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Sustainability of Amazonian fruit trees plots in Loreto, Peru

Sustentabilidad de parcelas con frutales Amazónicos en Loreto, Perú

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Abstract

This research aimed to: a) evaluate the vegetation indicators of Amazonian fruit trees with the diversity of weeds and soil with the number of arthropods in the plots of farmers that were established by INIA and IIAP in the area of influence of the road Iquitos - Nauta from the Loreto state, Perú, and b) evaluate the carbon sequestration, and the socio-economical and ecological sustainability of the plots with Amazonian fruit trees in the area of influence., Thirty-seven farmers were surveyed. The alpha indicator of vegetation diversity reached an index value of 2.07 and the arthropod index was 1.91. The highest carbon (C) value in the biomass was found in the guava fruit tree (*Inga edulis* Mart.) in plot 17, with a total carbon stock of 90 $t \cdot ha^{-1}$ and a CO_2 flux value of 22 $t \cdot ha^{-1} \cdot a^{-1}$. Additionally, uvilla (*Pouroma cecropiifolia* Mart.) with pijuayo (*Bactris gasipaes* Kunth) reached a total C uptake of 117.19 $t \cdot ha^{-1}$ with a CO_2 flow of 33.42 $t \cdot ha^{-1} \cdot a^{-1}$. The highest accumulation of C in the soil was in plot 23, with 66.5 $t \cdot ha^{-1}$, reducing CO_2 emission by 243.84 $t \cdot ha^{-1} \cdot a^{-1}$. In the sustainability evaluations, it was found that the economical, ecological, and socio-cultural dimensions reached values of 3.20, 3.33, and 2.04, respectively. It is concluded that Amazonian fruit trees are sustainable in the economic and ecological dimensions. However, in the sociocultural dimension, sustainability is weak.

Key words: *sustainability, biodiversity, arthropods, carbon, amazonian fruit trees.*

Resumen

La investigación tuvo por objetivos: a) Determinar los indicadores de diversidad en vegetación de los frutales amazónicos y diversidad de artrópodos del suelo en las parcelas de agricultores que fueron instalados por el INIA e IIAP en el área de influencia de la carretera Iquitos – Nauta, Loreto. b) Determinar el secuestro de carbono en parcelas con frutales amazónicos en el área de influencia de la carretera Iquitos – Nauta, Loreto. c) Evaluar la sustentabilidad económica, ecológica y social de las parcelas con frutales amazónicos en el área de influencia de la carretera Iquitos – Nauta, Loreto. El área de estudio en la región Loreto – Perú, se encuestó a 37 agricultores. El indicador alfa de diversidad en la vegetación, alcanzó el valor del índice 2.07 y el índice de artrópodos fue de 1.91. Los mayores valores de carbono (C) en la biomasa se encontró en el frutal de guaba (*Inga edulis* Mart.) en la parcela 17, con una reserva total de carbono de 90 $t \cdot ha^{-1}$ y con valor de flujo de CO_2 de 22 $t \cdot ha^{-1} \cdot a^{-1}$. La asociación de uvilla (*Pouroma cecropiifolia* Mart.) con pijuayo (*Bactris gasipaes* Kunth) captó en total 117.19 $t \cdot ha^{-1}$ con un flujo de CO_2 de 33.42 $t \cdot ha^{-1} \cdot a^{-1}$. La mayor acumulación

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de C en el suelo fue en la parcela 23 con 66.5 t·ha^{-1}, reduciendo la emisión de CO_2 en 243.84 t·ha^{-1}·a^{-1}. Las evaluaciones de sustentabilidad en la dimensión económica alcanzaron el valor de 3.20, la dimensión ecológica alcanzó el valor de 3.33 y la dimensión sociocultural alcanzó el valor de 2.04. Se concluye que los frutales amazónicos son sustentables en la dimensión económica y ecológica. Sin embargo, en la dimensión sociocultural presenta sustentabilidad débil.

Palabras clave: *Sustentabilidad, biodiversidad, artrópodos, carbono, frutales amazónicos.*

I. Introduction

Amazonian fruit trees are considered promising because of their great nutritional potential, and have suitable characteristics to be transformed into sustainable crops since they can be used in conservation and ecosystem restoration practices, especially as part of agroforestry systems in the Amazon where, in a more orderly manner, they are established in association with other agricultural and forestry crops (González, 2013). Plots with Amazonian fruit trees are intended to satisfy food needs and generate income for producers through their commercialization (Jadán, 2012). These species are high in carbohydrates, vitamins and minerals, which help prevent many diseases (Gonzales & Torres, 2011). In the area of the Iquitos - Nauta road, in the Loreto region, Amazonian fruit trees are not only of great economic and nutritional importance (Araujo et al., 2021), but also environmentally important. In these plots, crop and space rotation is practiced to give soil periodic fallow, which allows the growth of secondary forests, with the consequent recovery of nutrients and the diversity of arthropods and other components of the soil macrofauna. In this sense, it is necessary to study these production units with sustainability criteria, *i.e.*, considering the social, environmental and economic dimensions. The sustainability of agricultural production units presents different methodologies, one of the most used is the "multi-criteria analysis" proposed by Sarandón et al. (2006). In Peru, this methodology has been used to study the sustainability of agricultural farms in the Amazonian region, such as oil palm farms from the Shanusi Valley in Loreto (Leveau, 2018), coffee farms from San Martin (Rojas et al., 2021) and Granadilla farms from Oxapampa (Romero, 2018). According to Pinedo et al. (2021), the "multi-criteria analysis" is the most widespread and applied methodology in the evaluation of sustainability because it is low cost, easy to apply and adaptable to the evaluation of agricultural production systems in Latin American countries.

