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ARTICLE

# Evaluation of Soil Quality and Health Sustainability of Cocoa (*Theobroma Cacao*) Crop in Two Production Systems, Morona, Santiago, Ecuador

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## ABSTRACT

The productive evaluation of cocoa in this research is proposed through an assessment of soil quality and crop health in an organic production system (SPO) Taisha canton and a conventional production system (SPCv) Morona canton. Methodology: Altieri and Nicholls establish a diagnosis of chemical, physical, biological and health indicators, with weightings high (10), medium (5) and low (1). Results: SPO soil quality, reflects weights 10 (high) for ammonium ion, zinc, copper, iron, manganese, moisture retention, biological activity, compaction, apparent density, residue status, color, organic matter, root development, erosion incidence; 5 (medium) potassium, phosphorus, calcium, sulfur, pH, texture; 1 (low) magnesium, boron, topsoil depth, for crop health values of 10 (high) appearance, crop growth, stress resistance or tolerance, weed competition, agrosilvopastoral system, plant diversity and management system, 5 (medium) potential yield, incidence of pests and diseases. The SPCv soil quality presented a weighting of 10 (high) for nitrogen, zinc, copper, iron, biological activity, compaction, bulk density, color, organic matter, root development, erosion incidence; 5 (medium) manganese, pH, texture, moisture retention, residue status; 1 (low) potassium, phosphorus, calcium, magnesium, sulfur, boron, topsoil depth; crop health 10 (high) crop appearance and growth, stress resistance or tolerance, weed competition,

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agrosilvopastoral system, plant diversity, management system, potential yield, 5 (medium) incidence of pests and diseases, 1 (low) surrounding natural diversity. Conclusions: The SPO for soil quality: 7.41 and for crop health: 7.59 weighted as sustainable, while the SPCv for soil quality: 6 and crop health: 6.76, resulting in a moderately sustainable production system.

***Keywords:*** Quality; Crop Health; Cocoa; Organic; Conventional

# 1. Introduction

Soil is a component that provides nutrients to plants and serves as support for food security and environmental protection [1]. Within the biosphere it serves to maintain the diversity of species and balance the ecosystem in constant human impact [2]. The quality of the soil and health of the crop are affected by the excessive use of agrochemicals, poor technical management, the non-incorporation of technology and knowledge into the production process, reducing production and food supply to the population [3]. In this context highlight that conventional agriculture depletes environmental resources, contaminating groundwater, reducing soil fertility, generating more problems for farmers seeking more sustainable production systems. On the other hand, organic agriculture experiences significant economic growth of 20% annually, positioning itself as an alternative to obtain food in an organic and sustainable way [4].

Indicate that organic agriculture is present in 191 countries, covering approximately 76 million hectares, with a base of at least 3.7 million producers. To achieve a sustainable production system in both approaches, it is necessary to evaluate the capacity of the soil to provide adequate physical, chemical and biological parameters (soil quality) and study the health of the crop to nourish the plants [5]. In the specific case of cocoa cultivation, which involves 52 countries with 92% of exports and 80% of imports worldwide, Ecuador contributes significantly with 70% of fine cocoa, with production of 337,149 tons in 2022. Morona Santiago contributes around 364 tons, showing progress in the agricultural sector. Given the high production, it is crucial to know the quality of the soil and the health of the crop, replacing the use of agrochemicals with fertilizers or environmentally friendly organic inputs [6]. The study proposes to analyze the interaction between soil and crop health in conventional and organic cocoa production systems in the communities of Paccha and Jimiaraentsa. It seeks to examine the key parameters that affect both the soil and the plants. The comparison of production in both systems will allow identifying the level of sustainability and determining which parameters are being vulnerable or need to be addressed, to improve productivity and performance.

Express that the Cocoa crop (*Theobroma Cacao*) has fibrous roots extending throughout the surface layer of the soil, its stem is woody, denoting that it is a perennial species that can reach 4 to 8 meters, its leaves with large, elliptical and pointed with a dark green color, arranged alternately on long branches, the flowers are small with five petals of white or cream color with a characteristic smell, the fruits are pods or ears, large and elongated, the seeds are surrounded by white pulp and juicy. It requires soils with considerable depth, light texture and rich in nutrients to promote optimal root development. They adapt to soils with a composition of 50% sand, 30% clay and 20% silt with an organic matter content greater than 3.5%. The suitable pH range is 5 to 7 which corresponds to slightly acidic soils. It is essential to carry out adequate maintenance from planting to harvest using sustainable agroecological techniques for good performance. Beginning of the form the evaluation of soil quality has been a practice used to describe and understand its characteristics and properties intended for crops, according to refers to the way in which the land is used, whether to increase productivity or for sustainable management of this resource. This term constitutes a fundamental basis for the application of good agroecological practices, with the objective of achieving optimal management, which allows calculating a soil quality index [7].

The soil quality indicators according to the methodology of Altieri y Nicholls to evaluate soil quality, propose an objective selection of those parameters that can facilitate the result without neglecting the functions and aptitudes of the agricultural soil, such as: texture, structure, pH, moisture retention, biological activity, macronutrients, micronutrients, compaction and infiltration, apparent density, arable layer depth, residue states, color and organic matter, root development, erosion. Monitoring the health of the crop involves various aspects of visual and technical measurement such as the general appearance of the crop, the level of stress, presence of pests and diseases, proliferation of weeds, root, vegetal and productive development, in conjunction with the evaluation of potential yield state that these elements are crucial to evaluate the sustainability of any crop and provide valuable information for producers [8].

