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Evaluation the sustainability of rice production systems under different conditions of infestation with M. graminicola.

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Abstract: The objective was to evaluate the sustainability of rice production systems under different conditions of infestation with M. graminicola, to determine population levels based on soil and root sampling following established protocols. They were evaluated in the Babahoyo and Quevedo cantons, both located in the Los Ríos Province; Coastal Region. Data were obtained through surveys, interviews, workshops, field day and direct field observations. The survey included 26 questions aimed at obtaining socio-cultural, economic and ecological information. The sample size is calculated using a neutrosophic statistic approach to deal with interval data. The survey population consisted of professionals, representatives of rice associations, small-scale rice producers and others. Based on the results obtained for sustainability in the two evaluated rice localities of Babahoyo and Quevedo, applying the already established formula, they reach a (ISGen) of 1.71 Babahoyo and 1.54 Quevedo are not considered sustainable, this because in both localities, there are dimensions that present values lower than 2, To consider a farm as sustainable, the General Sustainability Index must be higher than 2 and, also; none of the three evaluated dimensions must have a value lower than 2. This is due to the lack of diversification for sales, low yields, few marketing channels, lack of sources of financing, low vegetation cover and negligible crop diversification, showing that two production systems are not sustainable for the conditions under which the sustainability evaluation was carried out.

Keywords: sustainability; rice production systems; M. graminicola, neutrosophic statistics, neutrosophic sample size

1. Introduction

One of the main staple food crops worldwide is rice, and for 2017, an area of approximately 167 million ha, an average yield of 4601.9 kg/ha and a production of 769 million t is reported. In Ecuador, in 2017, 358100 ha were planted, with an average yield of 2978.5 kg/ha and a production of 1 066 614 t (FAOSTAT 2019). For the first period of 2018, a yield of 4.81 t/ha is estimated, with the province of Loja having the highest yield with 9.10 t/ha, and Los Rios the lowest yield with 3.64 t/ha[1] .

Rice is a critical crop in Ecuador because it is the main livelihood of a large number of small-scale farmers, so it is essential to increase yields per hectare and the quality of the harvested product.

Increased productivity can be achieved by improving cultivation technology and using improved varieties while maintaining sustainable agriculture principles.

Among the limiting factors of rice cultivation in recent years are pests and diseases. Rice is affected by various pests, including nematodes, which cause damage to the crop and lower yields. The nematodes associated with rice are Ditylenchus angustus, Aphelenchoides besseyi, Hirschmanniella spp, Heterodera oryzicola and Meloidogyne graminicola. Being, M. graminicola the most important parasitic nematode in most rice growing areas of the world[2] Ravichandra, 2008, reports that yield can be reduced by approximately 11 percent due to biotic factors such as pests and diseases. Under simulated flooding or intermittent flooding conditions, yield losses caused by M. graminicola range from 20% to 80% and 11% to 73%, respectively[3].

In Ecuador, M. incognita is reported with 80 - 89 % of population incidence This nematode species has recorded high population densities that in some cases exceed 20000 second instar (J2) juveniles of M. graminicola/10 g of roots [4]

In the province of Los Ríos, studies determined a higher incidence in Cantón Quevedo where a population of 10000-125787 (J2) in 10g of roots was reported and a lower incidence in Cantón Babahoyo with 3500-17500 (J2) in 10g of roots. It is considered a severe problem for rice cultivation because of its negative effect on yield and, consequently, the decrease in farmers' profitability or economy dedicated to its cultivation (Triviño, 2016). Thus, it is essential to identify the areas with the highest incidence of this nematode and evaluate sustainability in rice production localities under different infestation conditions with M. graminicola.

Sustainability, is based on an adequate relationship between human and ecological systems, allows improving and developing the quality of life while maintaining the structure, functions and diversity of agricultural systems. Sustainability requires three elements: Environmental sustainability: development compatible with the maintenance of the biological processes on which natural ecosystems are based. Economic sustainability: economically viable development. Socio-cultural sustainability: socially and culturally optimal development[5].

This paper aims to evaluate the sustainability of rice production systems under different conditions of infestation with M. graminicola using neutrosophic satistics[6].

Neutrosophy and Neutrosophic Statistics

This section is dedicated to describing some basic concepts of neutrosophy and neutrosophic statistics[7].