Agriculture as a sustainable economic activity must: achieve efficient crops, in order to be more productive and profitable so as to ensure future viability; recover more arable land, preserving the quality of the natural resources it uses (water, soil, soil slope, etc.) by minimizing its impact on nature (erosion, pollution, desertification, etc.) and extending biodiversity; train farmers in good practices and safe use of technologies, provide a transfer of appropriate technological knowledge to achieve increasingly sustainable agriculture (Syngenta, 2021). Sustainable agriculture seeks to improve the quality of the environment; in other words, it is directly related to the protection of natural resources, for food and energy security, and is conditioned by the provision of natural resources and environmental services in a geographical area (Duran, 2010). On the other hand, Karamelikli (2016), analyzes that, sociocultural sustainability is in relation to environmental sustainability, because it has a harmonious relationship between living organisms and the natural environment, likewise, it has to be sufficiently productive to meet the basic needs and reasonable desires of the entire world population, to enhance the occupation of the countryside and rural development, to be compatible with the preservation of cultural diversity, to promote social equity, etc. Likewise, in the plots, with Amazonian fruit trees, there are diverse species of fauna, flora and varied ecosystems. Preserving this biodiversity is important because it guarantees the sustainability of all forms of life and contributes to the stabilization of other ecosystems in the region. Regarding diversity studies, Lingmann & Jankowski (2014), have described the scale of local spatial analysis and multicriteria spatio-temporal sensitivity to assess the suitability of land by weights that express probability distributions of habitat characteristics to define the inclusion and exclusion of areas with suitability in land use. Dyer et al. (2017) stated that within the studies of biodiversity in agriculture, the appropriate methodology is the measurement of alpha diversity, which studies the diversity within the same community at the same habitat, and the Shannon index (H′) that is the way to calculate the proportion of coverage from each species in a given area. The study of arthropods is important in ecosystem services since it has the function of maintaining the balance in ecosystems (Cerna et al., 2015). Iannacone et al. (2000), stated that earthworms are sensitive to many agricultural practices, so they can be considered indicators for measure soil fertility. Soil functions are affected in agroecosystems, such as water and air dynamics. Biogeochemical processes, microorganisms and soil itself define soil quality (Dexter, 2004). Hernández & Vargas (2005) indicate that there are international mechanisms for different countries to buy and sell CO_2 absorption services, which is an important source of financing to protect and conserve resources and the environment, while at the same time improving the economy. Changes in soil quality can be monitored with easy and accurate indicators determined by reproducible methods (Moebius et al. 2007). Additionally, it is important to develop and promote appropriate cultural practices in Amazonian fruit orchards to improve the livelihoods of farmers, but also to reduce CO_2 emissions and retaining carbon, thus providing important environmental services to the society (Food and Agriculture Organization, 2003). On the other hand, Conservación Internacional (2021) indicates that companies should reduce their carbon footprint and offer offsets to reduce carbon emissions. This is an opportunity for the Amazonian fruit tree production plots to venture into these offers to improve their economic income. To estimate the amount of carbon sequestration in the biomass and soil, there are several allometric models, where it is related to the dry mass of a component or the entire tree, with variables of tree size, such as diameter at breast height, height, basal area and volumen (Alegre et al., 2000; Arévalo et al., 2002).

IIAP (2002), conducted a study on the evaluation of carbon in the Nanay river basin, in which it reported a value of 104.03 tons/ha in 'varillales' ecosystems and 226.19 t/ha in 'aguajales' ecosystems García et al., (2012), studied the total soil organic carbon stock (COS), aerial biomass and necrosome in the aguajales (*Mauritia flexuosa* L.) of the lower and upper part of the Aguaytía river basin, in the Department of Ucayali, Peru. They found that the upper zone presented less total carbon (3.78 t/ha) compared to the lower zone, which showed significantly higher values (197.86 t/ha). In addition, aerial biomass showed significantly similar data for both zones, being 96.33 t/ha for the low zone and 51.28 t/ha in the high zone. Values for necrosome were lower in both zones. They also determined the amount of carbon accumulated in the aerial biomass, with a result of 96.33 t/ha. In economic sustainability evaluation, Tongo & Soplin (2022) indicates that the economic dimension indicator was lower than environmental dimension and social dimension indicator but was lower variable too, in livestock production systems in the high jungle of Peru.

Therefore, the objective of this study was to evaluate the sustainability of Amazonian fruit tree plots in production located along the Iquitos - Nauta highway, Loreto, as an alternative to migratory agriculture that preys on the Amazon. For this is necessary analyze economic, social and environmental dimension of the agroecosystem.

II. Material and methods

The study was conducted in a humid tropical zone the Province of Maynas in the Department of Loreto, located in northwestern Peru, in the area of influence of the Iquitos - Nauta road, which extends from the District of San Juan Bautista to the jurisdiction of the city of Nauta, covering approximately 96 km. It has altitude of 121 m.a.s.l., average annual temperature of 27.3 ºC, average annual relative humidity of 91.6 % and average annual precipitation of 3 282.2 $mm \cdot a^{-1}$ (Holdrige et al.,1971). For the research, the population centers with the largest number of inhabitants were chosen, settled on the left margin of the Iquitos - Nauta road and the right margin of the Itaya River, for which a qualitative study of 37 cases was carried out.

The information on sustainability was obtained through a questionnaire with structured questions on technical and socioeconomic aspects, considering the indicators proposed by Sarandón et al. (2006). This scale ranges from 0 to 4, where 0 is considered less sustainable and 4 more sustainable. The selection of sub-indicators, variables and the weighting of each one of these, was carried out jointly with those responsible for the plots under study and the support of technicians and professionals from the Agrarian Agency of the Province of Maynas. Sustainability data was analyzed through the economic, ecological and sociocultural formulas proposed by Sarandón (2006). The Sub-indicators, variables and valuation scales to evaluate the economic sustainability of the plots producing Amazonian fruit trees on the Iquitos - Nauta highway can be seen in the Table 1. On the other hand, Table 2 shows the Sub-indicators, variables and valuation scales to evaluate the ecological sustainability of the plots producing Amazonian fruit trees on the Iquitos - Nauta highway. For its part, Table 3 shows the sub-indicators, variables and valuation scales to assess the sociocultural sustainability of the plots producing Amazonian fruit trees on the Iquitos-Nauta highway. Finally, following the criteria of Sarandón et al. (2006), who considers that, by replacing the values of the indicators in the respective formulas, the general index of sustainability is determined, considering sustainable when its indicators and the general index of sustainability are higher of 2. Likewise, it should be noted that none of the three dimensions evaluated should have an indicator with a value less than 2. General Sustainability Index was calculate with the economic (IK), environmental (IA) and sociocultural (ISC) indexes, whose formulas are shown in Table 4.

The alpha diversity of vegetation and soil arthropods surrounding the Amazonian fruit trees was also evaluated using the formula proposed by Shannon - Weaver.

For vegetation, samples were extracted using the wood quadrant method with dimensions of one square meter (1 m^2) and five points were randomly distributed internally, each point was considered weed subsamples totaling 25 subsamples. The samples were introduced in paper bags and then in plastic bags, duly labeled to later be transferred to the laboratory of the Herbarium Amazonense of the National University of the Peruvian Amazon (UNAP), where the identification of the vegetations found was carried out.

