



Rescuing local knowledge with regards to soil management and fertility in the Amazon Region of Ecuador

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ABSTRACT

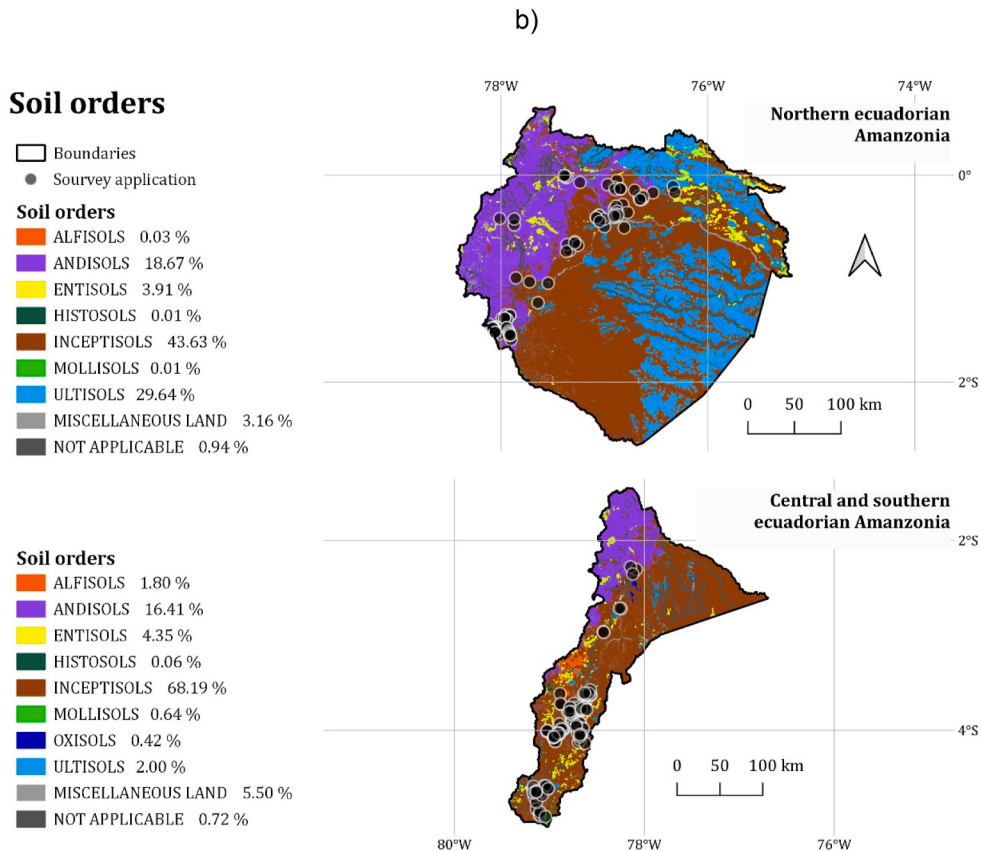
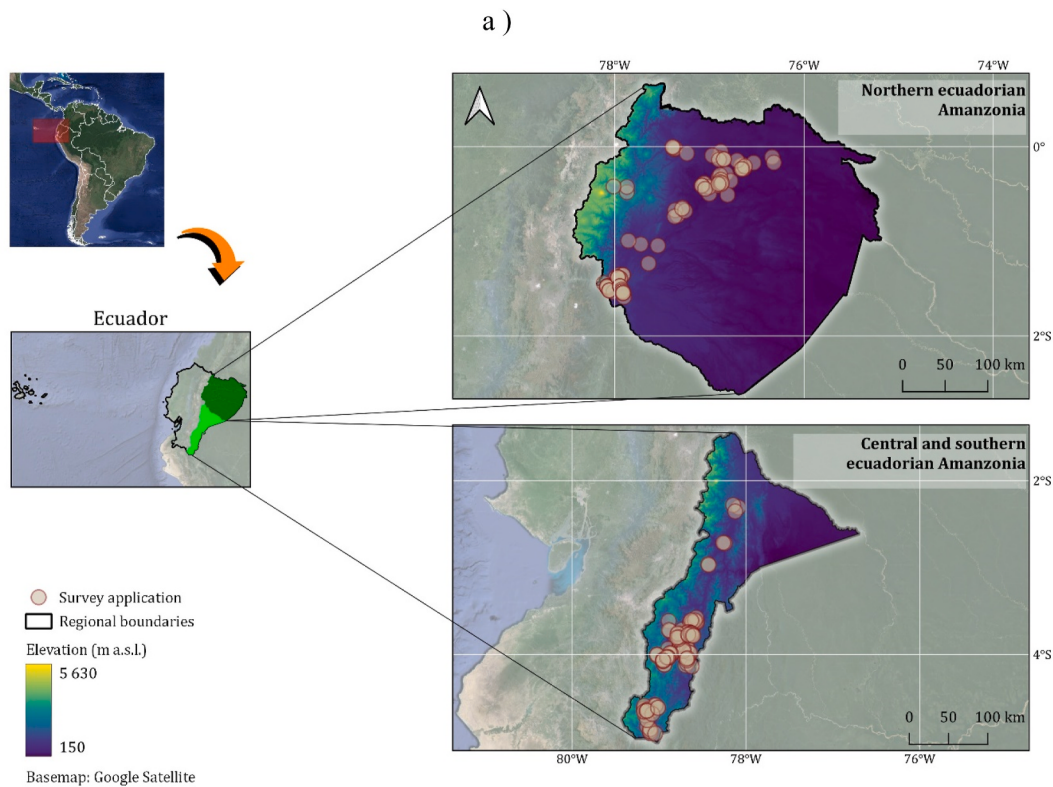
Sustainable soil management methods that consider farmers' needs and soil conservation, require the integration of scientific knowledge and farming practices. Therefore, this study has asked a. How do farmers perceive fertility indicators in relation to their management in agriculture? b. What strategies do small farmers implement to maintain soil health on their farmland? c. Are there correlations between scientific findings and farmers' perceptions of soil management indicators and practices in the Ecuadorian Amazon? A total of 287 surveys were applied with 35 questions that covered the general data of the respondent, visible indicators of soil fertility, soil management and conservation practices, as well as knowledge acquisition. The soil scientific data were obtained from the map made by the MAG and FAO (2018) of the locations where the surveys were conducted. The results show that farmers have an in-depth knowledge with respect to soil fertility, identifying several visible indicators, including some plants that indicate productive soils, while utilizing various practices that degrade the soil and others that contribute to soil conservation at the local level. Although the indicators used by the farmers were mainly based on observation, in many respects they coincided with scientific assessments of fertile or infertile soils. These farmers, with their vast practical experience and knowledge accumulated over generations, developed a deep understanding of the telltale signs of soil fertility. There is not always concordance between the two forms of knowledge, however, the synergy between traditional and scientific knowledge illustrates the importance of integrating different forms of knowledge for effective and sustainable land management.

1. Introduction

One of the primary natural resources on which much of the world's population depends is soil, used by many people as a means of livelihood and subsistence (Tarfasa et al., 2018). Farmers use this resource, making decisions based on the traditional knowledge of their forebears, customs and above all on the knowledge acquired by direct interaction with the environment and then transmitted

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Fig. 1. a) Location of the study area (Ecuadorian Amazon) and agricultural sectors where surveys were applied, depicted with a digital elevation model. b) Soil orders of the Amazon Region of Ecuador according to the Geopedological map of continental Ecuador (MAG, 2020). The map was disaggregated into northern, and southern Amazon for better visualization.

over time to their descendants, simultaneously adapting to new knowledge and applying this in their production practices (Dawoe et al., 2012).

