NSS
Neutrosophic Sets and Systems, {Special Issue: Advances in SuperHyperStructures and Applied Neutrosophic Theories)}, Vol. 74, 2024
University of New Mexico

# Evaluation of Sustainable Agricultural Practices Using Organic Fertilizers for Soil Recovery in Salache: A Neutrosophic Superhypersoft Set Approach

**Jorge Fabián Troya Sarzosa [1] and Julio Cesar Alegre Orihuela [2]**

[1] Technical University of Cotopaxi, Ecuador; jorge.troya@utc.edu.ec
[2] National Agrarian University La Molina -UNALM, Peru; julitoalegre@gmail.com

**Abstract.** Modern agriculture faces critical challenges due to soil degradation and the urgent need for sustainable practices to preserve the environment. This study analyzed the impact of organic fertilizers, including vermicompost, compost, manure, and control, on the development of Lupinus mutabilis and Pisum sativum. Different groups were evaluated based on chemical and physical soil properties, plant attributes, and crop cycles using Neutrosophic SuperHyperSoft Sets. The results demonstrated that vermicompost is the most effective option for optimizing soil properties and improving crop yields. In conclusion, the use of vermicompost and other organic sources is proposed as an effective strategy to enhance soil fertility and crop productivity, particularly in degraded lands, while fostering the adoption of more sustainable agricultural practices.

**Keywords:** Vermicompost, soil fertility, agricultural yield, agricultural sustainability, Neutrosophic SuperHyperSoft Sets.

## 1 Introduction

Soil desertification due to erosion is a critical environmental challenge that affects the productive capacity of land, particularly in areas with slopes exceeding 40% [1]. This process, driven by inadequate agricultural practices, limits food production and triggers economic and social issues such as poverty, migration, and family disintegration, perpetuating the vulnerability of communities [2]. Therefore, it is urgent to adopt comprehensive measures that combine soil restoration with sustainable development to ensure the well-being of affected populations [3].

In Ecuador, soil erosion is especially critical in areas with slopes greater than 12%, where soil losses range between 5 and 50 tons per hectare per year. Approximately half of the agricultural soils exhibit some degree of degradation, affecting soil fertility and productive capacity [4], which negatively impacts rural communities [5]. Furthermore, the expansion of agricultural frontiers, extensive livestock farming, and unplanned urbanization have increased the rate of degradation, affecting nearly 47% of the country's soils [6].

Hence, this study analyzes the impact of organic fertilizer sources on the development of Lupinus mutabilis and Pisum sativum in the Salache region [7]. The objective is to evaluate their effect on soil fertility properties, crop yields, and the efficiency of the applied treatments. The study proposes the use of tools such as Neutrosophic SuperHyperSoft Sets (NSHSS) to assess multiple attributes in modeling the complexity and uncertainty inherent in sustainable agricultural practices, as well as statistical analysis of the treatments involving organic fertilizers [8], such as vermicompost, to restore eroded soils [9].

## 2 Preliminaries

### 2.1 Neutrosophic SuperHyperSoft Sets.

This section serves the purpose of remembering the basic notions of Fuzzy Extension SuperHyperSoft Sets and neutrosophic theory [10].

**Definition 1 (**[1, 9, 10]**).** Given U is the initial universe set and E is the set of parameters. A pair

$(F, E)$ is called a *soft set* (over U) if and only if F is a mapping of E into the set of all subsets of U.

That is to say, having a set E of parameters and fixing a parameter $\varepsilon \in E$, then $F(\varepsilon) \in \mathcal{P}(U)$, where $\mathcal{P}(U)$ denotes the power set of U and $F(\varepsilon)$ is considered the set of ε-elements of the Soft Set $(F, E)$ or the set of ε-approximate elements of the Soft Set [11] [12].

It is not difficult to realize that fuzzy sets are soft sets, this is a consequence of the α-levels definition of a membership function $\mu_A$ using the following formula:

$F(\alpha) = \{x \in U \mid \mu_A(x) \geq \alpha\}$, $\alpha \in [0, 1]$. Thus, if the family F is known, the function $\mu_A$ can be reconstructed using the following formula:

$$\mu_A(x) = \sup_{\substack{\alpha \in [0,1] \\ x \in F(\alpha)}} \alpha$$

Thus, a fuzzy set is a $(F, [0, 1])$ Soft set.