This approach is recognized as one of the key foundations in agricultural production, since it involves the natural defenses of plants against pests, diseases and physiopathies, which can affect the health and quality of food To counteract these adverse factors, actions are carried out that include the diagnosis of pests and diseases, their detection as well as monitoring and control through the implementation of corrective measures established by good agricultural management [9].

Rererence [10] propose an evaluation of crop health with adequate indicators to determine the sustainability of agroecological systems: appearance, crop growth, resistance, tolerance to stress, incidence of pests or diseases, competition for weeds, current or potential yield, plant diversity, surrounding natural diversity, establishment of agrosilvopastoral systems, allowing us to know the health status of the crops and estimate an appropriate value for each production system. Sustainable soil management refers to the capacity of an ecosystem, whether natural or managed by humans, to provide resources in various productive activities without compromising the integrity of the soil and the surrounding environment. Sustainable management of the environment contributes to evaluating the responsibility of producers in the use of natural resources, including the use of soil, water, air, preservation of forests, correct disposal of solid waste, guaranteeing good plant development, which represent a challenge for global food sovereignty [11]. The main objective is to evaluate the quality of soil and health of cocoa crops (*theobroma cocoa*) through indicators adapted to the locality, in an organic and conventional production management system, in the Paccha and Jimiarentsa localities, Morona Santiago, Ecuador.

## 2. Materials and Methods

**Study Area**

The research area of conventional cocoa cultivation called (SPCv) is located in the Paccha community, belonging to the Proaño parish, Morona canton, Morona Santiago province. The study plot is located on the property of Mr. Fausto Chávez, access to this place is through the Proaño road in an easterly direction, taking the entrance to the Paccha road about 2 km from the aviation antennas that form part of the Amazonian paradise community, as expressed in **Figure 1**, whose coordinates are: 821906.00m E and 9750109.00m S.

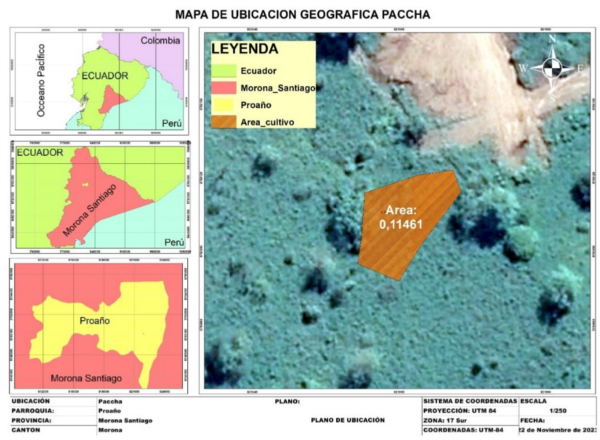


**Figure 1.** Geographic location map of Paccha.

Source: Own elaboration.

The organic cocoa growing area called (SPO) will be located in the Jimiarentsa community of the Taisha parish, in the Taisha canton of the province of Morona Santiago, specifically on the property of Mr. Mario Wampio. To access this place, use the Tutinentsa road, **Figure 2**, whose coordinates are: 229723.00m E; 9721772.00m S.

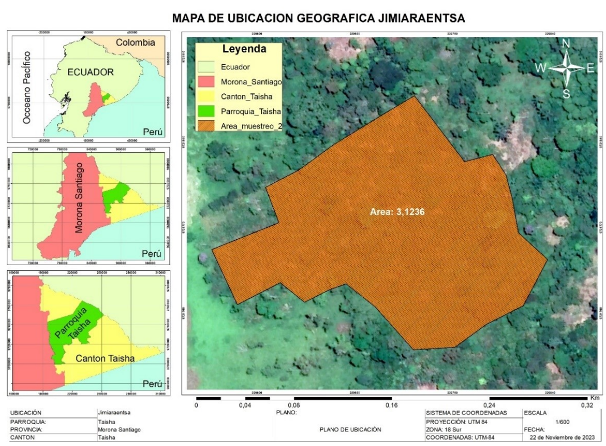


**Figure 2.** Jimiaraentsa geographic location map.

Source: Own elaboration.

The research study adopts a mixed, qualitative and quantitative approach since a sequential protocol was used for the measurement of independent and dependent variables established as indicators of soil quality: texture, structure, pH, moisture retention, biological activity, macronutrients, micronutrients, compaction and infiltration, apparent density, arable layer depth, residue states, color and organic matter, root development, erosion and crop health indicators: appearance, crop growth, resistance, tolerance to stress, incidence of pests or diseases, competition for weeds, current or potential yield, plant diversity, surrounding natural diversity, establishment of aggressive pastoral systems according to the methodology of[12].

Establishing a quantitative approach by collecting data from the laboratory, after having carried out soil sampling to assess its quality. The study is also considered qualitative because a visual analysis was carried out based on the physical characteristics observed in the two cocoa cultivation systems, allowing an assessment of health to be carried out, generating data that was later reflected in an amoeba diagram according to the methodology[13].

Type of research is characterized by its descriptive approach, since it involves a visual analysis in the field to evaluate the state of 25 plants, selected in a random process, to establish representative values of the health of the Cocoa crop. In addition, it has an explanatory component since it uses data obtained both from the laboratory and from visual analysis in the field to understand the current state of soil quality and crop health, thus allowing to explain possible effects on the evaluated parameters. The relational nature of the research lies in the comparison of data between a conventional production system and an organic system to determine sustainability, the temporality is classified as a cross-sectional study since a single analysis of parameters was carried out to compare the results[14].