Traditional knowledge is based on one's own or acquired experience, in addition to observation; this is different from scientific knowledge, which is developed through controlled experimentation (Winklerprins, 1999). As such, traditional knowledge has been applied by indigenous peoples for thousands of years and has not been presented within scientific research on soil management (Payton et al., 2003; Rushemuka et al., 2014) and conservation and instead is always represented as 'primitive experiences and activities' with relation to soil (Barrera-Bassols and Zinck, 2003). Scientists rarely value indigenous soil systems because of the different properties considered and languages used across regions. However, both systems report the ways humans seek to understand natural patterns and processes, albeit in significantly different ways. Typically, it is because soil scientists are not trained in the methods for accessing knowledge contained in indigenous systems.

In recent years, attention to local knowledge has increased, resulting in the recognition of small-scale farmers, who maintain direct contact with their soils, facing increasingly complex management problems; therefore it is necessary to further research programs within the field of soil productivity, taking into account the perceptions of the local population and their traditional knowledge (Kuldip et al., 2011). Other important aspects to understand in regards to how farmers correlate to soil properties, is to understand the knowledge that they possess, based on their experience so that they are considered and included in the research.

Ethnopedologists have observed how indigenous people maintain a strong soil classification system, the same one that has been used as a guide in local management for several generations (Gruver and Weil, 2007). To cite just a few recent examples, it is known that among the savannas of Cameroon, more than 70% of farmers rely on traditional methods to identify productive agricultural land (Ndaka et al., 2015). In northern Ethiopia, traditional knowledge has been seen to play a fundamental role in soil fertility management (Occelli et al., 2021). Sinha et al. (2020) revealed that in northwestern India, farmers have extensive knowledge of the quality of their soils, and that it coincides with laboratory-derived determinations of parameters. In northwestern Brazil, a close relationship between the prevailing peasants' knowledge and knowledge within the context of soil classification approaches has been observed (Hill et al., 2020).

Despite the importance of farmers' knowledge, some of the local indicators are not capable of recording changes that occur over time nor are they sensitive to detect the long-term state of soil health (Hermans et al., 2021). This author mentions that when analyzing physical-chemical parameters with the perception of farmers, they found discrepancies on the effect of incorporating crop residues on soil erosion. Gowing et al. (2004) also identified some discrepancies between local and scientific knowledge when classifying soils, which could be linked to differences in the methodologies used. In addition, they noted that the classifications made by farmers are often based more on criteria of comparison than on an established hierarchical structure. In any case, it is essential to seek synergies and complementarities between local knowledge rooted in the practical experience of communities and scientific knowledge based on rigorous research.

These examples highlight the importance of valuing farmers' knowledge, in order to improve and sustain agricultural production potential, especially in rural areas (Pauli et al., 2012; Rogé et al., 2014). In addition, they are a reference for farmers to use in planting crops, livestock management, fallowing, or planting forests. The practices utilized for the management of this resource are all dependent upon how the soil is used (fertilization, incorporation of organic matter, ploughing, crops planted, irrigation etc), the type of irrigation (drip, sprinkler, gravity), as well as pruning, pest and disease control, which is directly related to the experience and knowledge acquired (Kuria et al., 2018; Suzuki et al., 2014; Trujillo et al., 2018).

However, farmers' knowledge of soil fertility is still very limited (Ndaka et al., 2015). In this regard, Braidotti et al. (2020) conducted a meta-analysis of studies conducted in developing countries on local and technical soil indicators. Fifty-eight percent of these studies were concentrated in Africa, followed by 23% in Latin America, with a focus on Mexico and Brazil, and the remaining 16% in Asia. In the case of Ecuador, few works have been published that have researched this subject or have been developed in the northern and southern Ecuadorian Sierra (Castillo et al., 2020; Jiménez et al., 2021, 2022), while in the other continental, natural regions of this country (known as Costa and Amazon), no research has been reported on this topic. Therefore, this research address a. How do farmers perceive indicators of soil fertility and soil contamination in relation to soil management in agriculture? b. What strategies do small farmers implement to maintain soil health on their farmland? c. Are there correlations between scientific findings and farmers' perceptions of soil management indicators and practices in the Ecuadorian Amazon? which is expected to contribute to providing viable alternatives to implement and to strengthen the sustainable management of this resource in the area.

2. Materials and methods

2.1. Study area

The study area is located in the Ecuadorian Amazon (Fig. 1), with an altitudinal gradient ranging from 500 to 2500 m above sea level (a.s.l), with the highest place in the region being the Sumaco volcano in the province of Napo with a height of 3900 m a.s.l, taking into account that the remaining high points do not exceed 2000 m of altitude (Espinosa et al., 2018). The precipitation levels in eastern Ecuador vary from east to west, showcasing an average annual rainfall of 2500 mm along this gradient (Sánchez et al., 2018). For the

central area 3245 mm of rain is recorded, considering the north to south gradient, where in the north, the highest rainfall is in Cotundo (Province of Napo – north zone) with a value of 4590 mm.

In the Puyo area (North zone), annual precipitation ranges from 4590 mm to 3245 mm, while to the south it varies between 2550 mm and 2110 mm. The province of Zamora Chinchipe experiences the least precipitation (south zone), averaging 1910 mm annually (Morán-Tejeda et al., 2016; Sánchez et al., 2018). With regard to temperature, the eastern area shows an average annual temperature of 20 °C, however, the temperature increases at the eastern border of the study area as well as from south to north (Morán-Tejeda et al., 2016). Humidity levels range from 85% to 90% (Sánchez et al., 2018).

The main soil orders are the Andisols, Inceptisols and Ultisols (Fig. 1). They are acidic soils, with medium to high contents of organic matter, but poor in nutrients due to high rainfall, low in calcium, magnesium, and potassium, shallow, with bulk density of 0,8 to 1,2 g/cc (Jiménez et al., 2007; Calero et al., 2018).

In the Amazon Region about 54% of the farms have between 10 and 50 ha, while 31% have an area of less than 10 ha, the productive aptitude of the Ecuadorian Amazon for crop production corresponds to only 17,5% of the entire territory (Nieto and Caicedo, 2012). The main characteristic of the study areas is that they are used for cattle ranching, which is reflected in the presence of extensive extensions of pastureland. However, these areas are not limited to cattle ranching alone; a variety of crops are also grown, ranging from cocoa (*Theobroma cacao*), sugarcane (*Saccharum officinarum*), banana (*Musa sapientum*), and oil palm (*Elaeis guineensis*), palm heart (*Bactris gasipaes*) to corn (*Zea mays*), yucca (*Manihot esculenta*) and coffee (*Coffea arabica*, *Coffea canephora*), Pitahaya (*Hylocereus undatus*), among others (Nieto and Caicedo, 2012; Torres et al., 2022). The intensification of agricultural and livestock activities reduces forest areas. This increases the continuous pressure on natural resources and the need to adopt more sustainable agricultural practices that balance production with environmental conservation.