Definition 1[8]: Let X be a universe of discourse. Three membership functions characterize a Neutrosophic Set (NS)[9], $u_A(x), r_A(x), v_A(x) : X \rightarrow\ ]^-0, 1^+[$, which satisfy the condition $^-0 \leq \inf u_A(x) + \inf r_A(x) + \inf v_A(x) \leq \sup u_A(x) + \sup r_A(x) + \sup v_A(x) \leq 3^+$ for all $x \in X$. $u_A(x), r_A(x)$ and $v_A(x)$ are membership functions of truthfulness, indeterminacy and falseness of x in A, respectively[10]. Images are of membership functions standard or non-standard subsets of $]^-0, 1^+[$.

Definition 2: ([11]) Let X be a universe of discourse. A Single-Valued Neutrosophic Set (SVNS) A on X is a set with the following the form[12]:

$$A = \{(x, u_A(x), r_A(x), v_A(x)) : x \in X\} \quad (1)$$

Where $u_A, r_A, v_A : X \rightarrow [0,1]$, satisfy the condition $0 \leq u_A(x) + r_A(x) + v_A(x) \leq 3$ for all $x \in X$. $u_A(x), r_A(x)$ and $v_A(x)$ denote membership functions of truthfulness, indeterminate and falseness of x in A, respectively. For convenience reasons a Single-Valued Neutrosophic Number (SVNN)[11] is expressed as $A = (a, b, c)$, where $a, b, c \in [0,1]$ and satisfy $0 \leq a + b + c \leq 3$ [11].

Neutrosophic Statistics extends the classical statistics, such that researcher ansd practioners could deal with set values rather than crisp values[13],.

Neutrosophic Descriptive Statistics included of all techniques to summarize and describe the neutrosophic numerical data characteristics.

Neutrosophic Inferential Statistics consists of methods that allow the generalization from a neutrosophic sampling to a population from which it was selected the sample[14].

Neutrosophic Statistical Number N has the form $N = d + i$, , where d is called determinate part and I is called indeterminate part[15].

According to classification, stratified random neutrosophic sampling the researcher groups the population by a strata according to a classification; afterwards, the reseracher takes a random sample (of appropriate size) to a criterion) from each group. If there is some indeterminacy, we deal with a neutrosophic sampling[16].

Here we describe some concepts of interval calculus, which shall be useful in this paper[17].

Given $N_1 = a_1 + b_1 I$ and $N_2 = a_2 + b_2 I$ two neutrosophic numbers, some operations between them are defined as follows,:

$N_1 + N_2 = a_1 + a_1 + (b_1 + b_2)I$ (Addition),

$N_1 - N_2 = a_1 - a_1 + (b_1 - b_2)I$ (Difference),

$N_1 \times N_2 = a_1 a_2 + (a_1 b_2 + b_1 a_2 + b_1 b_2)I$ (Product),

$\frac{N_1}{N_2} = \frac{a_1 + b_1 I}{a_2 + b_2 I} = \frac{a_1}{a_2} + \frac{a_2 b_1 - a_1 b_2}{a_2(a_2 + b_2)} I$ (Division).

A de-neutrosophication process gives a number in interval form= $[a_1, a_2]$ for centrality.

$$\lambda([a_1, a_2]) = \frac{a_1 + a_2}{2} \qquad (2)$$

In a neutrosophic statistics environment[18], the sample size may not be precisely known. Neutrosophic sample size is taken as an interval instead of a crisp Sample could be calculated using neutrosophic in the case proportion method as follows [19]

$$n = \frac{\frac{4PQ}{d^2}}{\frac{\frac{4PQ}{d^2} - 1}{N} + 1}$$

(3=

where

n: sample size

N: target population (universe)

P: the probability of success

Q: the probability of error

d: Percentage error

2. Materials and Methods

Two localities infested to varying degrees by nematodes were selected. The level of infestation was determined based on soil sampling following established protocols. Considering the above, Canton Babahoyo and Canton Quevedo was selected, both located in the Province of Los Ríos; Coastal Region.

Data to determine the sustainability of the selected areas were obtained through surveys, interviews, workshops, field days and direct field observations. The survey included 26 questions aimed at obtaining socio-cultural, economic and ecological information. The survey population consisted of professionals, representatives of rice associations, small-scale rice producers and others.

The methodology used was "multicriteria proposed by Sarandón [20], three indicators and nine sub-indicators were identified to measure economic sustainability; three indicators and 10 sub-indicators to measure environmental sustainability and three indicators with seven sub-indicators for the social dimension (Table 1).

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Table 1: Indicators to measure the sustainability of rice production systems.

