relatives, followed by 15.1% of respondents, particularly from the sites Macará and Zapotillo, who said they had acquired their knowledge by their own means. In Celica, Sozoranga, and Pindal, farmers indicated that they had acquired their knowledge through training or other practices (13.4%), while at the same time revealing that support for learning or training is limited or does not exist, due principally to the location of their sites far from population centers, whereas the remaining percentage was attributed to a lack of response.

Most of the respondents (78%) in 14 of the 16 localities, mentioned

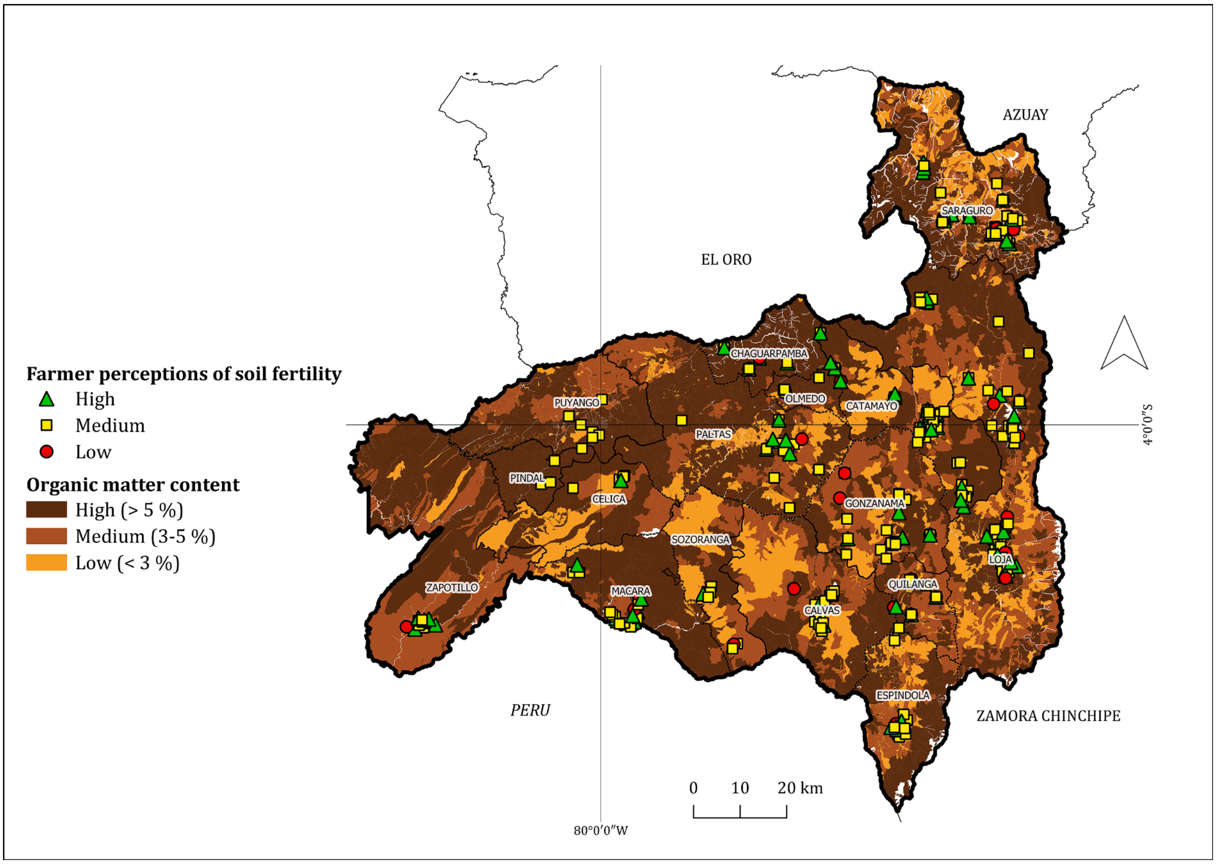

Fig. 5. Comparison between soil organic matter according the soil organic matter map of continental Ecuador 2019 (MAG, 2019) versus the perception of soil fertility (high, medium, low) in the province of Loja.

that in the past, the soils were more fertile than now, indicating that their harvests years ago were more productive than today, revealing this to be due to soil impoverishment as a result of poor management. This is in contrast to the sites of Chaguarpamba and Olmedo (19% of the respondents), where they consider that there has not been a change in soil productivity, and affirm that their products have the same quality as always.