2.2. Gathering information and sample size

The surveys were collected in the Ecuadorian Amazon, which was divided for this study into two zones: north and south. The northern region includes the provinces of Napo, Pastaza, Orellana, and Sucumbíos, where 38,5% of the total area is dedicated to crops, including pastures for livestock, polycultures or farms (Huera-Lucero et al., 2020; Vargas Burgos et al., 2022). On the other hand, the southern region includes the provinces of Morona Santiago and Zamora Chinchipe, representing 61,43% of crops and livestock (Vargas Burgos et al., 2022).

The choice of farms was carried out considering the availability of the people involved. However, in certain areas of the Amazon, the information collection process could not be carried out in an equitable manner due to the presence of isolated communities and villages, which made it difficult to conduct surveys in those places.

A semi-structured survey was designed with 35 open and closed-ended questions (Jiménez et al., 2021), divided into subtopics as shown in Fig. 2. 287 surveys were conducted, the number of which were based on the population dedicated to agriculture in the Amazon Region (north, and south zone) which includes 25623 producers and/or families (INEC, 2014) and a sample size for accuracy

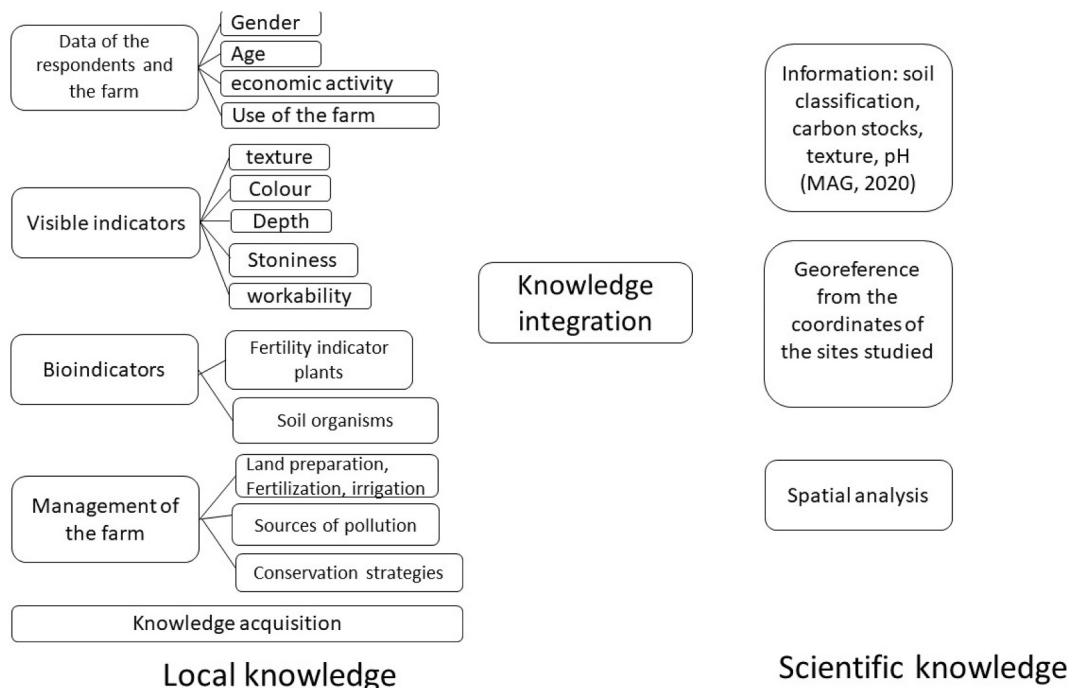


Fig. 2. Main parameters addressed in the survey applied to local farmers and compared with scientific knowledge.

levels of $\pm 7\%$, where the confidence level is 93% (Israel, 1992).

The open-ended questions were considered under certain farmer criteria as shown in Table 1.

The information on carbon stocks, pH and textural class (0–30 cm) obtained from the national maps was extracted from the databases of the Ministry of Agriculture and Livestock (MAG) and the Food and Agriculture Organization of the United Nations (FAO, 2020), which were constructed from soil profiles sampled in the Amazon region. This information was consolidated from the study sites and subjected to statistical analysis. Regarding the parameters data, 100 data points were used for south zone and 200 data points for north zone. In total, we worked with 300 values extracted from the map of the in the places where the surveys were conducted. Maps for soil parameters such as carbon stocks, clay and pH were created in raster format, with a spatial resolution of 1 km.

Information surveys were georeferenced to a point shape file using the Spreadsheet Layer plugin (QGIS-SpreadSheetLayers, 2021), with open source QGIS software version 3.20-Odense (QGIS Development Team, 2021), where geospatial analysis was performed and maps in scaled vector format 1:25000 were generated according to the contrasted information of the main indicators of soil fertility.

This information was consolidated from the study sites and subjected to statistical analysis. Regarding the carbon stocks parameters data, 50 data points were used for each study site. In total, we worked with 300 values extracted from the map of the (MAG, 2020) in the places where the surveys were conducted.

Table 1

Parameters recognized by farmers to determine soil characteristics.

Features	Parameters considered by farmers
Do you consider the soils of your farm?	
Clay	• Soil sticks to hand tools easily. • Water accumulates. • If you mechanically till the soil after a heavy rain it gets “damaged”. • Soil sticks to your boots.
Sandy	• You have to water constantly. • They are poor soils. • Dusty soils when there is wind.
Loam	• They are fertile soils. • Does not stick to the Blade. • It is easy to work. • They are medium soils, neither as heavy as clay nor as loose as sand. • Soils that retain humidity.
Do your soils have a lot of stoniness?	
Yes	• Difficulty and resistance for tillage, when tillage is with a tractor it tends to get stuck constantly, especially if they are large rocks. • Difficulty to retain water. • When plowing the soil by hand, the tools are hit by the presence of stones.
No	• Loose soils, tillage with machinery or by hand is easily accomplished. • Retain water.
Are your soils easy to work with?	
Yes	• Loose soils, tillage with machinery or by hand are easily accomplished. • Seed is gently buried. • Retains water. • Soil remains loose. • Dark color.
No	• Difficulty and resistance for tillage. • Not easy to sow. • Difficulty to retain water. • Compact soils. • Light color.
Are the soils of your farm?	
Shallow	• Plants with superficial roots are grown, as short-cycle crops • Perennial crops do not have good yields. • When plowing the land, you can see its layers of different colors and soil structure.
Deep	• The cultivation of perennial plants, such as fruit trees, that have deep roots, is promoted. • Crops planted in deep soils give good yields. • When plowing the land, the black or brown color is uniformly observed.
Which soils are better?	
Near the banks of the rivers	• Sediment accumulates due to flooding.
With slope	• There is greater soil erosion.
Plains	• Water does not accumulate.
Before planting how do you prepare the soil?	
Plow with ox	• Till the land with animal traction, mainly with oxen.
Plow with tractor	• Soil tillage with machinery or other motorized equipment.
Manual plow	• Preparation of the land using hand tools such as hoe, rake, and shovel.
Weeding	• Eliminate weeds or weeds from crops.
Do you have to add humus or fertilizers to grow?	
Animal manure	• Manure from cattle, sheep, goats, poultry, guinea pigs and other minor species.
Fertilizer	• Chemical fertilizers mainly nitrogenous or with phosphorus and potassium content.