DIMENSIÓN ECONÓMICA (IK)	DIMENSIÓN ECOLÓGICA **(IA)**	DIMENSIÓN SOCIO CULTURAL **(IS)**
ECONOMIC DIMENSION (IK)	ECOLOGICAL DIMENSION (**IA)**	SOCIO-CULTURAL DIMENSION (**IS)**
A.- Food self-sufficiency	**A.- Biodiversity Management**	**A.- Satisfaction of basic needs**
A1.- Diversification of production	A1.- Vegetation cover management	A1.- Housing.
A2.- Production area of Self-consumption	A2.- Crop rotation	A2.- Access to education
B.- Net monthly income by group	A3.- Crop diversification	A3.- Health access and coverage
B1.- Monthly income from cultivation	B.- Soil management	A4- Services.
C.- Economic risk	B1.- Fertilizer application	**B.-Acceptability of the production system**
C1.- Diversification for sale	B2.- Water management	B1.- Producer satisfaction level
C2.-Number of marketing channels	C.- Pest management	**C.- Social integration**
C3.-Dependence on external inputs	C1.- Pest control	C1.- Level of social integration
C4.- Area under cultivation	C2.- Levels of nematodes/100g of soil C3.-Levels of nematodes/10g of roots	D.- Knowledge and Ecological Awareness
C5.- Productivity		D1.- Knowledge of agroecosystems

A, B, C, D = Indicadores; A1, B1, C1, D1= Sub indicadores

The economic dimension considered the following indicators: food self-sufficiency, net monthly income and economic risk. The ecological dimension, I consider the following indicators: biodiversity management, soil management, pest management. The socio-cultural dimension considered the following indicators: satisfaction of basic needs, acceptability of production systems, social integration and ecological knowledge and awareness. Each indicator considered a series of variables, all of which are described in Table 1.

The General Sustainability Index (ISGen) was calculated using data from the economic (IK), ecological (IE) and socio-cultural (ISC) indicators.

The proposal developed used scales from 0 to 4, with 0 being the least sustainable category and 4 the most sustainable. Regardless of the units in which they were originally obtained, the values of each indicator were expressed in the values of this scale. The threshold value of 2 was considered as an acceptable level of sustainability, following Sarandon and Flores[21].

Economic indicator (IK) is calculated as follows

$$IK = \frac{2\left(\frac{A1 + A2}{2}\right) + B + \left(\frac{C1 + C2 + C3 + C4 + C5 + C6}{6}\right)}{4} \quad (4)$$

Ecological Indicator (EI

$$IE = \frac{\left(\frac{A1 + A2 + A3}{3}\right) + \left(\frac{B1 + B2}{2}\right) + \left(\frac{C1 + C2 + C3}{3}\right)}{3} \quad (5)$$

Sociocultural Indicator (ISC)

$$ISC = \frac{2\left(\frac{A1 + A2 + A3 + A4}{4}\right) + B + C + D}{5} \quad (6)$$

For its calculation, data from the economic (IK), environmental (IA) and social (IS) indicators will be used, valuing the three dimensions equally.

$$ISGen = \frac{IK + IA + IS}{3} \quad (7)$$

3. Results

The Babahoyo canton has approximately [5130 , 5136] UPAs (agricultural production units in Spanish) of rice. Canton Quevedo has approximately [700, 720] rice production units. Using neutrosophic statistic with intervalar data a representative sample, 94 surveys will be conducted in the Babahoyo canton and 88 in the Quevedo.

Economic sustainability

Food self-sufficiency (FS), net monthly income per group (NMI) and economic risk (ER) were considered as indicators. For Quevedo, FSA, NMI, and ER values were equal to 1.06, 2.07 and 1.24, respectively. For Babahoyo, on the other hand, the ASA, NMI and ER values were 0.91, 2.66 and 1.54 (Table 1). Based on this data, the economic sustainability value (IK) for Babahoyo was equal to 1.5 and for Quevedo equal to 1.4; therefore, the agricultural systems are not sustainable (Table 1).

Among the sub-indicators used, it is essential to highlight that in both study localities, there is little crop diversification in most of the productive units, therefore, farmers have fewer products to feed themselves and to sell. On the other hand, most producers have low productivity due to the problems of pests and diseases, floods, weeds and poor seed quality, few marketing channels and lack of sources of financing.

Environmental sustainability

The indicators to determine environmental sustainability were biodiversity management (MBD), soil management (MS) and pest management (MP). The values found for Quevedo were equal to 0.85, 1.54 and 0.54 for MBD, DM and PM and for Babahpyo of 0.97, 1.28 and 0.81 for MBD, DM and PM; respectively (Table 1). Therefore, the total environmental sustainability for the Babahoyo production system reached a value of 1.02 and for Quevedo it was equal to 0.97, these results show that they are not sustainable in the environmental dimension because they did not reach values equal to two or more.

Among the most important aspects influencing the final result are that the majority of farmers do not apply crop rotation, only 25% of the farmers manage.