To evaluate the macrofauna of the soil surface of the surrounding environment of the Amazonian fruit trees, the sampling was systematic and consisted of delineating a quadrant of 25 m^2 around the base of the fruit trees. The arthropods were collected with the help of the entomological mesh and support of the hand. The specimens were placed in a glass jar with 70 % alcohol, then labeled and taken to the Plant Health Laboratory of the Faculty of Agronomy - UNAP, where they were separated by counting the total number of individuals per species and identified by

Table 1: Sub-indicators, variables and valuation scales to assess the economic sustainability of plots producing Amazonian fruit trees on the Iquitos - Nauta highway

Economic dimension	Assessment scales				
	0	1	2	3	4
A: Economic income from the plots					
A1: Diversification of Amazon fruit trees	has one fruit tree	has 2 fruit trees	has 3 fruit trees	has 4 fruit trees	has more than 4 fruit trees
A2: Self-consumption production area	Lower than 0,5 hectare	0,60 ha to 1 ha	1.1 ha to 1,5 ha	1.5 ha to 2,0 ha	More than 2 hectares
B: Monthly net income per producer	self-consumption	Lower than 1000 soles / hectare	1001 to 1500 soles/hectare	1501 to 2000 soles/hectare	More than 2000 soles/hectare
C: Economic risk					
C1: Diversification for sale	one fruit tree	2 fruit trees	3 fruit trees	4 fruit trees	More than 4 fruit trees
C2: Number of marketing channels for sale	no way of marketing	one avenue of marketing	2 avenues of marketing	3 avenues of marketing	More than 3 avenues of marketing
C3: Dependence on external inputs	76 % to 100%	51 % to 75 %	26 % to 50 %	1 % to 26 %	0 %

Source: Adapted from Sarandon (2006)

Table 2: Sub-indicators, variables and valuation scales to evaluate the ecological sustainability of plots producing Amazonian fruit trees on the Iquitos - Nauta highway

Ecological dimension	**Assessment scales**				
	0	**1**	**2**	**3**	**4**
A: Soil Life Conservation					
A1: Organic remains on the ground	More than 25 % coverage	49 % to 25 % coverage	75 % to 50 % coverage	99 % to 74 % coverage	100 % coverage
A:2 Vegetated ground cover time	No permanent coverage	Eventually covered	three months of coverage	Six months of coverage	with permanent cov-erage
A3: Diversity of Amazon fruit trees	monoculture	association a fruit tree with one crop	association of 2 fruit trees with a crop	association of 2 fruit trees with 2 crops	association of more than 2 fruit trees with more than 2 crops
B: Erosion risk					
B1: Predominant slope	More than 45 %	30 % to 45 %	15 % to 30 %	5 % to 15 %	0 % to 5 %
B2: Vegetal cover	More than 45 %	46 % to 25 %	74 % to 47 %	99 % to 75 %	100 %
C: Biodiversity management					
C1: Spatial biodiversity	Without diversity	little diversity	moderate di-versity	high diversity	Very high diversity
C2: Temporary biodiversity	negligible biological activity	little biological activity	Moderate bio-logical activity	High biological activity	Very high biological activity

Source: Adapted from Sarandon (2006)

Table 3: Subindicadores, variables y escalas de valorización para evaluar la sustentabilidad sociocultural de las parcelas productoras de frutales amazónicos en la carretera Iquitos -Nauta

Sociocultural dimension	**Assessment scales**				
	0	**1**	**2**	**3**	**4**
A: Satisfaction of basic needs					
A1: Access to health	No access	with post access			
A2: Access to education	no access	with access to initial education	with access to primary education	with access to secondary education	
A3: Living place	no access	with access			
A4: Services	no access	access a service	access two services	access three services	access to more than three services
B: Production system acceptability					
B1: Degree of satisfaction to the needs	dissatisfied	indifferent to satisfaction	a bit satisfied	satisfied	Very satisfied
B2: Youth desertion	greater than 50 %	50 % desertion	25 % desertion	15 % desertion	0 % desertion
C: Social integration to organizational systems					
C1: Associativity	no association	associated with an institution	associated with two institutions	associated with three institutions	associated with more than three associations
C2: Active participation	no participation	little participation	moderate participation	high participation	very high participation
C3: Voting equality	there is no equality	little practice of equality	moderate equality practice	high equality practice	very high equality practice
C4: Political integration	without integration	little integration	moderate integration	high integration	very high integration
C5: Knowledge acquisition	communal ignorance	little communal knowledge	moderate communal knowledge	high communal knowledge	very high communal knowledge
C6: Community agenda control	ignorance of the communal plan	little knowledge of communal plan	moderate knowledge of communal plan	high knowledge of communal plan	Very high knowledge of communal plan
D: Knowledge and ecological awareness	unknown residual management	little residual management	moderate residual management	high residual management	very high residual management

Source: Adapted from Sarandon (2006) and Dahl (2008).

Table 4: Sustainability calculation formulas and general index

Indicators	Formula
Economic (IK)	$\frac{\frac{(A1+A2)}{2}+B+\frac{C1+C2+C3}{3}}{3}$
Ecological (IE)	$\frac{\frac{2A1+A2+A3}{4}+\frac{2B1+B2+B3}{4}+\frac{C1+C2}{2}}{3}$
Sociocultural (ISC)	$\frac{2\left[\frac{(A1+A2+A3+A4)}{4}\right]+2(B1+B2)+(C1+C2+C3+C4+C5)+D}{12}$
General index (IG)	$\frac{IK+IE+ISC}{3}$

Source: Adapted from Sarandon (2006).

families. The diversity index in species richness, both of the vegetation and of soil arthropods, was used the formula proposed by Shannon-Weaver (1949) which is presented below:

$$H'=-\sum_{i=1}^{s} pi*logpi$$

s = number of species (richness)
pi = proportion of individuals of the species/ respect to the total number of individuals ni/N
ni = number of individuals of the species i
N = number of all individuals of all species

The carbon sequestration in biomass and soil also was determined in the study area using the allometric equations proposed by Arévalo et al. (2002) and Rueda (2014) for biomass, and the proposed by Walkley (1947) for soil. For the evaluation of the plant biomass, the presence of litter at the base of the Amazonian fruit trees was calculated, adding to the calculation of the tree biomass. For the calculation of litter biomass, 1 square meter grid was used, randomly placed at the base of the fruit trees, the total fresh litter matter contained in the grid was weighed, and from this total a sample was extracted. fresh sub-sample of approximately 300 g which was labeled to be sent to the laboratory, dried in a recirculating air oven at 70 °C for 48 hours and thus the weight of dry matter of the subsamples was obtained. Likewise, the tree biomass was calculated, using allometric equations, proposed by Arévalo et al. (2002). The allometric equation for litter biomass was:

$$Bh(t/ha) = ((PSM/PFM) \times PFT) \times 0.04$$

Bh = litter biomass in dry matter
PSM = dry weight of the sample collected g
PFM = fresh weight of the sample collected g
PFT = total fresh weight per 0,25 m^2
0.04 = conversion factor

And for biomass of living trees that do not have an allometric equation, the following formula was used:

$$BA= (0{,}1184\ DAP^{2{,}53}) \times 0.01$$

BA = living tree biomass
0,1184 = constant
DAP = diameter at chest height
2,53 = exponential constant

III. Results and Discussions

3.1. Evaluation of sustainability

3.1.1. Economic sustainability

From the plots evaluated, 86.5 % were economically sustainable, 55 % of the plots diversify into different fruit and agricultural crops (A1=3). 15 % grow plants in areas larger than 1.5 ha (A2=4) and 63 % have a net income higher than 1 200 soles per month (B=4). 68 % have two or three Amazonian fruit trees for sale, 86 % have one sales route (C1=2) and 51 % depend from 1 % to 25 % on external inputs (C3=3) (Table 5). The respondents stated that one of the major limitations for sales is the number of marketing routes and this is a critical point for the economic risk.