To determine soil quality in the organic production system (SPO) and conventional production system (SPCv), it was carried out using different field, laboratory and visual methodologies established by[15], evaluating physical parameters. important chemical and biological factors to determine which system is sustainable as seen in **Table 1**.

Crop health was determined using the visual methodology chosen by[16] according to the indicators, characteristics, scales and methodologies presented in **Table 2**.

The methodologies allowed us to know the state of the soil and the crop in organic and conventional production. The sustainability of the two agroecosystems was analyzed using the methodology proposed by[17], which propose ranges (1–4) with a non-sustainable valuation (1), range of (4.1–7) moderately sustainable valuation (5), and ranges of (7.1–10) sustainable valuation (10), applied to the quality and health of the crop to determine sustainability.

**Table 1.** Parameters to evaluate soil quality.

| N. | Parameter | Detail | Scale | Methodology | N. | Parameter | Detail | Scale | Methodology |
|---|---|---|---|---|---|---|---|---|---|
| 1 | N | >40 ppm | 10 | Kjelahl method | 12 | pH | 7.6–6.5 | 10 | Soil and water suspension pH method, with Potentiometer |
| | | 40–20 ppm | 5 | | | | 6.4–5.1 | 5 | |
| | | <20 ppm | 1 | | | | <5 | 1 | |
| 2 | P | >20 ppm | 10 | Bray Method I, | 13 | Texture | loam, silt loam, clay loam >35% | 10 | Bouyoucos method |
| | | 10–20 ppm | 5 | | | | sandy loam, clay loam, clay | 5 | |
| | | <10 ppm | 1 | | | | Sandy | 1 | |
| 3 | K | >0.41 meq/100 ml | 10 | Ammonium acetate method | 14 | Moisture retention | >70 | 10 | Soil water retention curve method |
| | | 0.40–0.21 meq/100 ml | 5 | | | | 70–30 | 5 | |
| | | <0.20 meq/100 ml | 1 | | | | <30 | 1 | |
| 4 | Ca | >8 meq/100 ml | 10 | | 15 | biological activity | >1 | 10 | Macrofauna method, as a biological indicator |
| | | 8–4 meq/100 ml | 5 | | | | 1 | 5 | |
| | | <4 meq/100 ml | 1 | | | | <1 | 1 | |
| 5 | Mg | >2.1 meq/100 ml | 10 | | 16 | Compaction and infiltration | Not compact, water infiltrates easily. | 10 | Porchet method |
| | | 2–1.2 meq/100 ml | 5 | | | | Thin compact layer, water infiltrates slowly. | 5 | |
| | | <1.1 meq/100 ml | 1 | | | | Compact, it floods. | 1 | |

**Table 1.** *Cont.*

| N. | Parameter | Detail | Scale | Methodology | N. | Parameter | Detail | Scale | Methodology |
|---|---|---|---|---|---|---|---|---|---|
| **6** | S | >20 ppm | 10 | Calcium chloride method | 17 | Apparent density | <1.1 | 10 | Volume cylinder method |
| | | 10–20 ppm | 5 | | | | 1.39–1.49 | 5 | |
| | | <10 ppm | 1 | | | | >1.58 | 1 | |
| **7** | B | >1 ppm | 10 | | 18 | Soil depth | >30 cm | 10 | Soil profile method |
| | | 1–0.5 ppm | 5 | | | | 10–20 cm | 5 | |
| | | <0.50 ppm | 1 | | | | <10 cm | 1 | |
| **8** | Cu | >4 ppm | 10 | DTPA method | 19 | Waste status | Well decomposed waste. | 10 | Visual method |
| | | 4–1 ppm | 5 | | | | Waste in the process of decomposition | 5 | |
| | | <1 ppm | 1 | | | | Presence of undecomposed organic waste | 1 | |
| **9** | Fe | >40 ppm | 10 | | 20 | Color and organic matter | Non-compact soil, water infiltrates easily | 10 | Munsell notation system method and LOI |
| | | 20–40 ppm | 5 | | | | Presence of thin compact layer, water infiltrates slowly | 5 | |
| | | <20 ppm | 1 | | | | Compact, waterlogged | 1 | |
| **10** | Mn | >15 ppm | 10 | | 21 | Root development | Good growth, healthy, with abundant roots. | 10 | DLR method |
| | | 15–5 ppm | 5 | | | | With limited growth some fine roots. | 5 | |
| | | <5 ppm | 1 | | | | Underdeveloped, sick and short. | 1 | |
| **11** | Zn | >7 ppm | 10 | | 22 | Erosion | There is no major sign of erosion. | 10 | Visual method |
| | | 2–7 ppm | 5 | | | | Little erosion. | 5 | |
| | | <2 ppm | 1 | | | | Severe erosion, soil dragging and presence of gullies are noted | 1 | |