4. Discussion

4.1. Soil fertility indicators

Local farmer's knowledge is dependent upon soil color to interpret soil fertility within the studied localities. This perception of farmers and the relationship of color with fertility has been reported in other related ethnopedological studies. For example, Buthelezi-Dube et al. (2020) indicated that darker soils may have a higher organic carbon content. Also, Brinkmann et al. (2018) demonstrated that soils of black color and clayey are fertile and retain water, while red and sandy soils retain less water where, as Ryder (2003) mentions, the fertility of white soils is lower than that of dark soils.

When comparing local and scientific knowledge, some discrepancies were observed, especially in the areas of Macará, Catamayo, and Zapotillo, where they mentioned having dark soils. However, they presented lower stock C values according to the map (Fig. 3) (FAO, 2018; MAG, 2019). On the other hand, several concordances were observed in Puyango, Saraguro, Loja, and Espíndola, which presented the highest C values and where the perceptions of those surveyed confirmed that their black or brown soils are indeed more fertile.

Another important indicator to determine soil fertility was the texture. According to the farmers' knowledge, loam texture soil is ideal for agricultural activities; therefore, they claim that the water does not puddle or run off very fast in their soils. This is corroborated by research such as Nethononda and Odhiambo (2011), that indicate that loamy soils are good for agriculture due to their infiltration rate and are generally free of water accumulation, unlike clay soils that, when wet and dry, are very sticky and difficult to plow (Buthelezi-Dube et al., 2020). In most of the study sites, concordances were found between what was mentioned by the respondents and the scientific data, especially in Puyango, Macará, Paltas, Pindal, which shows that farmers largely know the characteristics of their soils.

The soil texture map of the province of Loja (MAG, 2019) agrees with the perception of farmers mainly in Catamayo, Celica, Pindal and Puyango, where according to the textural class, the farmers indicated that soils are difficult to work with because they tend not to drain when it rains or their crops are irrigated. The research carried out by Rogé et al. (2014), states that clay soils were described as the most productive in drought years but also difficult to cultivate in humid years; the opposite occurs with sandy soils, which are easier to cultivate in humid years but are the least productive. This will also depend on the crop; in clay soils the yield of the rice grain is higher (Dou et al., 2016), and the areas of Zapotillo and Macará are producers of good quality rice.

Most of those surveyed believe that their soils are less stony and easy to work with. García et al. (2012) explain that fertile soil is quite soft and comfortable to work with. When fertility decreases, the soil becomes harder and more compact. This is in agreement with the results obtained from Kome et al. (2018), where about 40% of the respondents understood that soils dominated by stones and rocky outcrops are infertile, as they impede root development, promote nutrient leaching and limit water retention.

More than 50% of the surveyed farmers in the towns of Puyango, Pindal and Zapotillo consider that their soils are deep, which allows