Table 5: Evaluation results of economic sustainability

Sustainability tests				Respondent (%)
Subindicators	Variables	Code	Value	
Food safety (A)	Amazonian fruit trees diversity	A1	3	55
	Self-consumption production area	A2	4	15
Gross income by producer (B)	Gross income by producer	B	4	63
Economic risk (C)	Diversification for sale	C1	2	68
	Marketing routes for sale	C2	2	86
	Dependency on external supplies	C3	3	51
Economic indicator			**3,20**	

Amazonian fruit trees are economically sustainable with a value of 3.2, despite it was not applied techniques in their management and not being dependent on external inputs. This is in agreement with Sarandón et al. (2006), who considered that a system with high dependence on inputs is not sustainable over time. Valarezo et al. (2020) reported that 70 % of lemon farms form Portoviejo, Ecuador are sustainable in the economic dimension, and one of their recommendations is to improve the diversification of production and marketing canals. Additionally, Ruíz et al. (2018) reported that 66.7 % of orange farms are economically sustainable. Nevertheless, they reported as critical points the lack of marketing routes and the high dependence on external inputs.

3.1.2. Ecological sustainability

The ecological sustainability was 94.7 % for the total plots evaluated, the criteria are detailed in Table 3, where 43 % of the plots have soil cover (A1=4), 57 % are permanently covered by weeds (A2=2). 46 % are diversified with medium association of fruit trees and other crops (A3=4), 62 % have a slope of 0 % to 3 % (B1=4), 43 % have vegetation cover between 75 % and 99 % (B2=4), 41 % have rainfall greater than (110 to 124) mm per month (B3=3), the plots are diversified by abundance of arthropods and other plants (C1=3), and 46 % of the plots are diversified by 25 % association of fruit trees and other crops (C2=4).

Amazonian fruit trees are ecologically sustainable reaching a value of 3.33 (Table 6). The biodiversity is the indicator that needs to be addressed, precipitation is one of the abiotic factors of greatest risk for soil erosion. Altieri (2012) and Foley et al. (2011) considered the ecological sustainability very important, due to the spatial variability of biodiversity, which has a serie of processes that interact at different temporal and spatial scales. Saynes et al. (2016) considered that maintaining cover the entire vegetation of the plots in a natural way is important in any agricultural system. Likewise, in fruit tree plots, the protection of natural resources should be promoted. Food security is conditioned by the provision of natural resources and environmental services in a geographical space and for the magnitude that nature recompose itself from anthropic influences (Duran, 2010). Agroforestry systems provide greater ecological sustainability, due to increased diversification of production systems, and soil moisture conservation (Arévalo et al., 2002). Mata et al. (2018) considers agroforestry systems to optimize production per unit area and make sustainable the production system while conserving the ecosystem.

Table 6: Evaluation results of ecological sustainability

Sustainability tests				Respondent (%)
Subindicators	Variables	Code	Value	
Conservation of life soil (A)	Organic residue in the soil	A1	4	43
	Time in cover soil	A2	2	57
	Amazonian fruit trees diversity	A3	4	46
Erosion risk (B)	Prevailing slope	B1	4	62
	Vegetable cover	B2	4	43
	Precipitation	B3	0	100
Biodiversity managment (C)	Spatial biodi-versity	C1	3	41
	Temporary biodiversity	C2	4	46
Ecological indicator			**3,33**	

3.1.3. Sociocultural sustainability

From the plots evaluated, 35.13 % were sociocultural sustainable, and the criteria is detailed in Table 4. Only a 79 % had access to housing with regular unfinished structure and others presented deteriorated structures (A1=2), 100 % had access to primary and secondary school without restriction (A2=2), 74 % did not have access to health centers, 42 % had electricity and cell-phone (A4=0), 55 % did not accept the production system due to the lack of attention to the agrarian sector and, therefore, they felt disillusioned (B1=2), 65 % of the young people preferred to stay in the area, they preferred to study to become an authority (B2=4), 39 % were not part of any organization (C1=1), 45 % did not participate actively in the community (C2=1). 55 % elected their authorities by an agreement in a communal assembly (C3=1), 24 % did not follow communal coexistence agreements (C4=1), 37 % considered that the leaders lead according to their interests and not for the benefit of the community (C5=2) and 32 % conceived ecological aspects with a broad vision (D=2) (Table 7). It could be observed that the satisfaction indicator of basic needs (B1) was the lowest and the systems were quite fragile, mainly due to deficiencies in access to education (A2) and health (A4). Altieri and Nicholls (2000) indicated that social sustainability in basic needs such as education (A2), housing (A3), health (A4) among others is a priority. Sepúlveda (2008) considered that social agents play a very important role in achieving sustainable development. Moreover, Aquino et al. (2018) pointed out that social indicators are oriented to evaluate producer satisfaction, quality of life and social integration. Being important the participation of related institutions and organized society in the construction of acceptable social conditions, focused on the availability of basic services and capacity building of human resources. The methodology proposed by Sarandón et al. (2006) has been easy to understand and adaptable, as well as low cost, to assess sustainability in Amazonian fruit tree production plots. The results of the sustainability of the Amazonian fruit trees reached a value of 2.86 (Table 8), indicating that the Amazonian fruit trees are sustainable (Sarandón et al., 2006).

The plots producing Amazonian fruit trees have critical points in sociocultural sustainability.

Table 7: Evaluation results of sociocultural sustainability

Sustainability test				Respondents (%)
subindicators	Variables	code	Value	
Satisfaction to basic needs (A)	Access to housing	A1	2	79
	Education access	A2	2	100
	Access to health and health coverage	A3	1	74
	Access to services	A4	0	42
Aceptability of production system (B)	Aceptability of production system	B1	2	55
	Abandonment of young people	B2	4	65
Social inte-gration into organizational systems (C)	Associativity	C1	1	39
	Active participation	C2	1	45
	voting equality	C3	3	55
	Knowledge adquisition (Election of authorities)	C4	1	24
	Community diary control	C5	2	37
Ecological knowledge and awareness		D	2	32
Sociocultural indicator			**2,04**	

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Table 8: General results of sustainability evaluation

IK	IE	ISC	IG
3,20	3,33	2,04	**2,86**

The Figure 1 shows the critical points on which it should be done a work to reduce them. Arnés and Astier (2003) considered a challenge for agriculture to address the high climate variability by designing highly efficient production systems in terms of water and energy management with low levels of environmental degradation and pollution.