**Table 2.** Parameters to evaluate Crop Health.

| N. | Parameter | Detail | Scale | Methodology | N. | Parameter | Detail | Scale |
|---|---|---|---|---|---|---|---|---|
| 1 | Appearance | Deep green foliage, no signs of deficiency | 10 | Altieri and Nicholls | 7 | Current or potential performance | Good or high in relation to the Ecuador average | 10 |
| | | Light green crop, with some discolorations | 5 | | | | Acceptable average in relation to the average of Ecuador | 5 |
| | | Chlorotic or unknown culture, with severe signs of nutrient deficiency | 1 | | | | Bad compared to the Ecuador average | 1 |
| 2 | Crop growth | Dense, uniform crop, good growth, with thick and firm branches and stems. | 10 | Altieri and Nicholls | 8 | Agrosilvopastoral system | Presence of agriculture, livestock, and forestry | 10 |
| | | Denser crop, but not uniform with new growth and still thin branches and stems | 5 | | | | Presence of agriculture and livestock | 5 |
| | | Sparse crop, poor growth, short and brittle stems and branches, very little new foliage growth. | 1 | | | | Presence of livestock | 1 |
| 3 | Resistance or tolerance to stress | They withstand heavy rains | 10 | Altieri and Nicholls | 9 | Plant diversity | With more than two shade species and even other dominant crops or weeds. | 10 |
| | | They suffer dry or very rainy seasons, they recover slowly | 5 | | | | With just a kind of shadow. | 5 |
| | | Susceptibles do not recover well after stress. | 1 | | | | Monoculture without shade. | 1 |

**Table 2.** *Cont.*

| N. | Parameter | Detail | Scale | Methodology | N. | Parameter | Detail | Scale |
|---|---|---|---|---|---|---|---|---|
| 4 | Disease incidence | <20% | 10 | Altieri and Nicholls | 10 | Surrounding natural diversity | Surrounded at least 50% of its edges by natural vegetation. | 10 |
| | | 20–45% | 5 | | | | Surrounded on at least one side by natural vegetation. | 5 |
| | | >50% | 1 | | | | Surrounded by other crops, vacant fields or roads | 1 |
| 5 | Pest incidence | <20% | 10 | Altieri and Nicholls. | 11 | Management system | Diversified organic, with little use of organic or biological inputs. | 10 |
| | | 20–45 | 5 | | | | In transition to organic, with replacement of inputs. | 5 |
| | | >50% | 1 | | | | Conventional cultivation, managed with agrochemicals. | 1 |
| 6 | Competition for weeds | Vigorous crop, it overcomes weeds or grasses and does not cause problems. | 10 | Altieri and Nicholls | | | | |
| | | Medium presence of weeds, crop suffers competition | 5 | | | | | |
| | | Stressed crops dominated by weeds | 1 | | | | | |

# 3. Results

For soil quality, average evaluation values were weighted considering: 10 (high), 5 (medium), 1 (low) exposed in the methodology of[17], obtaining the following values for the SPO and SPCv systems, as expressed in **Table 3**.

In **Table 3**, the chemical analysis of the element Nitrogen could be observed with 59.9 ppm, weighting a value of 10 (high) in the SPO; for SPCv a value of 69.7 ppm with a high range (10) indicated that Amazonian soils are rich in nitrogen, The studies of cocoa farms in the Amazon, obtaining a value of 42 ppm, considered within the high range, evidencing good growth and development of cocoa plants in some systems naturally. For phosphorus, the result for SPO was 13.6 ppm, weight 5 (medium); in the SPCv it presented 9.4 ppm with a value of 1 (low); obtained a concentration of 10.09 ppm giving a value of 5 (medium), managing an organic system, while for the conventional production system there are differences due to the conventional management that is used, making use of synthetic inputs in its productive system. Potassium reflected a value for SPO 0.36 meq/100 ml with a weighting of 5 (medium); The SPCv obtained 0.17 meq/100 ml with a weighting of 1 (low), because farmers do not technically manage the fertilization processes; According to[19] they determined that in cocoa cultivation its K content is 0.176 meq/100 ml, presenting soils low in potassium content, which directly influences crop yield.

**Table 3.** Descriptive statistics of crop health indices.

| SOIL QUALITY | | | | | | |
|---|---|---|---|---|---|---|
| Indicator | Characteristics | Weighing | SPO | Assessment | SPCv | Assessment |
| N | >40 ppm | 10 | 10 | High | 10 | High |
| | 40–20 ppm | 5 | | | | |
| | <20 ppm | 1 | | | | |
| P | >20 ppm | 10 | 5 | Half | 1 | Low |
| | 10–20 ppm | 5 | | | | |
| | <10 ppm | 1 | | | | |

**Table 3.** *Cont.*

| | SOIL QUALITY | | | | | |
|---|---|---|---|---|---|---|
| **Indicator** | **Characteristics** | **Weighing** | **SPO** | **Assessment** | **SPCv** | **Assessment** |
| K | >0.41 meq/100 ml | 10 | 5 | Half | 1 | Low |
| | 0.40–0.21 meq/100 ml | 5 | | | | |
| | <0.20 meq/100 ml | 1 | | | | |
| Ca | >8 meq/100 ml | 10 | 5 | Half | 1 | Low |
| | 8–4 meq/100 ml | 5 | | | | |
| | <4 meq/100 ml | 1 | | | | |
| Mg | >2.1 meq/100 ml | 10 | 1 | Low | 1 | Low |
| | 2–1.2 meq/100 ml | 5 | | | | |
| | <1.1 meq/100 ml | 1 | | | | |
| S | >20 ppm | 10 | 5 | Half | 1 | Low |
| | 10–20 ppm | 5 | | | | |
| | <10 ppm | 1 | | | | |
| Zn | >7 ppm | 10 | 10 | High | 10 | High |
| | 2–7 ppm | 5 | | | | |
| | <2 ppm | 1 | | | | |
| Cu | >4 ppm | 10 | 10 | High | 10 | High |
| | 4–1 ppm | 5 | | | | |
| | <1 ppm | 1 | | | | |
| Fe | >40 ppm | 10 | 10 | High | 10 | High |
| | 20–40 ppm | 5 | | | | |
| | <20 ppm | 1 | | | | |
| Mn | >15 ppm | 10 | 10 | High | 5 | Half |
| | 15–5 ppm | 5 | | | | |
| | <5 ppm | 1 | | | | |
| B | >1 ppm | 10 | 1 | Low | 1 | Low |
| | 1–0.50 ppm | 5 | | | | |
| | <0.50 ppm | 1 | | | | |
| pH | 7.6–6.5 | 10 | 5 | Half | 5 | Half |
| | 6.4–5.1 | 5 | | | | |
| | <5 | 1 | | | | |
| Texture | Medium textures (loam, silt loam, clay loam >35%) | 10 | 5 | Half | 5 | Half |
| | Sandy loam, clay loam (<35% sandy clay), clay | 5 | | | | |
| | Sandy | 1 | | | | |
| | >70 | 10 | | | | |
| Moisture retention | 70–30 | 5 | 10 | High | 5 | Half |
| | <30 | 1 | | | | |
| biological activity | >1 | 10 | 10 | High | 10 | High |
| | 1 | 5 | | | | |
| | <1 | 1 | | | | |
| Compaction and infiltration | Non-compact soil, water infiltrates easily. | 10 | 10 | High | 10 | High |
| | Presence of thin compact layer, water infiltrates slowly. | 5 | | | | |
| | Compact, it floods. | 1 | | | | |