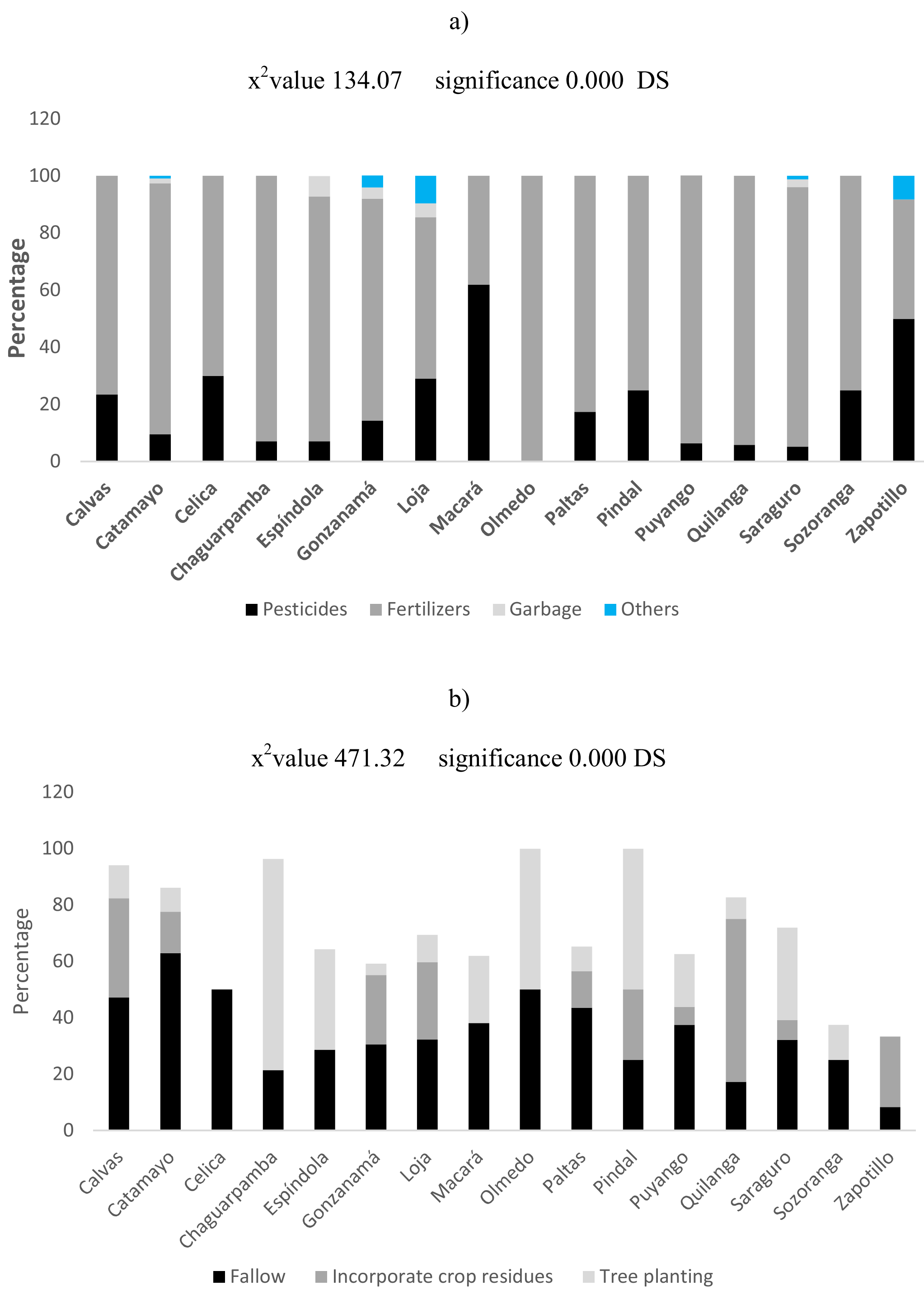

Fig. 6. Farmers perception about soil contamination and soil conservation in the study area: a) main forms of soil contamination, and b) soil conservation strategies according to local knowledge (the three main soil strategies mentioned are presented) in the province of Loja, (*n*= 610), DS indicates significant as a result of chi-square test (P<0.05).