Given a binary operation * for subsets of the set U, where $(F, A)$ and $(G, B)$ are soft sets over U. Then, the operation * for soft sets is defined as follows:

$(F, A) * (G, B) = (J, A \times B)$, where $J(\alpha, \beta) = F(\alpha) * G(\beta)$; $\alpha \in A$, $\beta \in B$, and $A \times B$ is the Cartesian product of the sets A and B.

**Definition 2** ([2, 3, 11, 12]). Let U be a universe set, $\mathcal{P}(U)$ the power set of U. Let $a_1, a_2, \ldots, a_n$, for $n \geq 1$, be $n$ distinct attributes, whose corresponding attribute values are respectively the sets $A_1, A_2, \ldots, A_n$, with $A_i \cap A_j = \emptyset$, for $i \neq j$, and $i, j \in \{1, 2, \ldots, n\}$. Then the pair $(F, A_1 \times A_2 \times \ldots \times A_n)$, where: $F: A_1 \times A_2 \times \ldots \times A_n \to \mathcal{P}(U)$ is called a *HyperSoft Set* over U.

**Definition 3** ([2, 3, 11, 12]). Let U be a universe set, $\mathcal{P}(U)$ the power set of U. Let $a_1, a_2, \ldots, a_n$, for $n \geq 1$, be $n$ distinct attributes, whose corresponding attribute values are respectively the sets $A_1, A_2, \ldots, A_n$, with $A_i \cap A_j = \emptyset$, for $i \neq j$, and $i, j \in \{1, 2, \ldots, n\}$. Then the pair $\left(F, \mathcal{P}(A_1) \times \mathcal{P}(A_2) \times \ldots \times \mathcal{P}(A_n)\right)$, where:

$F: \mathcal{P}(A_1) \times \mathcal{P}(A_2) \times \ldots \times \mathcal{P}(A_n) \to \mathcal{P}(U)$ is called a *SuperHyperSoft Set* over U.

**Definition 4** ([4, 5, 13-15]). Let U be a universe set, $\mathcal{P}(U)$ the power set of U. Let $a_1, a_2, \ldots, a_n$, for $n \geq 1$, be $n$ distinct attributes, whose corresponding attribute values are respectively the sets $A_1, A_2, \ldots, A_n$, with $A_i \cap A_j = \emptyset$, for $i \neq j$, and $i, j \in \{1, 2, \ldots, n\}$. Then the pair $\left(F, \mathcal{P}(A_1) \times \mathcal{P}(A_2) \times \ldots \times \mathcal{P}(A_n)\right)$, where:

$F: \mathcal{P}(A_1) \times \mathcal{P}(A_2) \times \ldots \times \mathcal{P}(A_n) \to \mathcal{P}\left(U\left(x(d^0)\right)\right)$ is called a *Fuzzy_Extension SuperHyperSoft Set* over U.

Where $x(d^0)$ is the fuzzy or any fuzzy extension degree of appurtenance of the element $x$ to the set U. Fuzzy extension means Fuzzy Set or Intuitionistic Fuzzy Set, Pythagorean Fuzzy Set, Fermatean Fuzzy Set, Neutrosophic Fuzzy Set, Plithogenic Fuzzy Set, etc [13].

Before concluding, let us recall some fundamental definitions of neutrosophic sets:

**Definition 5** ([8]). The *Neutrosophic set N* is characterized by three membership functions [14], which are the truth-membership function $T_A$, indeterminacy-membership function $I_A$, and falsity-membership function $F_A$, where $U$ is the Universe of Discourse and $\forall x \in U$, $T_A(x), I_A(x), F_A(x) \subseteq ]^-0, 1^+[$, and $^-0 \leq \inf T_A(x) + \inf I_A(x) + \inf F_A(x) \leq \sup T_A(x) + \sup I_A(x) + \sup F_A(x) \leq 3^+$ [15].

See that according to the definition, $T_A(x), I_A(x)$, and $F_A(x)$ are real standard or non-standard subsets of $]^-0, 1^+[$ and hence, $T_A(x), I_A(x)$ and $F_A(x)$ can be sub-intervals of $[0, 1]$. $^-0$ and $1^+$ belong to the set of hyperreal numbers.

**Definition 6** ([8, 16, 17]). The *Single-Valued Neutrosophic Set* (SVNS) $A$ over $U$ is $A = \{< x, T_A(x), I_A(x), F_A(x) > : x \in U\}$, where $T_A: U \to [0, 1]$, $I_A: U \to [0, 1]$ and $F_A: U \to [0, 1]$. $0 \leq T_A(x) + I_A(x) + F_A(x) \leq 3$.