**Table 3.** *Cont.*

| SOIL QUALITY | | | | | | |
|---|---|---|---|---|---|---|
| **Indicator** | **Characteristics** | **Weighing** | **SPO** | **Assessment** | **SPCv** | **Assessment** |
| Apparent density | <1.1 | 10 | 10 | High | 10 | High |
| | 1.39–1.49 | 5 | | | | |
| | >1.58 | 1 | | | | |
| Soil depth | >30 cm | 10 | 1 | Low | 1 | Low |
| | 10–20 cm | 5 | | | | |
| | <10 cm | 1 | | | | |
| Waste status | Waste in various states of decomposition, old waste well decomposed. | 10 | 10 | High | 5 | Half |
| | Waste in the process of decomposition | 5 | | | | |
| | Presence of organic waste and does not decompose | 1 | | | | |
| Color and organic matter | Black or dark brown floor | 10 | 10 | High | 10 | High |
| | Light brown or reddish soil | 5 | | | | |
| | pale colored soil | 1 | | | | |
| Root development | Good growth, healthy, with abundant roots. | 10 | 10 | High | 10 | High |
| | With limited growth some fine roots. | 5 | | | | |
| | Underdeveloped, sick and short. | 1 | | | | |
| Erosion | There is no major sign of erosion. | 10 | 10 | High | 10 | High |
| | Little erosion is observed. | 5 | | | | |
| | Severe erosion, soil dragging and presence of gullies are noted. | 1 | | | | |
| Average | | | 7.41 | | 6 | |

* Nutritional content, whose scale presented by [18] in the guide to soil fertility and nutritional requirements.

Calcium in the SPO has a value of 4.94 meq/100 ml with a weight of 5 (medium), showing good root development; In the SPCv, 3.99 meq/100 ml was obtained, weighing a value of 1 (low), this is because the soil has an acidic pH, ivestigation of the soil in a farm located in the Ecuadorian Amazon obtained 1.41 meq/100 ml of calcium, being in a medium range. For the magnesium analysis, the SPO obtained 1 meq/100 ml and the SPCv was established 0.98 meq/100 ml, weighted with a value of 1 (low); Due to the acidic pH of the soils, it also has a low cation exchange capacity; In the province of Zamora Chinchipe, Yantzasa canton, a silvopastoral system was evaluated, with a magnesium value before the application of lime with results of 1 to 1.5 meq/100 ml, denoting low access of the roots to nutrients low mobility and nutrients found at greater depths. The sulfur present in the SPO is 12.26 ppm with a value of 5 (medium) because the soil does not have a continuous organic fertilization plan, causing a nutritional imbalance; For SPCv, 1.58 ppm was measured with a value of 1 (low), evidencing the rotting of the tips of the leaves, generating curling and subsequent fall; in comparison with [20] where a value of 3.29 ppm was obtained, defining that Amazonian soils have an average concentration of the element depending on the type of soil and amount of organic matter. Zinc analysis showed a concentration of 11.24 ppm in the SPO; For SPCv, a value of 8.82 ppm was obtained, considering a high range for the two production systems, according to the research by [21], who obtained a value of 8.6 ppm, state that interference problems arise with the absorption of Mg and B, reducing the concentration of these elements. Regarding the data obtained from copper, in the SPO a concentration of 18.76 ppm was evaluated due to the leaf litter content; for SPCv a value of 19.96 ppm since fungicides are used to control diseases with a weight of 10 (high) for the two production systems; very different values with those reported by [22] detailing a value of 1.76 ppm of copper in their study managed as indigenous organic systems, the same ones that are vulnerable to attack by pests and diseases. He iron obtained in the SPO is 191.40 ppm; for SPCv a value of 231.8 ppm establishing a weighting of 10 (high) for both systems, which may affect the absorption of essential nutrients for the good growth of the cocoa crop; has obtained a value of 429.4 ppm considered within the high range, having problems with element blocking and absorption of essential elements. The manganese content was obtained for SPO 127.20 ppm weighting a value of 10 (high); which acts as an enzyme activator in growth processes, promoting the conversion of nitrates; for SPCv, 8.82 ppm was presented, weighing a value of 5 (medium) because the soil is fertilized with chemicals that can alter soil parameters; In contrast to [23] obtains 8.70 ppm, mentioning that Amazonian soils have a medium manganese content. In relation to the results obtained for Boron, in the SPO there is a content of 0.31 ppm; in the SPCv a value of 0.41 ppm, weighting the systems with a value of 1 (low), because there is a high concentration of zinc, presenting deformities in the leaves and fruits; as investigated by Martínez García et al. (16) obtaining a result of 0.15 ppm of Boron, thus demonstrating that the soils of the Amazon and especially of Morona Santiago are low in Boron content. The pH value obtained in the SPO is 5.47 and for the SPCv a value of 5.2 corresponding to acidic soils with a weight of 5 (medium). representing low content of Ca, Mg and F; corroborating with the research in the Ecuadorian amazon where values of 5.57 are reported as an acidic soil suitable for cocoa cultivation.