2.3. Data analysis

Data from physical surveys were harmonized into an Excel database. To compare local knowledge between the two study zones, the statistical analysis used was the chi-square test ($p < 0,05$). As for the analysis to compare the pH, Texture and Carbon of the soils of these zones, a Mann-Whitney test ($p < 0,05$) was used since the data were not normal, also, Spearman statistical correlations ($p < 0,05$) were made between the chemical variables of the soil and, between the comparison of local knowledge with the scientific knowledge of soil texture. To evaluate if there are significant statistical differences in the data of the physical-chemical analyses of the soil between zones, a non-parametric analysis was performed with the Mantey Whitman test ($p < 0,05$) using SPSS 24.0 statistical software.

3. Results

There were 63% men and 37% women of the 287 farmers surveyed. Their age ranges from 17 to over 70 years; ethnicities were 4% indigenous, 8% white and 87% mestizo. Regarding education level, 7% had no education at all or did not answer the question, 14% reported primary education, 42% secondary education and 37% higher education (Table 2).

3.1. Soil fertility indicators

The indicator that predominates in zones studied is soil color, being black mentioned by 60% of the farmers as a characteristic that distinguishes fertile soils, followed by the brown color (Table 3), with farmers' perception of darker soils in the southern zone. As reported by the farmers, approximately 60% of their soils have clay, which has more than 30% sand (Table 3). In the study area 83,5% of farmers consider that their soils are not stony and, 89% report that they are easily workable.

Regarding the depth of the soils, our results indicate, according to the perception of farmers, more than 60% suggest that their soils are shallow, which limits the sowing of species with deep roots. Our findings also showed that in the opinion of the respondents (41,8 %), the most fertile soils are those that are close to the riverbanks (Table 3).

The presence of various organisms was also considered as an indicator of soil fertility. Earthworms were reported approximately 100% present in two study zones (96,4 and 97,1% in south and north zones respectively); crickets, beetles, spiders, snails, ants, etc. were also mentioned (Table 3).

In Fig. 3 it is observed that the textural class of the soil differs with the criteria of the farmers, especially regarding sandy soils. There are more coincidences between clay and loamy soils according to local and scientific knowledge.

In both areas, farmers emphasize that crops thrive mainly on fertile soils. Among the most prominent crops are a variety of vegetables such as *Lactuca sativa* L., *Brassica oleracea*, medicinal plants and fruit trees, including citrus such as *Citrus × sinensis* L. (orange), *Citrus reticulata* L. (mandarin), and *Citrus × lemon* L. (lemon), *Psidium guajava* L., *Carica papaya* L., *Inga edulis* y *Musa × paradisiaca*, *Theobroma cacao* L.

Regarding the plants indicating poor soils, the respondents identified most notably the grasses *Cynodon dactylon* L. Pers. (grass), *Digitaria decumbens* L. (setaria), and *Brachiaria decumbens* L. (brachiaria) (Fig. 4). Regarding the plants indicating poor soils, the respondents identified most notably the grasses *Cynodon dactylon* L. Pers. (grass), *Digitaria decumbens* L. (setaria), and *Brachiaria decumbens* L. (brachiaria) (Fig. 4). Weeds or arvenses are in the same way bioindicator plants according to farmers, as they develop in a

Table 2

Variables gender, age, ethnic group, and education level according to the perceptions of farmers across different zones of the Ecuadorian Amazon in relation to various soil variables (Chi-square test, $p < 0,05$).

Parameter	South Zone (%) 168 surveys	North Zone (%) 69 surveys	Total (%) 237 surveys	X value	Significance
Gender					
Male	57,7	76,8	63,3	7,659	0,006 ^b
Female	42,3	23,2	36,7		
Age					
17–35 years	44,0	33,3	40,9	7,696	0,103
36–55 years	33,3	46,4	37,1		
56–70 years	15,51	13,0	14,8		
No response	3,6	7,2	4,6		
Ethnic group					
Mongrel	86,9	92,8	88,6	10,631	0,005 ^a
Indigenous	2,4	7,2	3,8		
Education level					
Elementary School	11,9	18,8	13,9	12,685	0,013 ^b
High School	37,5	52,2	41,8		
Superior	41,1	29,0	37,6		
None	4,8	0,0	3,4		
No response	4,8	0,0	3,4		

^a Statistical difference significant at 0,01.

^b Statistical difference significant at 0,05.

Table 3

Main indicators of soil fertility according to the perception of farmers among the different zones of the Ecuadorian Amazon against various soil variables (Chi-square test' $p < 0,05$).

Question	South Zone (%) 168 surveys	North Zone (%) 69 surveys	Total (%) 237 surveys	X value	Significance
Are your soils colored?					
Yellow	5,4	5,8	5,5	9,007	0,061
Brown	21,4	37,7	26,2		
Black	65,5	49,3	60,8		
Reddish	5,4	7,2	5,9		
No response	2,4	0,0	1,7		
Do you consider the soils of your farm?					
Clay	16,1	37,7	22,4	13,971	0,003 ^a
Sandy	10,7	11,6	11,0		
Loam	70,8	49,3	64,6		
No response	2,4	1,4	2,1		
Do your soils have a lot of stoniness?					
Yes	16,1	7,2	13,5	3,286	0,193
No	81,0	89,9	83,5		
Don't know	3,0	2,92	3,0		
Are your soils easy to work with?					
Yes	89,9	87,0	89,0	0,677	0,713
No	9,5	11,6	10,1		
No response	0,6	1,4	0,8		
Are the soils of your farm?					
Shallow	60,7	85,5	67,9	14,156	0,001 ^a
Deep	36,9	14,5	30,4		
No response	2,4	0,0	1,7		
Which soils are better?					
Near the banks of the rivers	50,0	21,7	41,8	22,635	0,000 ^a
With slope	22,0	18,8	21,1		
Plains	26,8	56,5	35,4		
Don't know	1,2	2,9	1,7		
Do your soils have worms or other types of living organisms?					
Yes	96,4	97,1	96,6	0,068	0,794
No	3,6	2,9	3,4		

^a Statistical difference significant at 0,01.

wide diversity of soil types. In the Ecuadorian Amazon we find *Sida acuta* Burm. F. (*escobilla negra*), *Portulaca oleracea* L. (verdolaga), *Baccharis latifolia* Pers. (chilca), *Parthenium hysterophorus* L. (parthenium weed).

3.2. Management and conservation strategies

Table 3 shows that most respondents use manual plowing, probably due to the steep slopes, economic constraints, with a few using tractor plows.

Farmers in the study locations have mostly composting plants (Table 4); however, they also use synthetic fertilizers such as urea, 10-30-10, and other compound fertilizers marketed in the region (e.g., green strength and blue nitrofoska) to fertilize their soils.

Our findings indicated that resting the soil, associating crops, and incorporating residues were the strategies most used by farmers (Fig. 5). However, there were also fundamentally contrasting opinions on the same issue such as planting trees and terraces that were mentioned only in South zone and to a lesser extent in North zone despite their recognized benefits (Fig. 5).

Most of the respondents explained that they do not use irrigation because it is not necessarily due to the high rainfall (Table 4). Table 5 shows that no significant correlation was found between people's perception of whether water accumulates in the soil due to the amount of irrigation or rainfall, and the different textural classes (sand, clay and loam).