Single-Valued Neutrosophic Sets (SVNS) were introduced with the idea of applying neutrosophic sets for practical purposes. Some operations between SVNSs are expressed below:

Given $A_1 = (a_1, b_1, c_1)$ and $A_2 = (a_2, b_2, c_2)$, two SVNNs, the sum of $A_1$ and $A_2$ is defined as:

$$A_1 \; A_2 = (a_1 + a_2 - a_1a_2, b_1b_2, c_1c_2) \tag{1}$$

Given $A_1 = (a_1, b_1, c_1)$ and $A_2 = (a_2, b_2, c_2)$, two SVNNs, the multiplication of $A_1$ and $A_2$ is defined as:

$$A_1 \; A_2 = (a_1a_2, b_1+b_2 - b_1b_2, c_1 + c_2 - c_1c_2) \tag{2}$$

The product of a positive scalar SVNN, A = (a, b, c) is defined as:

$$A = (1 - (1 - a), b, c) \tag{3}$$

The *Single-Valued Neutrosophic Number* (SVNN) is symbolized by $N = (t, i, f)$, such that $0 \le t, i, f \le 1$ and $0 \le t + i + f \le 3$.

## 3 Results

### 3.1 Description of the experiment.

The study employed essential tools such as labels, drip tape, an A-frame level, stakes, string, a shovel, a hoe, a rake, and a measuring tape, complemented by native forest plants, an auger, and organic fertilizers (vermicompost, poultry manure, and bovine manure). The experimental material included bench terraces cultivated with Lupinus mutabilis and Pisum sativum. These resources and practices were applied to plots designed to evaluate the recovery of eroded soils and sustainable agricultural yields.

The experimental design was conducted at the Technical University of Cotopaxi following a split-plot scheme in a completely randomized block design with three replications, resulting in 24 experimental treatments. The analyzed factors included terrace management (single crop of Lupinus mutabilis and associated crop with Pisum sativum) and organic nutritional sources (no fertilizer, vermicompost, poultry manure, and bovine manure).

During the trial, three soil samplings were performed to assess changes in initial conditions, after the first crop cycle, and at the end of the second. The indicators measured included germination, plant height, number of branches, flowers, and pods, as well as yield, demonstrating the effectiveness of the applied practices in improving soil fertility and agricultural productivity.

### 3.2 Modeling with Neutrosophic SuperHyperSoft Sets

The study proposes determining the elements of the study universe for the types of fertilizers and crops to be applied, as outlined in Table 1. Additionally, it establishes the structure of the attribute groups (super-attributes) of the Neutrosophic SuperHyperSoft Sets (see Table 2).

**Table 1:** Types of fertilizers and crops in the experimental design. Source: Own elaboration.

| Fertilizers and crops | Code | Items |
|---|---|---|
| Organic sources | FO1 | Vermicompost |
| | FO2 | Compost (bovine) |
| | FO3 | Manure (poultry) |
| Soil texture | S1 | Sandy loam (sand (62%), silt (32%) and clay (6%)) |
| Terraces | Z1 | Cultivation with Lupinus Mutabilis |
| | Z2 | Growing with Pisum sativum |

**Table 2:** Structure of the attributes of the neutrosophic SuperHyperSoft sets. Source: Own elaboration.

| Super-attributes | Code | attributes | Sub-attributes | $(x(d^0))$ |
|---|---|---|---|---|
| Chemical and physical properties ($a_i$) for the $P(A_i)$ | a1 | pH | Fertilizer extract: water 1:2.5 | SVNN |
| | a2 | Electrical conductivity (EC) | Fertilizer extract: water 1:2.5 | |
| | a3 | MO | % | |
| | a4 | Nitrogen (N) | % | |
| | a5 | Phosphorus (P) | % | |
| | a6 | Potassium (K) | % | |
| | a7 | Calcium (Ca) | % | |
| | a8 | Magnesium (Mg) | % | |
| | a9 | Copper (Cu) | % | |
| | a10 | Iron (Fe) | Ppm | |
| | a11 | Manganese (Mn) | Ppm | |
| | a12 | Zinc (Zn) | Ppm | |
| Plant indicators ($b_i$) for the $P(B_i)$ | b1 | Germination | % | |
| | b2 | Number of floors | Average | |
| | b3 | Height | Cm | |
| | b4 | Number of branches | Average | |
| | b5 | Number of flowers | Average | |
| | b6 | Number of Pods | Average | |
| Crop cycle ($c_i$) for the $P(C_i)$ | c1 | First cycle | 04/18/2017 to 04/02/2018 | |
| | c2 | Second cycle | days | |