For soil texture, a clay texture was determined for the SPO, for the SPCv a sandy clay and gravel texture was obtained, weighting a value of 5 (medium) due to its geographical location near river banks; showing data for a clay loam soil, denoting that in general aspects the Amazonian soils are clay loam or clay. Moisture Retention, for the SPO a value of 71.33% was obtained weighing 10 (high), for the SPCv a value of 53% valuing a range 5 (medium) remaining semi-humid, these differences due to the type of soil texture and the type of agriculture applied, porosity has been determined greater than 60%, meaning that Amazonian soils are capable of retaining water in a good percentage. The Biological Activity in relation to the edaphic macrofauna resulted in a value of 9.91 for the SPO and for the SPCv a value of 9, weighing a high range (10), obtained 1129 individuals analyzed in periods of high precipitation and moisture retention, establishing a considerable presence of macrofauna in the soil in tropical Amazonian climates. The SPO obtained a value for compaction (0.107 kg/cm$^2$) and infiltration (31.51 cm/h); the SPCv a value of 0.113 kg/cm$^2$ (compaction) and 31.51 cm/h (infiltration) establishing a value of 10 (high) due to minimal soil tillage practices; [24] reported a compaction (0.09 kg/cm$^2$), infiltration of 37.4 cm/h in the town of Zamora, demonstrating that the soil is less compact due to the intensive tillage applied to the soils. The result of the apparent density for the SPO established a value of 0.998 g/cm$^3$, weighting a value of 10 (high); in the SPCv it obtained 0.741 g/cm$^3$, with a high range (10) allowing root development and less soil compaction; In Ecuadorian amazon obtained an apparent density value of 0.057 g/cm$^3$, that soils have a good apparent density. For the analysis of soil depth, 4 cm was determined for the SPO and for the SPCv a value of 3 cm, establishing a rating of 1 (low) considering that conventional tillage is not applied and they are rich in organic matter, which tends to be almost exposed soils, a superficial soil profile, they applied a technique for creating an arable layer through vertical tillage and sowing methods, allowing more fertile soils to be obtained by increasing its arable layer. The state of SPO residues was determined, showing various stages of decomposition such as leaf litter, cocoa waste, decomposing grasses, weighing a value of 10 (high) and for the SPCv it was valued at 5 (medium) as it had residues in the initial stage of decomposition; In Ecuadorian amazon, the nutrients such as N, Ca and Mg that best benefit from the decomposition of leaf litter, the higher nutritional content of Ca, Mg, Mn, B. Color and organic matter in the SPO showed a result of 5.71% MO and a brown color (10 YR 6/8) assuming a value of 10 (high) and for the SPCv a value of 15.11% MO and a dark grayish yellow color (25 YR 5/2) setting a value of 10 (high), is obtained 5% OM, due to the accumulation of plant remains, the climate and the agricultural management of the region. The analysis of root development in cocoa crops was evidenced for the two production systems, roots with a good state of growth, having adequate depth and development, also observing the development of secondary roots, which was weighted with a value of 10 (high); In relation to Ecuadorian amazon who observed root development in cocoa, a length of 3.91 cm was obtained because they are plants with a shorter establishment time. For the result of erosion, the two production systems were valued with a range of 10, without evidence of the presence of gullies or frequent earth movement due to the high content of organic matter, which allows good aggregation and fertility, The health of the crop evaluated visually allowed us to know the state of the plant in relation to the deficiency of nutrients in the soil, both in organic (SPO) and conventional (SPCv) production systems, evaluating 25 cocoa plants. taken at random, considering not evaluating plants that are close to the edge since they are not significant for the visual analysis, by applying 11 indicators with their corresponding scale according to **Table 4**.