3.3. Forms of soil contamination

In most of the study locations (55,7%), respondents consider chemical fertilizers to be the biggest contaminants of the soil (Table 4, Fig. 3). In the southern region, farmers identified chemical fertilizers as the main sources of contamination, while in the northern region, pesticides were the most prominent. On the other hand, the remaining alternatives, such as garbage, mining, and organic fertilizers, accounted for less than 15 % in both study areas.

3.4. Knowledge acquisition

Approximately half of the respondents (54 %) indicated that their knowledge had been inherited, which is the opposite what is happening today. A significant portion of respondents report that the knowledge they possess is mainly inherited from their parents

Soil texture

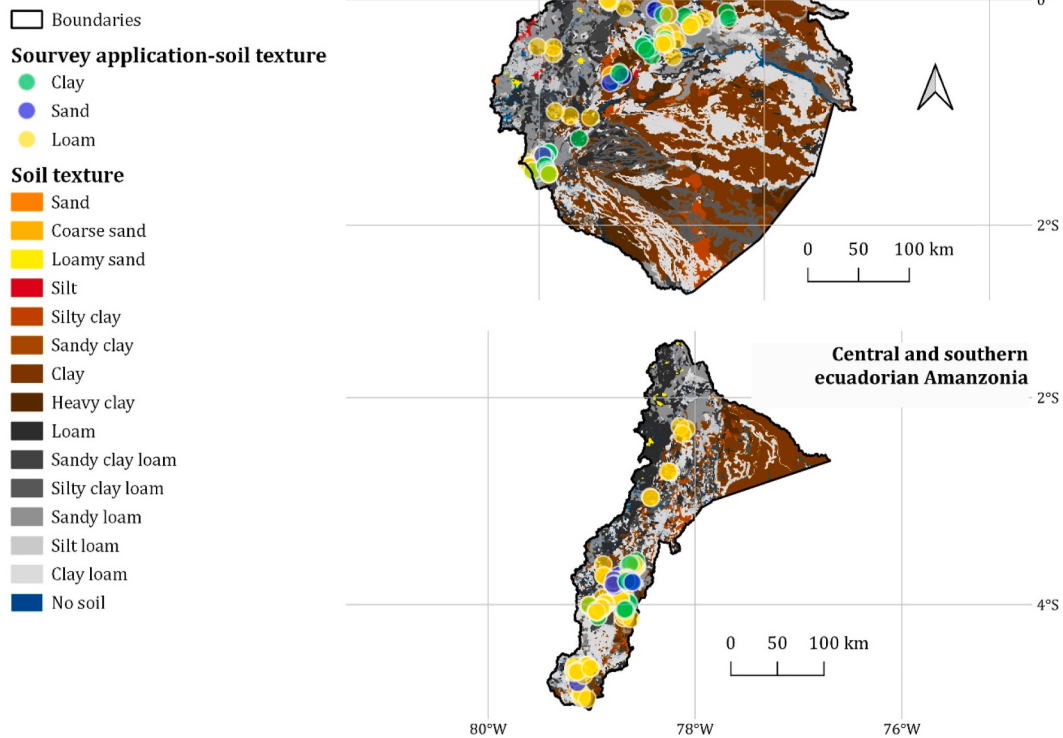


Fig. 3. Contrast of textural classes (MAG, 2020) with the perception of farmers in the Ecuadorian Amazon. The map was disaggregated into northern, and southern Amazon for better visualization.

and grandparents, as stated by 42,2% of respondents, which has allowed peasants and indigenous people to develop or inherit agrosystems that have adapted well to local conditions (Value 7,228, significance 0,027).

3.5. Physical-chemical parameters

It can be seen in Fig. 6 that there were no significant statistical differences between the northern and southern zones.

The soil pH of the investigated sites is presented in two groups; north zone presents the highest values (less acidic) not showing significant differences between them. In another group South zone, which show lower or acidic values, without statistical differences between them (Fig. 6).

In general, there are also weak negative correlations between the percentage of clay and organic carbon in the soil ($r = -0,405$; $p < 0,001$) (strong clay, weak COS) and the organic carbon of the soil with the pH ($r = -0,162$, $p < 0,001$) (Strong COS, pH more acidic).

When examining the correlation between variables related to soil texture according to local knowledge and scientific knowledge, no significant correlation was found between the two ($r = 0,052$; $p > 0,05$). This suggests that local perceptions and knowledge about soil texture do not always necessarily coincide with scientific findings.

4. Discussion

4.1. Soil fertility indicators

The Ecuadorian East is characterized by abundant vegetation that provides organic matter to the soil, while also among these landscapes, the Sumaco and Reventador volcanoes contribute ash to the soil which darkens it (Sánchez et al., 2018).

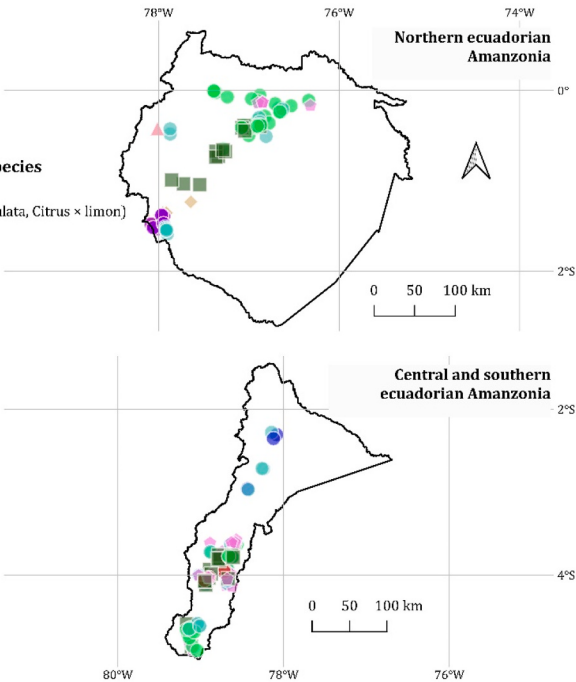
Light colors such as yellow, red and, white was mentioned with percentages of less than 8%. It can be assumed that these are poor soils within these areas, due to the high precipitation as well as high iron and aluminum contents that present with an acidic pH level (Sánchez et al., 2018). This is due to these soils containing large amounts of organic matter, unlike pale, red or white soils which were reported as unhealthy and therefore not suitable for agriculture (Jiménez et al., 2021).

Most of the Amazon Region of Ecuador has loamy soils, sandy loams and clayey loams, and by contrasting the information with the

a)

Fertile soil species

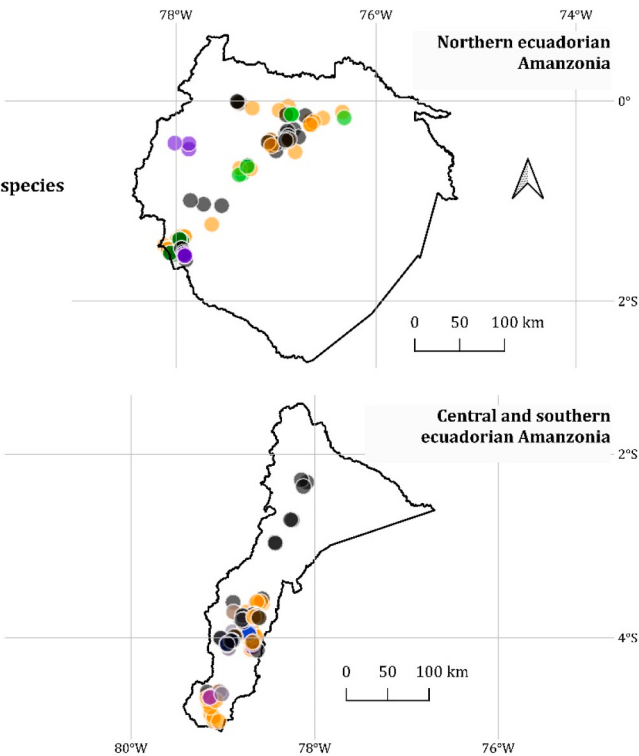
- Boundaries
- Sourvey application-fertile soil species**
 - Carica papaya
 - Citrus (Citrus × sinensis, Citrus reticulata, Citrus × limon)
 - Colocasia esculenta
 - Grassland
 - Inga edulis
 - Manihot esculenta
 - Medicinal plants
 - ◆ Musa × paradisiaca
 - ▲ Rubus caesius
 - Saccharum officinarum
 - Vegetables



b)