3.2. Identification of Amazonian fruit trees

Table 9 shows the list of Amazonian fruit trees most frequently mentioned by those responsible for the plots; ten Amazonian fruit trees belonging to eight botanical families were identified, located in an area of 69 hectares. Amazonian fruit trees are characterized by their varied nutritional composition, seasonality in production, i.e., they only produce fruit during one period of the year, presenting an alternative for human and animal consumption (Velazco et al., 2020). In addition, Gonzales & Torres (2011) consider that there are 193 species of fruit trees in Loreto, of which 139 are harvested from natural areas for consumption by the rural population and commercialized in

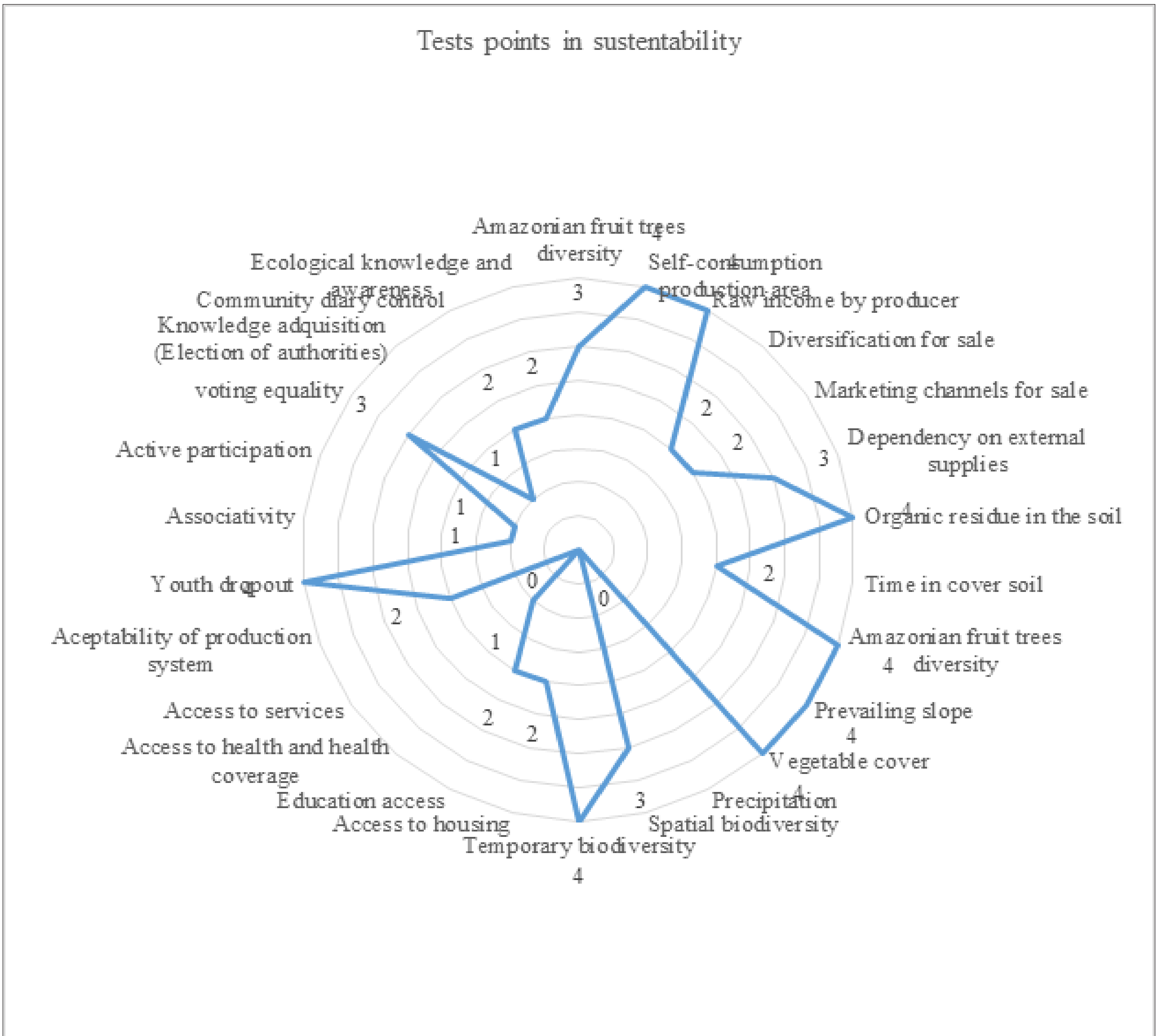

Figure 1: Tests points in sustainability of the producing plots in Amazonian fruit trees along Iquitos – Nauta, road in Loreto

Table 9: List of Amazonian fruit trees with most frequency mentioned in Iquitos – Nauta road in Loreto

Family	Common Name	Scientific name
Arecaceae	aguaje, achual	*Mauritia flexuosa* L.
	Pijuayo	*Bactris gasipaes H.B.K.*
	ungurahui	*Oenocarpus bataua* Mart.
Bombacaceae	Zapote	*Matisia cordata* Humb. Y Bon-pl.
Fabaceae	Guaba	*Inga edulis* Mart.
Icacinaceae	Umarí	*Poraquiba quadrangularis* L.
Motaceae	Uvilla	*Pourouma cecropiifolia* Mart.
Sapotaceae	Caimito	*Pouteria caimito* (Ruiz y Pav.) Radlk
Myrtaceae	pomarrosa	*Syzygium jambos* (L.) Alston
Moraceae	pan del árbol	*Artocarpus altilis* (Parkinson) Foseberg

Amazonian cities. They also indicate that they are semi-domesticated in the different farms and orchards of producers where selection and domestication continue. Meanwhile, Mostacero et al. (2017), reports for northern Peru 45 species of fruit trees; which are distributed in 18 families. Mitjans et al. (2019) also identified 17 species of native fruit trees, distributed in 14 families and 17 genera.

3.3. Assessment of vegetation diversity and soil arthropods

3.3.1. Determination in the vegetation.

Figure 2 shows the alpha diversity of vegetation diversity, whose value is 2.074, indicating that the study area is within the normal range in species equity and is emerging as an ecologically sustainable agroecosystem. These data indicate that, the study area is naturally diversified, since the farmer for lack of budget or ignorance does not provide maintenance to their plots. Castro et al. (2019) reported a diversity value closer to that found in this study (2.06). Those authors observed that the greatest number of species belong to the families Asteraceae (12) and Poaceae (5) in Junin state, being the district of *Villa rica* the most diverse. On the other hand, Vásquez et al. (2016) recorded 148 species, of which 129 corresponded to weed species, classified into 33 botanical families in the Amazon region.