**Table 4.** Indicators, scale characteristics for assessment of crop health.

| Indicator | Characteristics | Weighing | SPO | Assessment | SPCv | Assessment |
|---|---|---|---|---|---|---|
| Appearance | Deep green foliage, no signs of deficiency | 10 | 8.40 | High | 8.20 | High |
| | Light green crop, with some discolorations | 5 | | | | |
| | Chlorotic or unknown culture, with severe signs of nutrient deficiency | 1 | | | | |
| Crop growth | Dense, uniform crop, good growth, with thick and firm branches and stems. | 10 | 8.5 | High | 8 | High |
| | Denser crop, but not uniform with new growth, branches and stems still thin | 5 | | | | |
| | Sparse crop, poor growth, short and brittle stems and branches, little new foliage growth. | 1 | | | | |
| Resistance or tolerance to stress | They withstand heavy rains | 10 | 8 | High | 8 | High |
| | They suffer dry or very rainy seasons, they recover slowly | 5 | | | | |
| | Susceptibles do not recover well after stress. | 1 | | | | |
| Disease incidence | <20% | 10 | 5.5 | Half | 5.2 | Half |
| | 20–45% | 5 | | | | |
| | >50% | 1 | | | | |
| Pest incidence | <20% | 10 | 5 | Half | 5 | Half |
| | 20–45 | 5 | | | | |
| | >50% | 1 | | | | |
| Competition for weeds | Vigorous crop, overcomes weeds | 10 | 9 | High | 8 | High |
| | Medium presence of weeds, crop suffers competition | 5 | | | | |
| | Stressed crops dominated by weeds | 1 | | | | |
| Current or potential performance | Good or high in relation to the Ecuador average | 10 | 5 | Half | 10 | High |
| | Acceptable average in relation to the average of Ecuador | 5 | | | | |
| | Bad compared to the Ecuador average | 1 | | | | |
| Agrosilvopastoral system | Presence of agriculture, livestock, and forestry | 10 | 10 | High | 10 | High |
| | Presence of agriculture and livestock | 5 | | | | |
| | Presence of livestock | 1 | | | | |
| Plant diversity | With more than two shade species and even other dominant crops or weeds. | 10 | 5 | Half | 10 | High |
| | With just a kind of shadow. | 5 | | | | |
| | Monoculture without shade. | 1 | | | | |
| Surrounding natural diversity | Surrounded at least 50% of its edges by natural vegetation. | 10 | 10 | High | 1 | Low |
| | Surrounded on at least one side by natural vegetation. | 5 | | | | |
| | Surrounded by other crops, vacant fields or roads | 1 | | | | |

**Table 4.** *Cont.*

| Indicator | Characteristics | Weighing | SPO | Assessment | SPCv | Assessment |
|---|---|---|---|---|---|---|
| Management system | Diversified organic, with little use of external inputs | 10 | 10 | High | 1 | Low |
| | In transition to organic, with replacement of inputs. | 5 | | | | |
| | Conventional cultivation, managed with agrochemicals. | 1 | | | | |
| Average | | | 7.59 | | 6.76 | |

Appearance analysis, as shown in **Table 4**, the average SPO was 8.40 and for the SPCv a value of 8.2, weighting a range of 10 (high), meaning that a lower percentage is being affected and It is visually evident in the leaves; according to [25] stating the highest value for the appearance of the crop because they were sustainable systems and did not present deficiency in the leaves, this asserts that the crops do not show differences for both systems. The growth of the cocoa crop was taken into account. the years of the plant showing an average for the SPO of 8.5 and for the SPCv an average of 8 giving a weight of 10 (high) showing that they are dense, well-established crops, with good growth and thickness of the stems.

Resistance or tolerance to stress was weighted for SPO and SPCv at a value of 8 (high) because they are plants that withstand heavy rains and are not sensitive; in corroboration with the research carried out by [26] where a correlation between resistance, growth, and plant performance is evident through Pearson analysis, explaining that the greater the growth, the greater the absorption of nutrients and this improves resistance to stress, generating greater productivity. For the Incidence of diseases in the SPO, a value of 5.5 (medium) and the SPCv with 5.2 (medium) resulted since it presented mild to severe symptoms caused by brown ear rot and witches' broom, established a lower significant relationship between crop growth and the presence of diseases, due to the lack of nutrients in the soil, water availability and, above all, the applied agricultural management.

Pest incidence analysis, an average of 5 (medium) was obtained in the two production systems due to the pests recorded as defoliating worms, mites, bed bugs, applying cultural practices obtained 11 to 14% lower presence of moniliasis in the fruit compared to the farmer's management, which decreased 40 and 50% of pests present. For weed competition, a value of 9 (high) was established for SPO and a value of 8 (high) for SPCv since there is adequate control of weeds in the crop, which states that the success of crop management is to eliminate the competition that the crop has. The current or potential yield for the SPO that grows national cocoa was 0.16 t/ha per year, acceptable in relation to the national average, indicating a value of 5 (medium); For the CCN-51 variety SPCv, 6.98 t/ha per year was recorded, weighing a range of 10 (high), meaning good in relation to the national average; According to the research carried out by [27] (national cocoa had 0.45 t/ha and CCN-51 a value of 0.75 t/ha, this due to the age of the crops.

For the agrosilvopastoral system, the SPO and the SPCv were weighted with a value of 10 (high) because agriculture, livestock and forest trees were present in both systems; According to the research of[28] in the system with transition to organic, agriculture, forest trees and livestock were evident, valuing a high rank (10). To know the plant diversity, the SPO was weighted with a value of 5 (medium) because the plantation only had one shade species within its crop; For the conventional production system, a value of 10 (high) was weighted as it had more than two shade species and other crops such as cassava, hibiscus and banana; in relation to the research by who had a diversity of trees and shrubs, and herbaceous plants on their farms.

With respect to the analysis of surrounding natural diversity in the organic production system, a weighting of 10 (high) was obtained and for the SPCv a range of 1 (low) was weighted; In relation to the research carried out by [29] they obtained a value of 4 for both systems because the systems were surrounded by other crops that compete with the crop, vacant fields and roads. Regarding the management system, a value of 10 (high) was given to the SPO since agrochemicals are not used and it is a diversified organic crop that does not cause damage to the environment; for SPCv a low rank (1) as it is a crop with agrochemicals that are not friendly to the environment.

## 4. Discussion

In relation to the production systems of Mr Mario Wampio located in Jimiaraentsa, the average of the indicators evaluated for soil quality is 7.41; For the conventional cocoa production system belonging to Mr. Fausto Chávez, there is an average of 6 for soil quality, as seen in **Table 5**, **Figure 3**.