Social Sustainability

The indicators were the satisfaction of basic needs (SNB), acceptability of the production system (ASP), social integration (IS) and ecological knowledge and awareness (CCE). For Quevedo, values of 2.62, 2.88, 2.90 and 1.64 were obtained for SNB, ASP, IS and CCE, respectively, and for Babahoyo the values were 2.62, 2.49, 2.63 and 1.73 for SNB, ASP, IS and CCE, respectively (Table 1). The general value of the SI in the two production systems was 2.6 for Quevedo and 2.4 for Babahoyo, therefore, they should be sustainable; however, they are not because the CCE indicator has a value of less than 2 for both locations.

Table 2.: Evaluation of sustainability in rice-producing localities with the multicriteria analysis method, in Quevedo and Babahoyo.

System	ASA	IMN	RE	IK	MBD	MS	MP	IA	SNB	ASP	IS	CCE	ISC
Quevedo	1.06	2.07	1.24	1.4*	0.85	1.54	0,54	0,97*	2.67	2.88	2.90	1.64	2.6**
Babahoyo	0.91	2.66	1.54	1.5*	0.97	1.28	0.81	1.02*	2.62	2.49	2.63	1.73	2.4**

IK= General economic indicator. Unsustainable, for having value < 2; ** Sustainable, for having value ≥ 2.

IK=economic indicator: ASA=Food self-sufficiency, IMN=Monthly net income per group, RE=Economic Risk. =Net monthly income per group, RE=Economic Risk.

IA= environmental indicator: MBD= biodiversity management, MS= soil management, MP= pest management.

ISC= social indicator: SNB= satisfaction of basic needs, ASP= Acceptability of the production system, IS= Social integration, CCE= Knowledge and Ecological Awareness.

These data are plotted in Figures 1, 2 and 3.

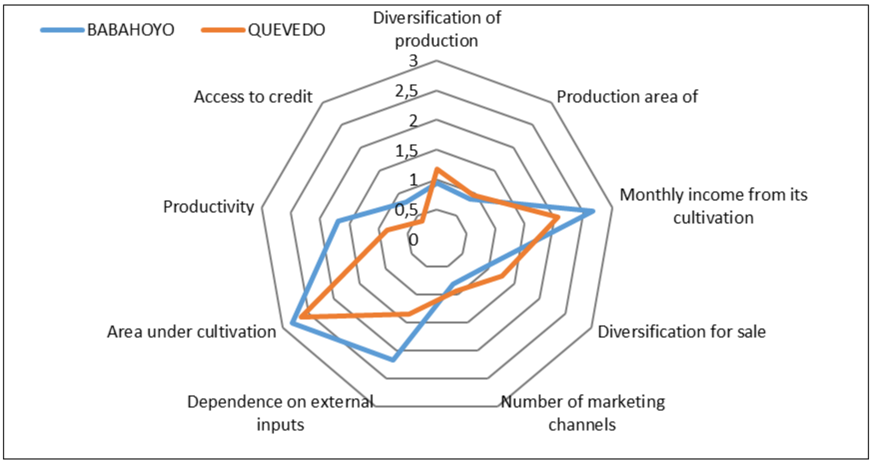

Figure 1. Components of the economic indicator (ISC) for rice production systems.

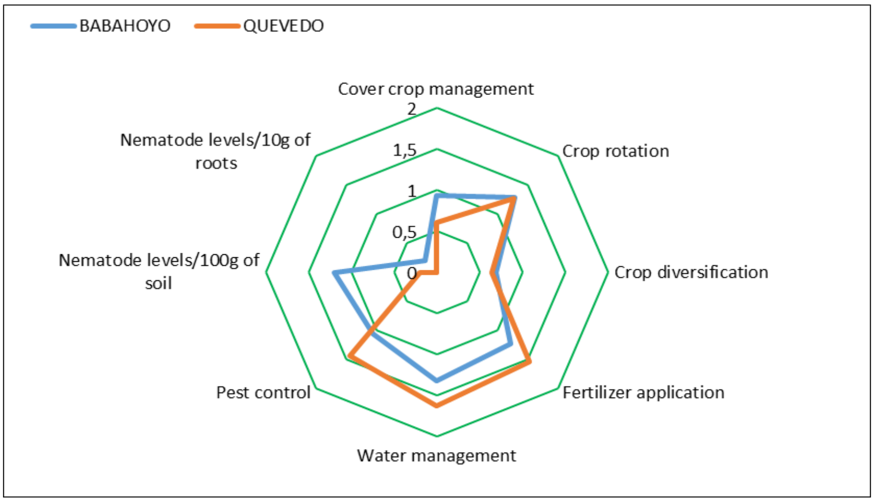

Figure 2: components of the ecological indicator (AI) for rice production systems.