3.3.2. Determination of soil arthropods

Figure 2 shows the index of arthropod diversity in the soil, which reached 1.9, indicating low biodiversity in terms of the equity of arthropod species. The index shows that, the area under study has a large number of individuals, but with low diversity. The "termites" (*Nasutitermes* sp.) that were found in the barks of Amazonian fruit trees were the most abundant species (1 200 individuals per 25 square meter) and the "bug" of the genus Reduvius has been the least abundant (2 individuals per 25 square meter). Table 10 shows the calculation of the alpha diversity of the arthropods found in the study area. According to Chao and Jost, (2012) arthropod diversity is related to soil conservation status. Ramírez et al.

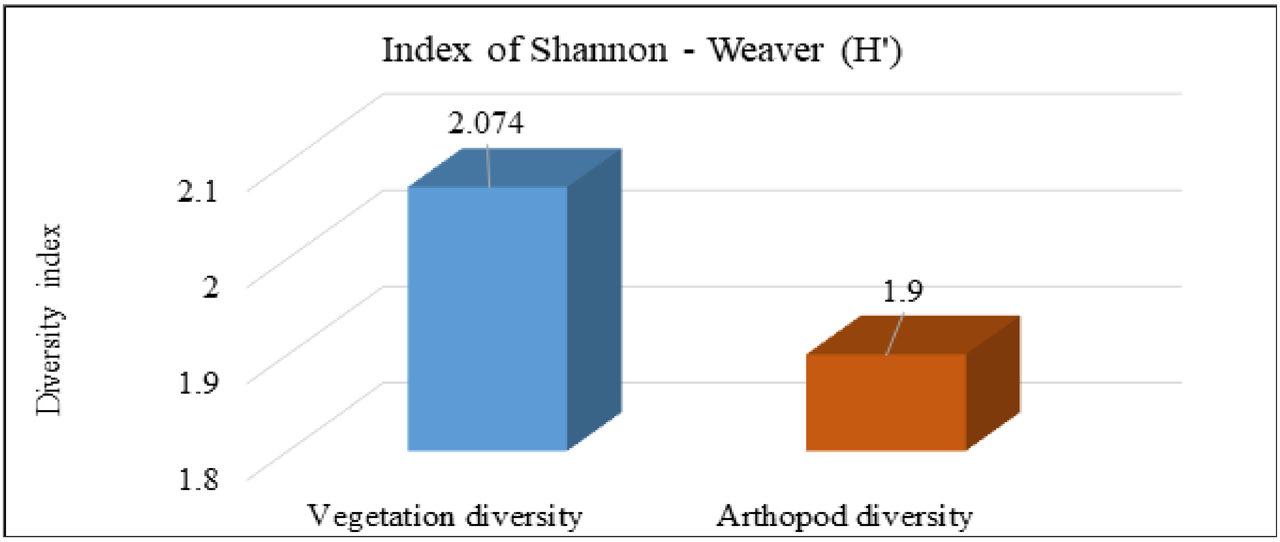

Figure 2: Shannon–Weaver index in vegetation and anthropods soil in Amazonian fruit producing plots in Iquitos – Nauta highway in Loreto

Table 10: Calculation of alpha diversity for arthropods in plots with Amazonian fruit trees on the Iquitos-Nauta highway in Loreto

Scientific name	Avg/kind 25 m^2	pi	lnpi	pi*l-npi	H´
Lumbricus terrestris Linnaeus 1758	93	0,034	-3,46	-0,1	
Lycosa erythrognatha Lucas 1836	41	0,02	-4,2	-0,1	
Thomisis sp. Sundevall 1883	27	0,01	-4,6	-0,04	
Rhynchonphorus sp. Linnaeus 1758	430	0,2	-1,8	-0,3	
Nasutitermes sp.	1200	0,5	-0,8	-0,4	
Gryllus sp.	8	0,003	-5,8	-0,02	
Mantis sp.	8	0,003	-5,8	-0,02	
Rasahus sp.	5	0,002	-6,3	-0,01	
Reduvius sp.	2	0,001	-7,2	-0,005	
Zelus sp.	5	0,002	-6,3	-0,01	1,91
Zoreva sp.	15	0,001	-5,2	-0,03	
Aphis craccivora	50	0,02	-4	-0,1	
Cerotoma sp.	22	0,01	-4,8	-0,04	
Colaspis sp.	34	0,013	-4,4	-0,05	
Diabrotica sp.	42	0,01	-4,2	-0,1	
Morpho menelaus	3	0,01	-6,8	-0,01	
M. rhetenor	5	0,001	-6,3	-0,01	
Anastrepha spp.	13	0,005	-5,3	-0,03	
Ecyton sp.	130	0,05	-3,02	-0,14	
Ectotomma sp.	230	0,08	-2,4	-0,2	
Atta sp.	270	0,1	-2,3	-0,2	
Polistes sp,	14	0,01	-5,2	-0,02	
Vespa sp.	18	0,01	-5	-0,03	
Total (N)	2665			-1,91	

(2019), found diversity with maximum of 1.58 and minimum of 1.44. Iannacone et al. (2000), a mean diversity of 2.33. De la Cruz et al. (2003) found high heterogeneity in the distribution according to plant formations present in the habitats sampled.

3.4. Carbon sequestration

3.4.1. Biomass carbon in the fruits

Figure 3 shows that 15 years old guaba (*Inga edulis*) trees (13 plants/ha) from plot 17 were the species that fix more carbon individually with uptake fluxes of 22.02 t·ha^{-1}·a^{-1}. The 12 years old Pijuayo (*Bactris gasipaes* H.B.K.) trees (20 plants/ha) from plot 32 produced a flux of 18.88 t·ha^{-1}·a^{-1}, the 14 years old uvilla (*Pouroma cecropiifolia* Mart.) trees (6 plants/ha) from plot 32 produced a flux of 14.54 t·ha^{-1}·a^{-1} and 18 years old pan del árbol (*Artocarpus altilis* (Parkinson) Foseberg) from plot 22 which captured 18,8 t·ha^{-1}·a^{-1}.