**Table 5.** Soil quality evaluation in organic and conventional cocoa production system.

| Feature | Organic Soil Quality | Conventional Soil Quality |
|---|---|---|
| Sustainable | 7.41 | |
| Moderately sustainable | | 6 |
| Not sustainable | | |

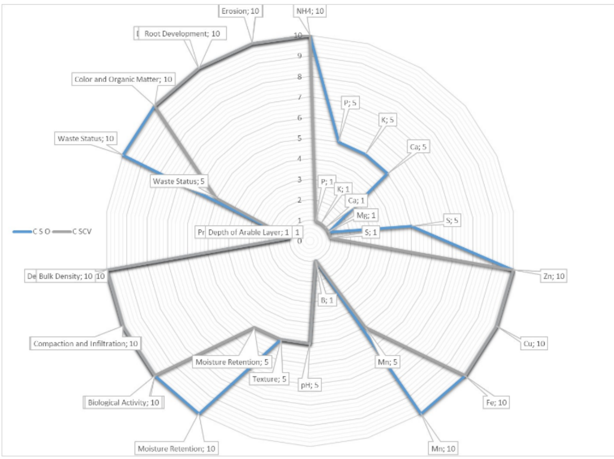


**Figure 3.** Evaluation of the quality of cocoa cultivation soils in organic and conventional systems.

Source: Own elaboration.

The national cocoa crop located in Jimiaraentsa uses an organic production system that, when the physical, chemical, biological and health parameters were evaluated, established that it is a sustainable system, while the CCN-51 variety cocoa crop located in Paccha is It is classified as a conventional production system and therefore represents a moderately sustainable result with respect to the analyzes carried out ex situ and in situ, as seen in **Figure 4**.

With respect to the health of cocoa cultivation with two different varieties, an average of 7.59 was established according to the visual evaluation for health in the organic production system while for the conventional production system an average of 6.76, as seen in **Table 6**.

Through the analysis carried out on the two systems, the values were established and sustainability was evaluated through indicators of soil quality and crop health, revealing that the organic production system is sustainable, because agrochemicals are not applied and it is environmentally friendly; The conventional production system is moderately sustainable, due to crop diseases and the deficiency of some nutrients in the soil; in relation to the research carried out by [30] where he did a sustainability analysis in the Penipe canton, evaluated through farm indicators to determine sustainability processes and parameters, in order to address critical or inflection points in their evaluations.

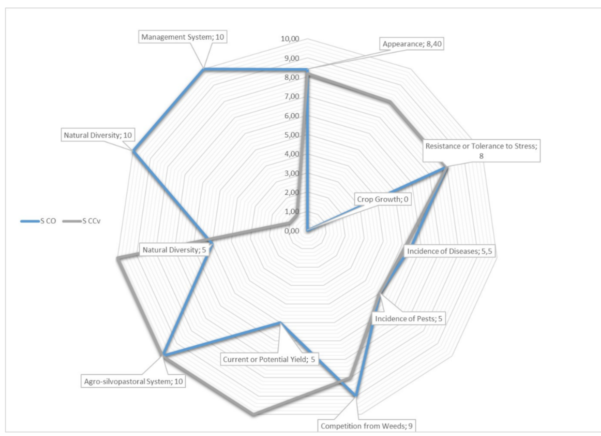


**Figure 4.** Evaluation of the health of cocoa cultivation in an organic and conventional system.

Source: Own elaboration.

**Table 6.** Evaluation of crop health in organic and conventional cocoa production systems.

| Feature | Health Organic Farming | Conventional Crop Health |
|---|---|---|
| Sustainable | 7.59 | |
| Moderately sustainable | | 6.76 |
| Not sustainable | | |

## 5. Conclusions

When evaluating the organic and conventional cocoa production systems, through indicators of soil quality and crop health, the organic production system (SPO) and conventional production system (SPCv), the organic farm of Mario Wampio exhibits low levels of Magnesium and boron, but adequate conditions for other nutrients in a clayey, non-compact soil with an acidic pH of 5.47. In Fausto Chávez's conventional farm, a lower content of potassium, phosphorus, calcium, sulfur and boron is observed, with a clay-sand-gravel texture and an acidic pH of 5.20.

Conventional and organic production systems were evaluated using indicators weighted at 1 (low), 5 (medium) and 10 (high), to determine sustainability in cocoa cultivation. The results indicated that the farm under the organic system was located in the sustainable range, registering a value of 7.41 in soil quality and 7.59 in crop health, applying environmentally friendly practices and processes.

In the evaluation of the farm with a conventional cocoa production system, it was classified as moderately sustainable, with an average of 6 in soil quality and 6.76 in crop health. These findings, derived from physical, chemical and biological analyzes in the ESPOCH laboratory in Morona Santiago, indicate that cocoa crops can achieve sustainability through adequate comprehensive management.

## Author Contributions

Conceptualization, C.M.; methodology, H.J.; validation, H.C.; formal analysis, C.W.; investigation, resources, data curation, C.M.; writing—original draft preparation, H.J.; writing-review and editing, H.C.; visualization, supervision, J.D. All authors have read and agreed to the published version of the manuscript.

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## Institutional Review Board Statement

The study does not require ethical approval.

## Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

## Data Availability Statement

Data can be provided by request to the email juanpablo.haro@espoch.edu.ec.

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## Conflicts of Interest

The authors declare no conflict of interest.

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