It is observed in Table 2 that there are 3 Neutrosophic SuperHyperSoft Sets, defined by the attributes $a_i$, $b_i$, and $c_i$. Each super-attribute is composed of the following pairs:

$$F: \mathcal{P}(A_1) \times \mathcal{P}(A_2) \times \ldots \times \mathcal{P}(A_{12}) \rightarrow \mathcal{P}\left(\mathrm{U}\left(x(d^0)\right)\right)$$

$$G: \mathcal{P}(B_1) \times \mathcal{P}(B_2) \times \ldots \times \mathcal{P}(B_6) \rightarrow \mathcal{P}\left(\mathrm{U}\left(x(d^0)\right)\right)$$

$$H: \mathcal{P}(C_1) \times \mathcal{P}(C_2) \rightarrow \mathcal{P}\left(\mathrm{U}\left(x(d^0)\right)\right)$$

The following treatments are proposed based on the combinations of each element in the set P(Fi) = {{FO1}, {FO2}, {FO3}}, P(Si) = {{S1}}, and P(Ti) = {{T1}, {T2}}. Thus, a new classification or grouping of elements is sought by considering the fertilizer and the crop type of P(Ti). Another important point is that the soil type has been restricted to sandy loam, based on the experimental conditions of the study. Therefore, the following elements and treatments (T) are proposed over the universe U, as well as each subsection of the study development (see Table 3).

**Table 3:** Complexity of the set of elements and $P(T_i)$ treatments in the study. Source: Own elaboration.

| Subsection | Description | Code | $P(T_i)$ |
|---|---|---|---|
| ▪ **3.3** Physical and chemical analysis of treatments. | Without subscription | S1 | $\{S_1, A_i\}$ |
| | Vermicompost | FO1 | $\{FO1, A_i\}$ |
| ▪ **3.4** Yield of the treatments. | Bovine manure | FO2 | $\{FO2, A_i\}$ |
| | Poultry manure fertilizer | FO3 | $\{FO3, A_i\}$ |
| ▪ **3.5** Yield of the treatments in relation to crop development. | Lupinus Mutabilis Cultivation | | $\left\{\{\{S1, A_i\}, C_i\}, \{B_i, Z_1\}\right\}$ |
| | | | $\left\{\{\{FO1, A_i\}, C_i\}, \{B_i, Z_1\}\right\}$ |
| | | | $\left\{\{\{FO2, A_i\}, C_i\}, \{B_i, Z_1\}\right\}$ |
| | | | $\left\{\{\{FO3, A_i\}, C_i\}, \{B_i, Z_1\}\right\}$ |
| | Pisum sativum cultivation | | $\left\{\{\{S1, A_i\}, C_i\}, \{B_i, Z_2\}\right\}$ |
| | | | $\left\{\{\{FO1, A_i\}, C_i\}, \{B_i, Z_2\}\right\}$ |

| Subsection | Description | Code | $P(T_i)$ |
|---|---|---|---|
| | | | $\{\{\{FO2, A_i\}, C_i\}, \{B_i, Z_2\}\}$ |
| | | | $\{\{\{FO3, A_i\}, C_i\}, \{B_i, Z_2\}\}$ |
| | Crop cultivation of Pisum sativum and Lupinus mutabilis. | | $\{\{\{S1, A_i\}, C_i\}, \{B_i, \{Z_1, Z_2\}\}\}$ |
| | | | $\{\{\{FO1, A_i\}, C_i\}, \{B_i, \{Z_1, Z_2\}\}\}$ |
| | | | $\{\{\{FO2, A_i\}, C_i\}, \{B_i, \{Z_1, Z_2\}\}\}$ |
| | | | $\{\{\{FO3, A_i\}, C_i\}, \{B_i, \{Z_1, Z_2\}\}\}$ |

### 3.3 Physical and chemical analysis of treatments

The physicochemical analysis of the organic fertilizers evaluated (vermicompost, bovine manure, and poultry manure) revealed significant differences in their attributes $a_i$ (see Table 4). The vermicompost exhibited a pH of 7.26, lower than that of the other fertilizers, with 7.39 and 8.84 for bovine manure and poultry manure, respectively. In terms of electrical conductivity, bovine manure reached the highest value at 15.56 ms/cm, followed by vermicompost and poultry manure. Organic matter ranged from 18.4% in poultry manure to 20% in vermicompost. Regarding macronutrients, vermicompost stood out in potassium (0.53%) and iron (400 ppm), surpassing the other fertilizers. These results highlight the advantages of vermicompost as a viable option to enhance soil fertility and provide essential nutrients.