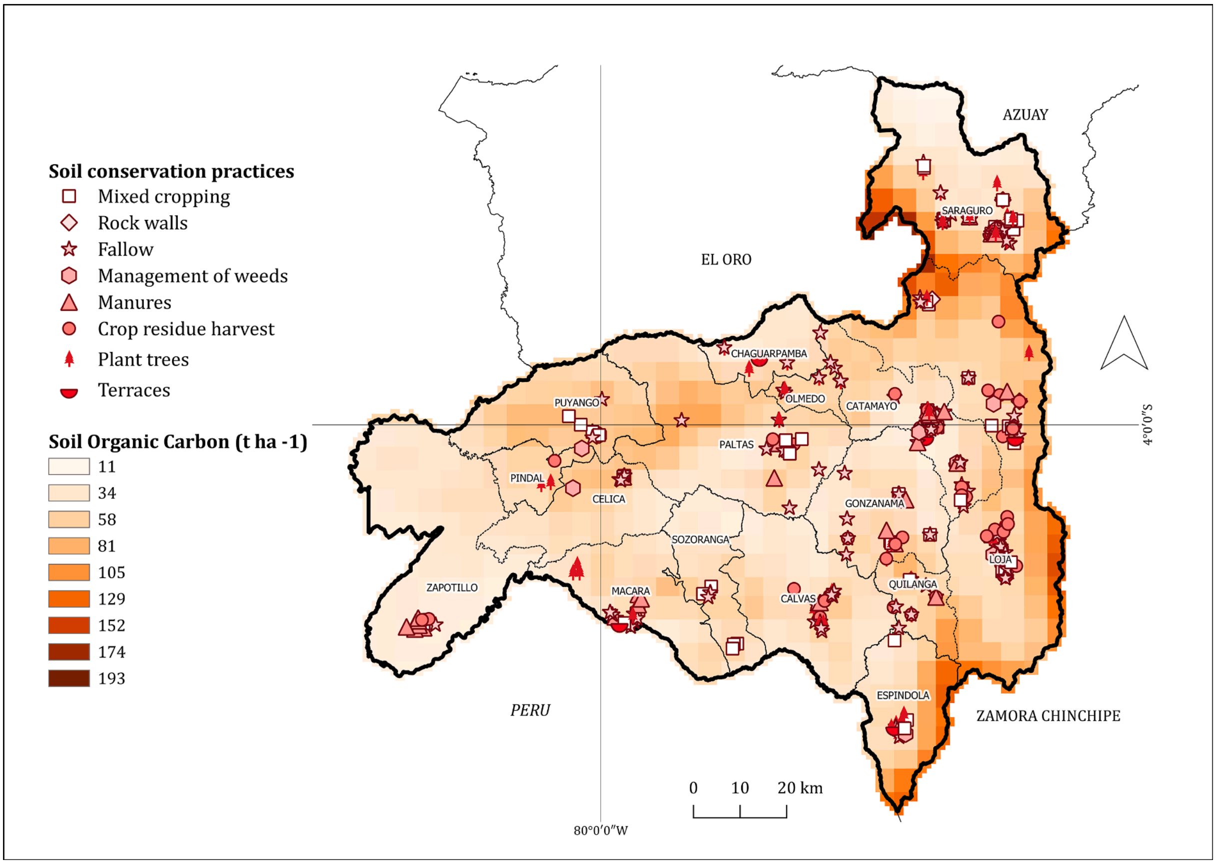

Fig. 7. Contrasting between soil organic carbon (SOC) stocks according to the stocks Carbon map of continental Ecuador 2019 (MAG, 2019) versus soil conservation strategies according to local knowledge in the province of Loja.

them to cultivate a variety of species such as fruit trees or perennials. However, the main crops that they plant are maize, rice and onion with the exception of Puyango which plants coffee that has a preference for rich and deep soils. Calvas and Olmedo had shallow soils, which are not suitable for crops since the roots of common plants cannot penetrate in order to get to the water and nutrients essential for their development (FAO, 2013). There are perennial crops that are grown in the province of Loja which require deep soils; however, the depth is a limiting factor for certain crops (Espinosa and Lima, 2019).