Figure 4 shows the carbon sequestration in fruit species from plot 32, the association of the 12 years pijuayo trees (20 plants/ha) and 14 years old uvilla (*Pouroma cecropiifolia* Mart.) trees (6 plants/ha), sequester 117.19 t·ha^{-1} and total flows of 33.42 t·ha^{-1}·a^{-1}. It was followed by the

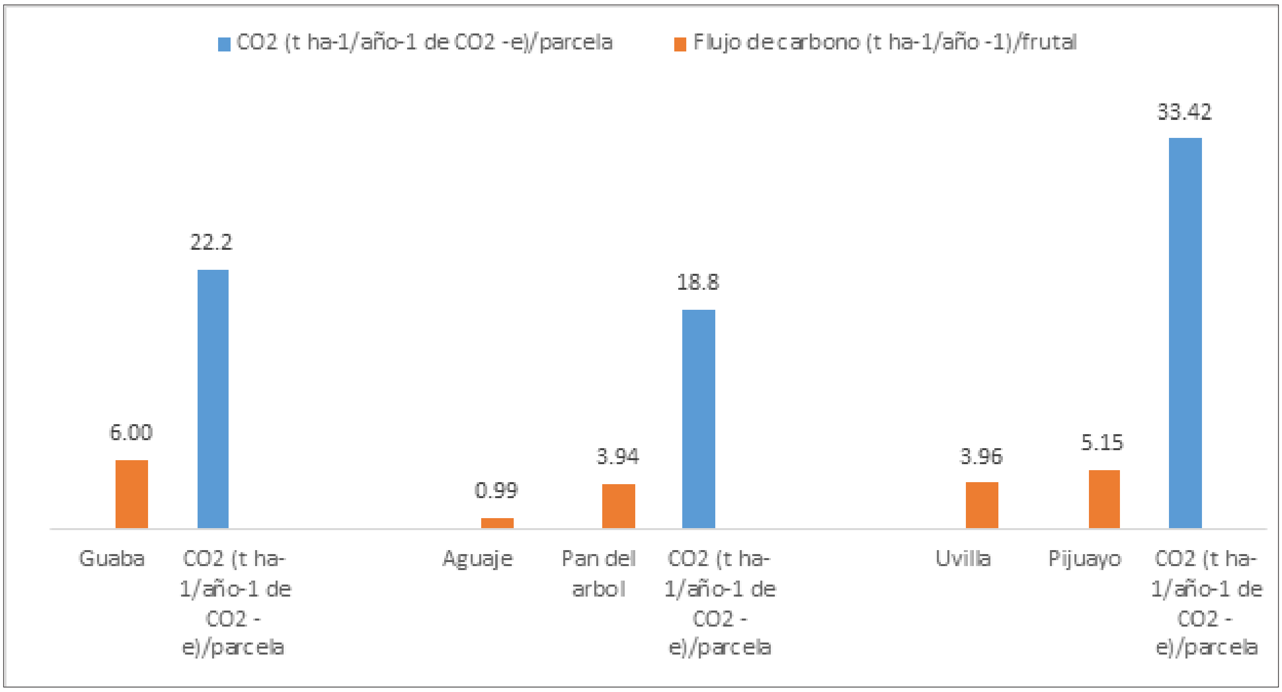

Figure 3: Carbon sequestration in biomass in Amazonian fruit trees in producing plots of Amazonian fruit trees in Iquitos - Nauta road, Loreto

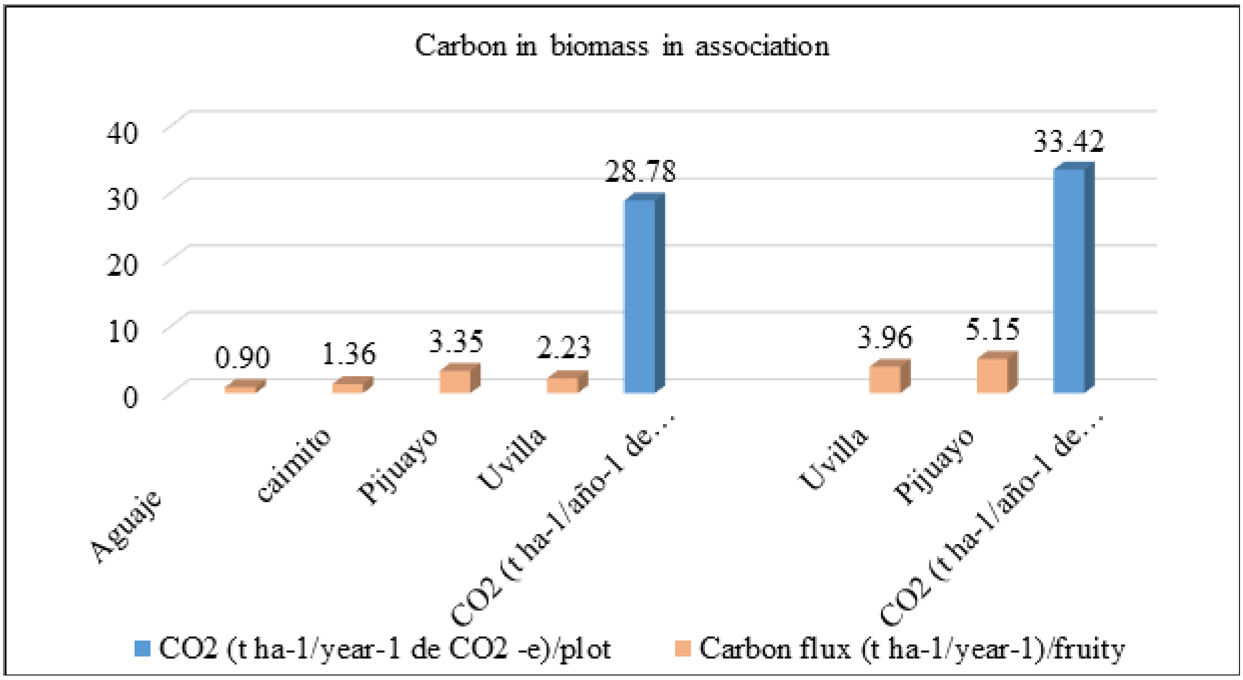

Figure 4: Carbon sequestration in biomass of fruit trees association in the producing plots of Amazonian Fruit trees in Iquitos – Nauta road in Loreto

association of four (04) species in plot 24, Pijuayo (*Bactris gasipaes* H.B.K.), uvilla (*Pouroma cecropiifolia* Mart.), caimito (*Pouteria caimito*) and aguaje (*Mauritia flexuosa* L.) can capture as a total reserve up to 99 $t \cdot ha^{-1} \cdot a^{-1}$ and total fluxes of 28.78 $t \cdot ha^{-1} \cdot a^{-1}$.

The highest annual CO_2 fluxes were observed in plots 32 and 22, which have higher diversity of species and number of plants per hectare. The lowest CO_2 fluxes were noticed in plots 10 and 36. Minimun tillage, pruning, organic fertilization maintained in these plots will be easily incorporated into the ecosystem services, thus allowing the area under study to be resilient to climate change. Amazonian forests are recognized for their importance in climate change mitigation, attributing to them the potential for carbon storage in biomass and soil, as well as the removal of greenhouse gases from the atmosphere (Baker et al., 2019 and Vicuña et al., 2019). García et al. (2012), evaluating trees and palms with DBH ≥ 10 cm in forests, found 88.60 $t \cdot ha^{-1}$ in total carbon sequestered, suggesting that the results are influenced by the age, density and extension of the fruit trees. Additionally, they found 51.28 $t \cdot ha^{-1}$ for the biomass of aguaje in high areas. Rueda (2014) found in plantations of guaba (around 200 has) a total of 6 180.21 $t \cdot ha^{-1}$ of carbon, in the biomass the value of 3 090.10 $t \cdot ha^{-1}$ and 11 330.30 $t \cdot ha^{-1}$ stored in the topsoil. Alegre et al. (2017) considered that systems covered permanently of *Centrosema macrocarpum* supply litter and therefore a rapid availability of nutrients and a strong defense against erosion. However, as total biomass they are much lower than trees, since they did not sequester more than 6 $t \cdot ha^{-1}$.