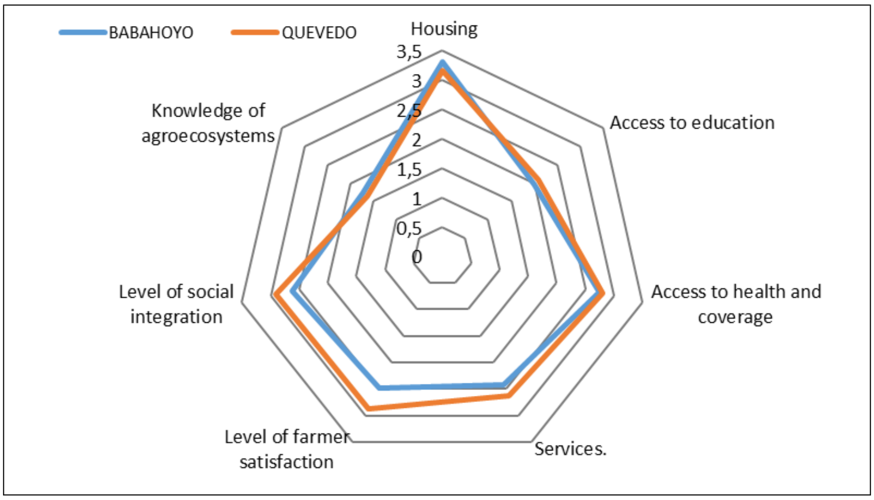

Figure 3: Components of the socio-cultural indicator (ISC) for rice production systems.

General sustainability index (ISGen)

In the case of the evaluated rice localities of Babahoyo and Quevedo, applying the already established formula, the two localities reach an (ISGen) of 1.71 and 1.54 respectively, they are not considered sustainable, because, in both localities, there are dimensions that present values lower than 2 (Table 2, Figure 4.).

Table 2. Results of ISg in rice production systems in Quevedo and Babahoyo.

System	IK	IE	IS	ISG
Quevedo	1.4	0.97	2.25	1.54**
Babahoyo	1.5	1.02	2.63	1.71**

**Sustainable; * not sustainable with value <2 (IK)

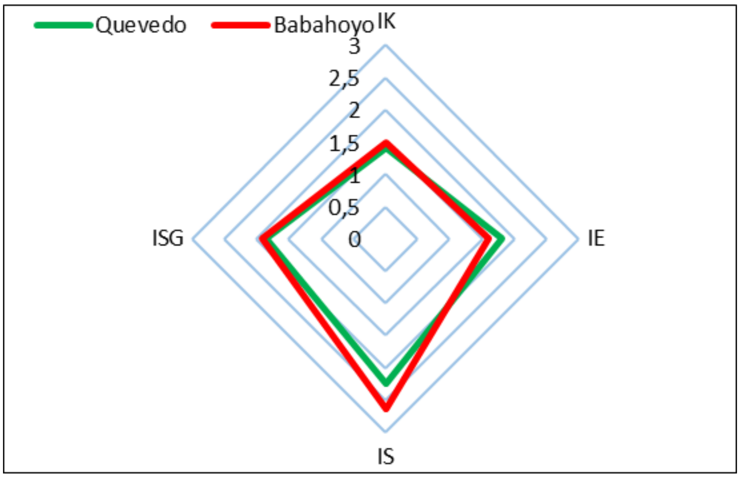

Figure 4. Result of IS gene, rice production system.

To consider a farm as sustainable, the General Sustainability Index (ISGen) must be greater than 2 and, in addition, none of the three dimensions evaluated must have a value less than 2. It is necessary to identify the critical points of the production systems in order to improve the sustainability of the systems.

5. Conclusions (authors also should add some future directions points related to her/his research)

1. Sample size is calculated using neutrosophic statistic to deal with interval data with the number of units not precisely known

In the economic dimension for the 2 localities, the causes of low sustainability were the lack of diversification for sales, low yields, few marketing channels and the lack of sources of financing.

2. In the ecological dimension, both Babahoyo and Quevedo producers, the factors that determine non-sustainability were: low vegetation cover and negligible crop diversification.

3. In the socio-cultural dimension, the group of producers from Babahoyo and Quevedo reached threshold value 2.

4. The Overall Sustainability Index was 1.54 and 1.71 for Quevedo and Babahoyo, respectively, showing that two production systems are not sustainable for the conditions under which the sustainability assessment was conducted.

5 Future works will concentrate on extending the framework to deal with neutrosophic multicriteria methods.

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