For farmers, good harvests are an indicator of fertile soil, as indicated by farmers in 14 of the 16 localities. Records of crop yields at the farm level are limited due to the fact that the farmers typically cultivate smaller plots (Brinkmann et al., 2018).

4.2. Main sources of soil contamination

In the study sites, fertilizers are considered a main source of contamination, and while they are applied to the soil to improve crop yield (Fig. 6a), it is done so without a specific fertilization plan, simply based on amounts recommended by store owners or other farmers. In some cases, the cheapest fertilizers are used and, at times, a lack of farmer training leads to inadequate fertilization.

Two of the most used fertilizers are urea and 10-30-10 (fertilizer that has 10% nitrogen, 30% phosphorus and 10% potassium), both of which are commercially available within the study area and are the most economical. Contamination is a factor because most fertilizers have nitrogen (N) and plants absorb less than half of the N from the fertilizer, where the rest of the N is lost through leaching or enters into the environment as nitrous oxide (Bahr et al., 2015); also, excessive use of fertilizers can negatively affect soil microorganisms (Kopittke et al., 2019; Singh et al., 2020).

The higher precipitation in areas such as Saraguro, Celica, and Catacocha could increase fertilizer leaching compared to other studied areas, where precipitation is lower, although this depends on additional edaphic characteristics and agricultural practices in each area. Therefore, implementing sustainable practices such as the correct application of fertilizers is key to reducing soil contamination.

Pesticides, based on the opinions of farmers, also contaminate the soil due to overuse in the control pests, diseases and weeds; according Singh et al. (2020) also reduces beneficial soil microorganisms. In addition, in several farms the packaging containers for the agrochemicals are not disposed of properly and remain on the land and are added to other types of inorganic household residues that affect the health of the soil, which ultimately causes an additional decrease in microorganisms and lowers the productivity of crops in the long term (not to mention the effect on the health of both the consumer and producer) (Damalas and Eleftherohorinos, 2011).

4.3. Soil management and conservation practices

Farmers manage the soil in a traditional way, with little technology, where manual tillage predominates by loosening the soil's surface layers and prepares it for planting. In addition, the irregular topography of the study sites does not always allow for the use of a tractor. According to the geopedological map of MAG (2019), 75% of the surface area of the province of Loja present with extreme slopes. In Catamayo, Macará, Zapotillo, and Paltas, farmers have the opportunity to use tractor plowing (31%), while 12% utilize an ox or other similar practices, where terrain conditions limit accessibility for agricultural machinery.

There are researchers such as those of Baker et al. (2007) and Dumanski et al. (2006) that indicate that any type of mechanical tillage is detrimental to soil conservation; however, this depends on soil management practices (Henke et al., 2019).

Approximately 30% of the surveyed farmers do not use irrigation for their crops, due a lack of water. They wait for the rainy season for sowing, especially in Quilanga, Celica, Chaguarpamba, Pindal and Puyango. In Zapotillo and Macará they use gravity and sprinkler irrigation because they have installed irrigation systems. In general, it is widely recognized that low water flow influences the vulnerability of rural families, while the few sources of water that may exist in an area can be easily contaminated by the unsustainable management of livestock (Hill et al., 2005; Sosa and Larrea, 2014).

Farmers in Ecuador have little support, a lack of government interest and a shortage of labor in sustainable land management practices which affect crop yields and limits soil conservation (Cevallos and Estrella, 2013). This correlates with studies by Desbiez et al. (2004) and MAG (2016), who state that less than 15% of farmers possess agricultural technology and socioeconomic conditions, and more than half do not even use oxen.

Management practices to maintain and increase soil fertility vary from farmer to farmer, even at the local level, because their knowledge and perceptions are generally based on experience, which allows them to detect differences in soil fertility levels within their farms (Dawoe et al., 2012; Kome et al., 2018). In the various studied localities, farmers mentioned that they practice different strategies for soil management and conservation.