3.4.2. Soil carbon

Soil C stock for the 0 cm to 30 cm depth ranged between 24.64 $t \cdot ha^{-1}$ and 66.5 $t \cdot ha^{-1}$ (Figure 5). The highest C storage was showed by 13 years old caimito (*Pouteria caimito*) specie (6 plants/ha) that captured 66.5 $t \cdot ha^{-1}$ in plot 23. The lowest storage were observed for the 15 years old umari (*Poraquiba quadrangularis* L.) specie (13 plants/ha) in plot 37 that captured 24.64 $t \cdot ha^{-1}$, and for the guaba and caimito association in plot 13, which captured a total C stock of 50.32 $t \cdot ha^{-1}$. These fluctuations in soil C stocks are probably due to the different processes of soil organic matter decomposition in which climatic factors intervene, being the most important the air temperature and humidity, especially when the soil surfaces are exposed for planting fruit trees or other activities.

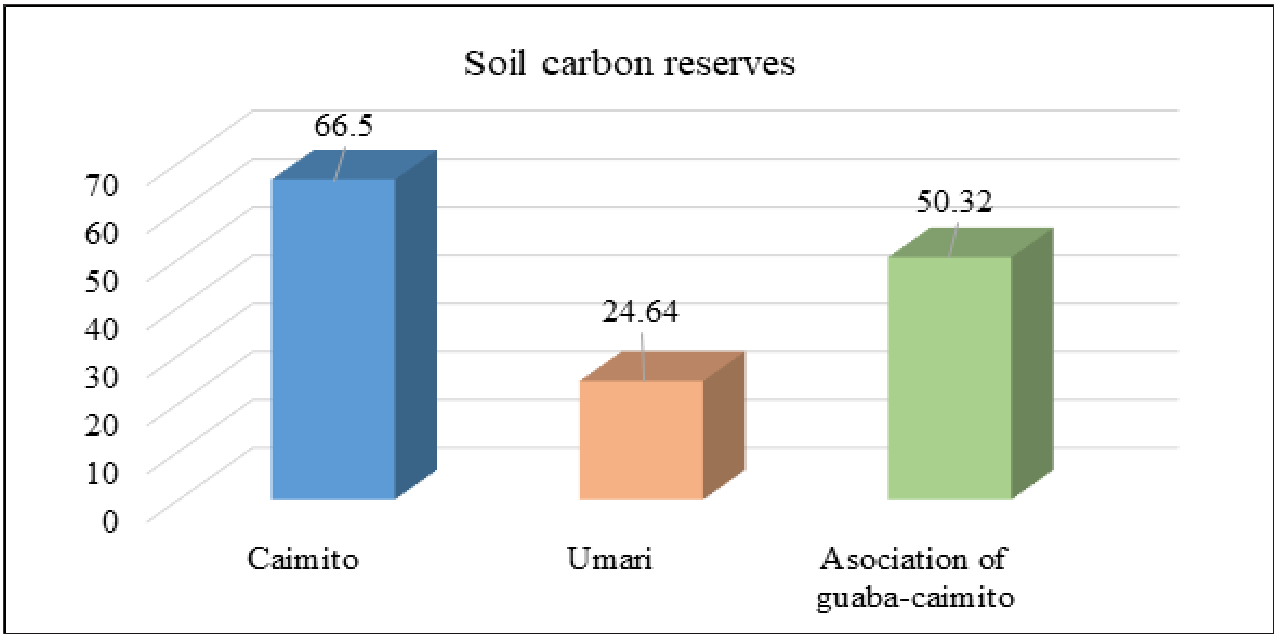

Figure 5: Soil carbon reserves at the depth of 0 – 30 cm in the producing plots of Amazonian fruit trees in Iquitos – Nauta road in Loreto

Soil functions are affected in agroecosystems, such as water and air dynamics. Biogeochemical processes, microorganisms and soil itself define soil quality (Dexter, 2004). Hernández & Vargas (2005) indicate that there are international mechanisms for different countries to buy and sell CO_2 absorption services, which is an important source of financing to protect and conserve resources and the environment, while at the same time improving the economy. Changes in soil quality can be monitored with easy and accurate indicators determined by reproducible methods (Moebius et al. 2007). Garcia et al. (2012), found values of 3.78 $t \cdot ha^{-1}$ of stored carbon and Rueda (2014) in 200 has of plants of the genus Inga, found 11 330.30 $t \cdot ha^{-1}$. The values found, is influenced by factors such as extension and type of plantations, plantation density, age, soil type, quality and environmental change, among others. García et al. (2012) considers that aguajes grow in hydromorphic soils and sequester large amounts of carbon greater than terrestrial ecosystems. They also indicate that, at a depth of 0 cm to 50 cm, they found carbon stocks that fluctuated from 51.28 to 193.9 $t \cdot ha^{-1}$, considering aguajales a great potential for greenhouse gas emissions.

Conclusions

The diversity index in vegetation reached a value of 2.74; kudzu (*Pueraria phaseoloides*) was predominant in the study area, while, for soil arthropods, it reached an index of 1.91 with a relatively low population of termites (*Nasutitermes* sp.).

Four species of the Amazonian fruit tree producing areas were the ones that captured the highest values of carbon in biomass. These were guaba (*Inga edulis*), pijuayo (*Bactris gasipaes* H. B.K.), uvilla *(Pouroma cecropiifolia* Mart.) and pan del árbol (*Artocarpus altilis* (Parkinson) Foseberg).

In associations of several fruit species, pijuayo with uvilla association sequester more CO_2 $ha \cdot a^{-1}$ and present more total fluxes than the association of four species such as pijuayo, uvilla , caimito (*Pouteria caimito*) and aguaje (*Mauritia flexuosa* L.). In the soil, the highest carbon stock at the depth of 0 cm to 30 cm was 66.5 $t \cdot ha^{-1}$, reducing CO_2 emissions by 243.84 $t \cdot ha^{-1} \cdot a^{-1}$.

In the sustainability evaluations, amazonian fruit trees are sustainable in the economic dimension (3.20) and ecological dimension (3.33). However, sustainability is weak in the sociocultural dimension (2.04).

Author contributions
Elaboration and execution, development of methodology, conception and design; editing of articles and supervision of the study have involved all authors.

Conflicts of interest
The signing authors of this research work declare that they have no potential conflict of personal or economic interest with other people or organizations that could unduly influence this manuscript.

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