**Table 4:** Results of physical and chemical analysis of organic fertilizers. Source: Own elaboration.

| $a_i$ | Unit | Vermicompost | Bovine manure | Poultry manure |
|---|---|---|---|---|
| pH | | 7.26 | 7.39 | 8.84 |
| EC | ms/cm | 10.47 | 15.56 | 10,10 |
| MO | % | 20,00 | 20,31 | 18.40 |
| Total N | % | 0.77 | 1.03 | 0.90 |
| P | % | 0.59 | 0.27 | 0.80 |
| K | % | 0.53 | 0.19 | 0.12 |
| AC | % | 0.75 | 0.65 | 2.30 |
| Mg | % | 0.37 | 0.43 | 0.94 |
| Cu | Ppm | 8 | 8 | 2 |
| Faith | Ppm | 400 | 120 | 200 |
| Mn | Ppm | 40 | 95 | 20 |
| Zn | Ppm | 18 | 10 | 32 |

### 3.4 Yield of the treatments

The soil analysis in the control treatment showed an initially high pH (9.59 in M1 and 9.05 in M2), with a slight decrease by the end of the second cycle (9.09 and 8.90, respectively). Electrical conductivity was low, with slight increases in both treatments. The sandy loam texture remained constant, while organic matter increased at the end of the first cycle but decreased by the end of the second, reflecting the dynamics of input and decomposition (see Table 5). Macronutrients such as nitrogen, phosphorus, and potassium decreased over time, attributed to crop uptake. Meanwhile, calcium and magnesium showed significant declines. These results underscore the need for sustainable practices to preserve soil fertility and optimize its management in agricultural systems.

**Table 5:** Yield of the control treatment from the soil analysis over two crop cycles. Source: Own elaboration.

| S1: Control treatment | | Start | | End of the 1st Cycle | | End of the 2nd Cycle | | Start | | End of the 1st Cycle | | End of the 2nd Cycle | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analysis | Unit | Level | | Level | | Level | | Level | | Level | | Level | |
| pH | | AL | 9.5 | AL | 8.87 | AL | 9.0 | Al | 9.0 | AL | 9.02 | LAL | 8.90 |
| EC. | mmhos/cm | NS | 0.2 | NS | 0.3 | NS | 0.3 | NS | 0.1 | NS | 0.5 | NS | 0.1 |
| MO | % | M | 4.9 | A | 6.7 | M | 4.7 | B | 2.8 | A | 5.8 | M | 4.1 |
| TOTAL N | ppm | M | 36.7 | M | 50.2 | M | 35.6 | B | 21.3 | M | 43.3 | M | 31.1 |

| S1: Control treatment | | Start | | End of the 1st Cycle | | End of the 2nd Cycle | | Start | | End of the 1st Cycle | | End of the 2nd Cycle | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | ppm | A | 89 | A | 85 | A | 53 | A | 103 | A | 88 | A | 26 |
| K | meq/100 g | A | 0.5 | A | 1.1 | A | 1.5 | A | 1.4 | A | 0.6 | A | 0.5 |
| AC | meq/100 g | A | 22 | A | 17 | A | 16 | A | 22 | A | 8 | A | 10 |
| Mg | meq/100 g | A | 1 | A | 3.7 | A | 1.7 | A | 2 | A | 2.1 | A | 1.9 |
| Cu | ppm | A | 8 | M | 2 | M | 1 | A | 8 | M | 2 | M | 1 |
| Mn | ppm | M | 5 | M | 5 | B | 4 | M | 5 | B | 2 | B | 4 |
| Zn | ppm | M | 3 | B | 1 | B | 1 | M | 3 | B | 1 | B | 1 |
| Ca/Mg | meq/100 g | A | 21 | 0 | 5 | A | 10 | A | 11 | O | 4 | O | 5 |
| Mg/K | meq/100 g | B | 2 | 0 | 3 | B | 1 | B | 1 | O | 3 | O | 4 |
| Ca+Mg/K | meq/100 g | A | 46 | 0 | 18 | 0 | 12 | O | 17 | O | 16 | O | 26 |

The use of vermicompost improved the chemical and physical properties of the soil by reducing pH and stabilizing electrical conductivity. Organic matter increased significantly, enhancing cation exchange capacity and the availability of essential nutrients. These structural improvements favored germination, growth, and crop resilience.