Tree planting was the second most mentioned option as a strategy to conserve the soil. The farmers in some cases plant multipurpose species such as pork nut (*Vachellia macracantha*), which offers several alternative uses, such as for the extraction of firewood, providing shade for animals, and, above all, contributing carbon and nitrogen content to the soil that is lost through erosion, runoff and leaching (Bationo et al., 2007; Romero et al., 2020).

Other strategies used by farmers include incorporating crop residues and animal manure; they are low-cost practices and most farmers have crops and raise animals on their farms (cows, guinea pigs, chickens, sheep, goats, rabbits). The organic residues facilitate the formation of organic amendments and help to conserve the soil (Dumanski et al., 2006; Palm et al., 2014).

In the Espíndola and Sozoranga areas, crop association predominates, as mentioned by farmers who associate corn with legumes, beans (*Phaseolus vulgaris* L.), and peas (*Pisum sativum* L.), which provide nitrogen and nutrients to the soil and also serve as food for domestic animals. Lal (2004) observed that leguminous crops reduce C and N losses from the soil; Blanco-Canqui and Lal (2009) also mentioned that crop residues and animal manure should be incorporated, otherwise the nutrient reserves decrease and soil compaction increases.

A lower percentage of farmers reported using terraces, adding perennial plants such as napier grass or elephant grass (*Pennisetum purpureum*) which is a perennial plant native to Africa, generally used as fodder because it has fiber and rhizomatous roots. This makes it an effective means for controlling soil erosion (Romero et al., 2020). Considering all the knowledge that farmers have, it can be compared to current scientific knowledge to provide for better conservation and sustainability strategies for soil resources within the province of Loja.

In general, it is key to promote, conserve and improve in certain cases these types of strategies that farmers have used for generations, because farmers know them well and widely, and they promote the local conservation of agro-biodiversity and ensure better soil management. This ultimately contributes to a decrease in greenhouse gas (GHG) emissions, which are the result of pesticide and fertilizer production (Altieri and Nicholls, 2008; Harvey et al., 2008).

4.4. *Acquisition of knowledge on soil management*

Local knowledge inherited by children from parents is an important source of knowledge for soil management in the study areas. This is in agreement with research by Dumanski et al. (2006) and Dumanski and Peiretti (2013) who maintain that the acquisition of traditional soil knowledge is procured from successful farmers, including local, regional, national Governmental sources, and especially from direct farmer to farmer training. In this way, the capacity of the farmer and the sustainability of the agricultural system is improved.

Other options to acquire knowledge were experience and training, mainly in Macará, Zapotillo, Espíndola and Sozoranga. This is in line with the research of Buthelezi-Dube et al. (2020), where they conclude that knowledge acquisition provides outlets towards developing new effective and relevant technologies for soil fertility assessment.

The fertility of the soil has decreased over time, and according to the criteria of the farmers, this decrease in fertility was more apparent among the farmers of Sozoranga, Quilanga, and Saraguro, whereas for the farmers of Chaguarpamba and Olmedo, the fertility has not changed. These findings are a warning about the soil management practices used by farmers, as they are not always sustainable and they should be implemented and complemented with other strategies that contribute to the conservation of this resource.

5. Conclusions

Farmers in the province of Loja have extensive knowledge about soil fertility, acquired over time mainly from their parents and grandparents. They mention that their soils have suffered a loss of fertility due to inadequate soil management, being perceived as poor or less preferable for their crops. Respondents identify soil fertility through their experience using visible indicators associated to loam texture, darker soil color, deeper soils; the contrast of edaphic indicators with local and scientific knowledge showed a high level of agreement. The findings demonstrate that some practices to soil management can contribute to soil conservation, these practices can be strengthened, extended to other farms and complemented with other practices, which is very important for future management practices and soil fertility conservation that can significantly influence the techniques that farmers implement.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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