Infertile soil species

- Boundaries
- Sourvey application-infertile soil species**
 - Grassland
 - Moss
 - Pteridium aquilinum
 - Shrubland
 - Trees
 - Undergrowth



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Fig. 4. Plant species indicative of (a) fertile soils and (b) infertile soils. The map was disaggregated into northern, and southern Amazon for better visualization.

textural classes according to the [MAG \(2020\)](#), several discrepancies between the two types of knowledge are evidenced ([Table 5](#), [Fig. 3](#)). Approximately 11% of respondents (see [Table 3](#)) reported having sandy soils, which they perceive as fertile, especially when they are “sandy soils with presence of organic matter, “as described by some farmers. While this texture may favor aeration and drainage, which is beneficial for certain crops, sandy soils also tend to have a lower water and nutrient holding capacity compared to clay or loamy soils ([Osman and Osman, 2018](#); [Shabanpour et al., 2020](#)). Therefore, while farmers’ perceptions may reflect their practical experiences in the field, it is important to complement this perception with field analysis. Stoniness and workability are two characteristics that are directly related, because stoniness limits the workability of the soil ([Buthelezi-Dube et al., 2018](#)). In the case of small farmers who till the land manually, a restriction is incurred at the time of plowing the land for planting with stony soils. In a study conducted in East Africa and Bangladesh, farmers considered stony soils unsuitable for agriculture because they heat easily due to being shallow and covered by gravel, and because these soils burn crops quickly in times of drought ([Payton et al., 2003](#)).

The fertility of alluvial soil is more fertile than other soils, as perceived by farmers in the investigated areas, however, according to an [Al-Jabri \(2007\)](#), soils near rivers have low organic matter and nitrogen content, low cation exchange capacity but they are more porous. Grasslands and other crops in the alluvial plains are distributed throughout the Ecuadorian East, being more marked in the north.

Another important indicator is the vegetation; farmers in the area consider species such as critics to be indicators of fertile soils. Citrus fruits prefer sandy soils on the surface and more clayey in the deepest portions and have good yields in fertile soils with a pH greater than 5 and less than 7,5 ([Srivastava and Singh, 2009](#)).

Other species such as corn that are a cultivated species are destined for the most productive soils. Soils that were previously occupied by forests suffer the pressure of human activities, which has led to the loss of fertility ([Sollins, 1998](#)). [Kogge-Kome et al.](#)

Table 4

Parameters of local knowledge on soil management in the study areas (Chi-square test, $p < 0,05$).

Questions	South Zone (%) 168 surveys	North Zone (%) 69 surveys	Total (%)	X value	Significance
Before planting how do you prepare the soil?					
Plow with ox	33,9	0,0	24,1	84,845	0,000 ^a
Plow with tractor	2,42	9,0	10,1		
Manual plow	33,3	52,2	38,8		
Weeding	0,0	8,7	2,5		
Other/No response	30,4	10,1	24,5		
Do you have to add humus or fertilizers to grow?					
No response	23,8	40,6	28,7	8,514	0,014 ^b
Animal manure	55,4	36,2	49,8		
Fertilizer	20,8	23,2	21,5		
How is waste used after weeding and harvesting?					
Not used	7,7	1,4	5,9	11,193	0,011 ^b
Don't know	85,1	81,2	84,0		
They are Incorporated into the soil	4,8	15,9	8,0		
They are burned	2,4	1,4	2,1		
What type of irrigation do you use?					
Aspersión	4,2	5,8	4,6	11,156	0,025 ^b
Dripping	6,5	2,9	5,5		
Not used	79,8	72,5	77,6		
By gravity	6,5	18,8	10,1		
No response	3,0	0,0	2,1		
What strategies do you use to conserve soil?					
Mixed cropping	26,8	1,4	19,4	34,36	0,000 ^a
Rock walls	1,2	0,0	0,8		
Fallow	22,6	33,3	25,7		
Crop residue harvest	14,3	26,1	17,7		
Plant trees	13,1	23,2	16,0		
Terraces	10,7	1,4	8,0		
Other/no response	11,3	14,4	12,3		
What do you consider to be the main sources of soil contamination?					
Chemical fertilizers	62,5	39,1	55,7	25,302	0,000 ^a
Garbage	3,0	7,2	4,2		
Organic fertilizers	14,9	7,2	12,7		
Mining	0,0	1,4	0,4		
Pesticides	17,3	43,5	24,9		
No response	2,4	1,4	2,1		

^a Significant statistical difference at 0,01.

^b Significant statistical difference at 0,05.

Soil organic carbon

□ Boundaries

Soil organic carbon (north)

(t C ha⁻¹) (area %)

Very low (0-20) (0.04 %)

Low (20-40) (3.44 %)

Moderate (40-70) (67.61 %)

High (70-90) (21.69 %)

Very high (90-320) (7.22 %)

Sourvey application-fertile soil species

● Crop residue harvest

● Fallows

● Mixed cropping

● Other

● Plant trees

● Rock walls

● Terraces

Soil organic carbon (south)

(t C ha⁻¹) (area %)

Low (20-40) (0.28 %)

Moderate (40-70) (48.50 %)

High (70-90) (39.49 %)

Very high (90-320) (11.73 %)

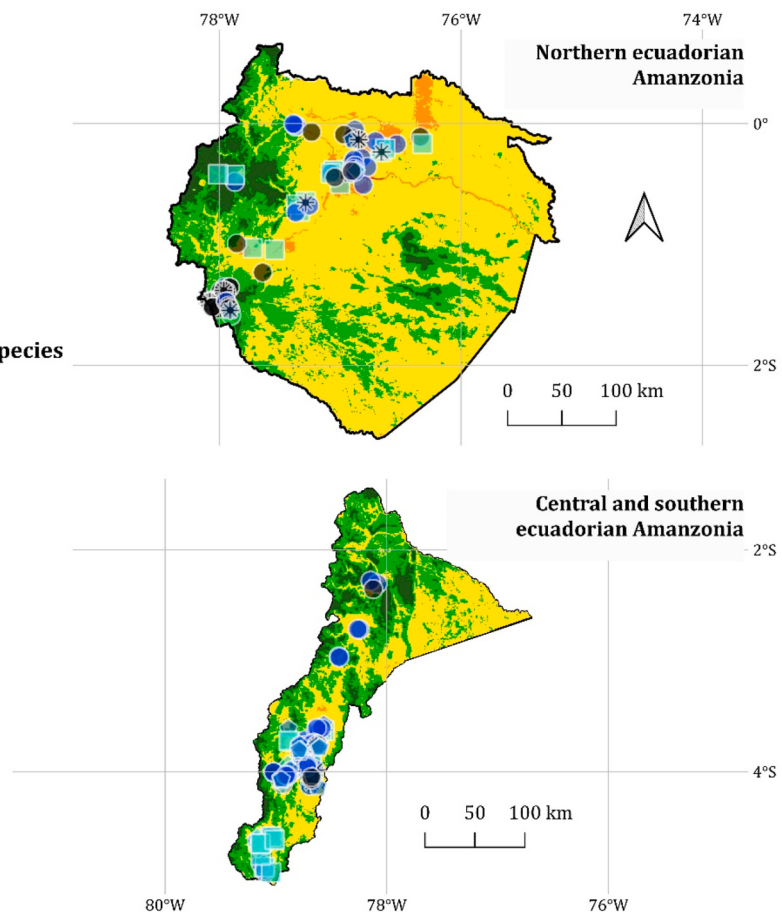


Fig. 5. Soil conservation practices used in the Ecuadorian Amazon and soil carbon stocks in the study area. The map was disaggregated into northern, and southern Amazon for better visualization.

Table 5

Percentage of respondents who perceive the accumulation of water in the soil, according to textural class.

Question	Soil texture	Percentage	Value	Significance
If you water or it rains a lot, does the water puddle on the soil?	Clay	9,41	0,68	0,794
	Sandy	3,83		
	Loam	16,38		
	No response/Do not know	0,70		
	Clay	10,10		
No	Sandy	3,83		
	Loam	23,34		
	No response/Do not know	0,70		

Carbon storage values in the two study areas range between 40 and 70 tons per hectare, which is considered a moderate range.

(2018), report that grasses can develop in fertile and infertile soils, due to the resistance they possess. The pastures are also used in the construction of terraces, to increase the protection of the soils, as is done in some places like Zamora Chinchipe (Yantzaza, Palanda and Zamora).

Ferns, spread across much of the planet, were also named as indicators of soil infertility, but, they are more diverse in tropical regions and develop in better proportion in humid and misty sites (Asanza et al., 2012). In the Ecuadorian Amazon they develop easily in degraded landscapes, which are not suitable for agricultural activities; within the study areas, it was indicated that they are present mostly in the provinces of Napo, Pastaza and Zamora Chinchipe. Also, it must bear in mind that weeds limit the development of crops, decreasing their yield, while at the same time, several of them easily develop in degraded soils (Omari et al., 2018).

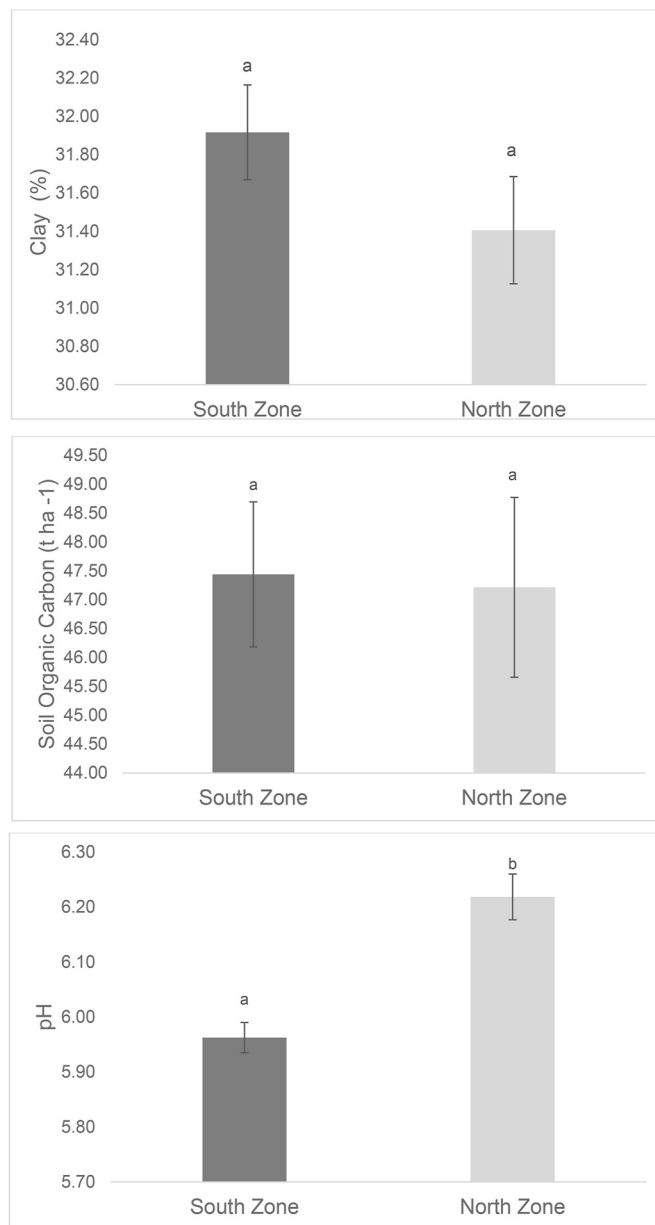


Fig. 6. a) Percentage of clay (ISRIC, 2017), b) carbon stocks (MAG and FAO, 2018) and c) soil pH at 30 cm depth (MAG, 2020) in the different provinces of Eastern Ecuador. The columns represent the average value of each parameter evaluated; the top bars show the standard error and different lowercase letters indicate statistically significant differences (Kruskal Wallis, $p < 0,05$) (MAG and FAO, 2018).

4.2. Management and conservation strategies

Manual plow and ox ploughing represents the first and second viable and economical option for small farmers in the area; this practice of ploughing is carried out in other parts of the country, mainly in small farms and places of steep slopes, characteristic of the Sierra and Amazon regions (Jiménez et al., 2021).

In the study area the farmers do not need to irrigate their crops, as high rainfall (greater than 2000 mm) supplies the water needs for crops while those who do irrigate do so by gravity. Farmers believe that irrigation destroys the soil, mainly in very clayey soils and those that have little infiltration as occurs in several areas of Amazon of Ecuador (Sánchez et al., 2018). Although most people do not irrigate, some had opinions about the potential effects of irrigation, mentioning “it causes soil erosion and nutrient carryover” and “water accumulates”. However, it is important to note that these opinions are related to precipitation rather than artificial irrigation. Specifically, in the Ecuadorian Oriente, annual rainfall exceeds 2000 mm, resulting in a humid climate and abundant rainfall (Sánchez et al., 2018). This high rainfall can cause soil washing, a natural phenomenon in which nutrients and other soluble elements are

washed into deeper soil layers or into nearby water bodies. Soils with those characteristics are very sticky and have a low infiltration rate, so they are more likely to erode (Nethononda and Odhiambo, 2011).

The strategy that was most mentioned in several study areas was to let the soil rest. Farmers in the two study areas probably practice it because it has no cost and they have observed good results after the soil rests several years (Pauli et al., 2012), making fallow part of the landscape of the farm (Kogge-Kome et al., 2018; Suzuki et al., 2014), while favoring soil fertility and crop yields.

Associating crops is also a management practice that is used in the study area, being more representative in South zone, where they associate cocoa with banana, and corn with bean crops. In other parts of the Ecuadorian Amazon they have integrated the traditional agroforestry system with fine cocoa (*Theobroma cacao*) and robust coffee (*Coffea arabica*), which are economically profitable and also generate a great contribution to the biodiversity of the area and food security (Torres et al., 2015). These options make it possible to improve the capacity of production systems to deal with external factors such as droughts, floods, pests and diseases (Astier et al., 2011).

The third strategy mentioned by farmers was the incorporation of crop residues, which is mainly evidenced in North zone (Fig. 5). Not only does the incorporation of organic waste increase crop production and soil organic matter (Ngwira et al., 2013), these strategies are also used in the Ecuadorian highlands because they reduce soil degradation (Castillo et al., 2020; Jiménez et al., 2024).

Another strategy is the planting trees such as *Erythrina edulis* (porotillo), *Cordia alliodora* (laurel), *Inga edulis* (guaba), are incorporated into cocoa and coffee plantations as a shade method (agroforestry system), most commonly applied in the province of South zone (Bravo et al., 2015). It is essential to maintain tree cover within agricultural systems to protect the soil and ecosystem (Harvey et al., 2008), especially in agricultural areas near national parks such as Podocarpus, Yacuambi and Yasuni.

It is noteworthy that farmers use at least two strategies to conserve the soil, and in several cases three or four strategies. These options currently under use could be implemented in other farms because farmers in the areas are already familiar with them and recognize their importance in improving soils. In addition, new strategies could be integrated that are of interest to farmers, contributing to a broader focus on the conservation of both species and soil.

4.3. Forms of soil contamination

Within the research areas, the small farmers apply the fertilizer and the amounts recommended by other farmers or commercial houses, and usually make a single application (but not always) during the phenological phase as required by the plant.

Chemical fertilizers are necessary to supply the soil with nutrients, however, at times by applying in quantities greater than those required by the crop and without considering the nutrient contents in the soil. As well, this medium- and long-term management strategy degrades soils, through erosion and runoff losses (Kogge-Kome et al., 2018) and could negatively influence crop yields (Stavi et al., 2016). In eastern Ecuador, such as North zone, it can also present high concentrations of Cd that exceed the limit of Ecuadorian legislation due to contamination by fertilizers (Barraza et al., 2017).

The pesticides contaminated the soil. These results are similar to other studies conducted in the Ecuadorian Sierra region, in Imbabura (northern Ecuador) for example 40% of the population considers pesticides to be the main source of pollution (Jiménez et al., 2021). The constant use of pesticides could contaminate rivers and groundwater through runoff (Knoke et al., 2014), especially in these localities where rainfall is high (over 2000 mm per year). Therefore, it is crucial to promote the informed application of pesticides, herbicides and fungicides in balance with the requirements of cultivation (Dumanski et al., 2006), while following all biosecurity standards.

Respondents consider that fertilizers contaminated soil, which probably occurs due to negative experiences with the application of homemade organic fertilizers, which in some cases are not processed correctly or are applied inappropriately. However, the addition of organic matter to the soil will improve soil fertility and decrease erosion (Corbeels et al., 2000; Kuria et al., 2018), being beneficial for soil and crop nutrition.

4.4. Knowledge acquisition

In places where traditional knowledge is being lost, this knowledge is no longer being transmitted from generation to generation; in some cases, people are leaving the fields to migrate to urban areas, generating an urgent need to conserve this knowledge, which will ultimately help to develop mechanisms to protect and conserve the diversity of the land (Battiste, 2005). The study areas have great plant diversity and culture, but a large part of these people depend on agricultural activity, and recently, it has been argued that knowledge of the environment is being lost in communities around the world (Battiste, 2005).

4.5. Physical-chemical parameters

Bravo-Medina et al. (2021) reports that in the Ecuadorian Amazon they have found clay values within different agricultural soil uses, which are like those presented in this paper.

The organic carbon of the soil of eastern Ecuador, indicates that the study sites have higher values in North and south zone, these carbon stock contents are between low and medium (Loayza et al., 2020). Farmers describe that they identify a soil with organic matter “by its leaves on the soil”, “by its color and the presence of macroorganisms” and “by the sowing and by its production”, they recognize several distinctive signs of a soil with organic matter, but this perception must be accompanied by laboratory analysis for soil management.

It has been observed that farmers could distinguish between soils with high organic matter and less fertile soils within their plots. In

response to these differences, they apply various good agricultural practices adapted to the specific characteristics of each soil type. For example, they employ techniques such as fallowing, tree planting and crop rotation to improve soil fertility and soil health (Fig. 5).

However, discrepancies have been identified between local knowledge and scientific knowledge regarding soil texture. Although statistical analyses have not revealed significant correlations between soils in terms of texture, it is important to deepen the understanding of these discrepancies. It is suggested that soil analyses be conducted at the farm level to assess soil physical and chemical characteristics more accurately in different areas, which will help clarify perceived differences. This finding highlights the importance of understanding and respecting farmers' traditional knowledge while integrating scientific information for effective soil management.

It was expected that the highest pH values be observed to the north of the study area because in these areas the precipitations from south to north gradually increase, which a range from 1910 to 4590 mm per year (Sánchez et al., 2018). However, Bravo-Medina et al. (2021) found in northwestern Ecuador, acidic pH to be around 6. The values obtained will also depend on the type of cultivation, management, landscape characteristics and mineralogy. Moreover, a low positive correlation between soil pH and clay percentage ($r = 0,109$; $p < 0,041$) (higher clay, higher pH or less acidic) exists. Therefore, our results suggest that texture and pH are predictors of soil C, as demonstrated by Delgado-Baquerizo et al. (2018) at different spatial scales.

5. Conclusions

This study explored the local knowledge of farmers in the Amazon Region of Ecuador (Ecuadorian Amazon), who identify soil fertility through visible indicators based on their experience. Scientific knowledge provides accurate and quantitative information; however, the knowledge of communities, which know and deeply respect the land, should not be neglected. Considering the conservation practices, they use and complementing them with powerful new strategies, a firm step to promote soil conservation in agricultural landscapes can be made. This is especially true because they have managed their farms for many years and know their benefits of soil conservation. In addition, it promotes a sense of belonging of soil management, motivating the farmer. However, the study also showed that there are unsustainable practices that generate concern, because they contribute to soil degradation. In addition, it should be noted that there were no significant correlations between local knowledge and scientific knowledge regarding soil texture between the two study areas. By and large, it is imperative to implement soil management plans that integrate agricultural systems and natural resources, which are promoted by local, national, and international organizations (e.g. the Global Soil Alliance), in order to promote the sustainability of the soil resource in the Amazon region.

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CRediT authorship contribution statement

Leticia Jiménez: Conceptualization, Data curation, Funding acquisition, Investigation, Supervision, Writing – original draft, Writing – review & editing. **Wilmer Jiménez:** Data curation, Methodology, Writing – original draft. **Lenín González:** Formal analysis, Writing – original draft. **Pablo Quichimbo:** Conceptualization, Investigation, Methodology. **Natacha Fierro:** Investigation, Writing – original draft. **Daniel Capa-Mora:** Conceptualization, Data curation, Formal analysis, Writing – review & editing.

Declaration of competing interest

No potential conflict of interest was reported by the authors.

Data availability

Data will be made available on request.

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