Agricultural yield also increased, reaching 0.98 kg of Lupinus mutabilis and 1.19 kg of Pisum sativum in dry grain at the end of two cycles. Overall, vermicompost emerges as an effective treatment to optimize soil quality and crop productivity (see Table 6).

**Table 6:** Yield of vermicompost from the soil analysis over two crop cycles. Source: Own elaboration.

| FO1: Vermicompost | | Start | | End of the 1st Cycle | | End of the 2nd Cycle | | Start | | End of the 1st Cycle | | End of the 2nd Cycle | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analysis | Unit | Level | | Level | | Level | | Level | | Level | | Level | |
| pH | | Al | 9.23 | AL | 9.3 | AL | 8.9 | AL | 9.41 | AL | 8.76 | Me AL | 8.41 |
| EC. | mmhos/cm | NS | 0.42 | NS | 0.6 | NS | 0.3 | NS | 0.28 | NS | 0.3 | NS | 0.3 |
| MO | % | M | 4.2 | A | 9.2 | M | 4.8 | B | 2.8 | A | 7.7 | M | 4.2 |
| TOTAL N | Ppm | M | 31.1 | A | 69.3 | M | 36.1 | B | 20.7 | M | 57.8 | M | 3 117 |
| P | Ppm | A | 137 | A | 205 | A | 99 | A | 84 | A | 171 | A | 75 |
| K | meq/100 g | A | 1.5 | A | 1.3 | A | 1.8 | M | 2.5 | A | 1 | A | 1.9 |
| AC | meq/100 g | A | 10 | A | 14 | A | 17 | A | 22 | A | 12 | A | 14 |
| Mg | meq/100 g | A | 1.5 | A | 3.3 | A | 2.4 | A | 1.5 | A | 3 | A | 2.6 |
| Cu | Ppm | A | 5 | M | 2 | M | 1 | A | 10 | M | 2 | M | 2 |
| Mn | Ppm | M | 10 | M | 5 | B | 4 | M | 8 | B | 3 | B | 4 |
| Zn | Ppm | M | 5 | B | 1 | B | 2 | M | 3 | M | 4 | B | 2 |
| Ca/Mg | meq/100 g | A | 7 | O | 4 | A | 7 | A | 15 | O | 4 | O | 5 |
| Mg/K | meq/100 g | B | 1 | O | 3 | B | 1 | B | 1 | O | 3 | B | 1 |
| Ca+Mg/K | meq/100 g | B | 7 | O | 14 | O | 11 | B | 9 | O | 15 | B | 9 |

The application of poultry manure reduced the soil pH from 9.18 to 8.5 and decreased the electrical conductivity from 0.75 to 0.2 mmhos/cm at the end of the second cycle. It also increased organic matter and improved the availability of macro and micronutrients by optimizing the structure, stability, and fertility of the soil. These changes favored cation exchange capacity and biological development, boosting agricultural productivity (see Table 7).

**Table 7:** Yield of poultry manure from the soil analysis over two crop cycles. Source: Own elaboration.

| FO2: Poultry manure | | Start | | End of the 1st Cycle | | End of the 2nd Cycle | | Start | | End of the 1st Cycle | | End of the 2nd Cycle | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analysis | Unit | Level | | Level | | Level | | Level | | Level | | Level | |
| pH | | AL | 9.18 | AL | 8.85 | Me AL | 8.41 | Al | 9.03 | AL | 8.41 | Me AL | 8.25 |
| EC. | mmhos/cm | NS | 0.75 | NS | 1 | NS | 0.3 | NS | 0.52 | NS | 0.8 | NS | 0.2 |
| MO | % | M | 3.3 | A | 7.4 | M | 4.2 | B | 2.8 | A | 5.7 | M | 3.8 |
| TOTAL N | Ppm | B | 24.5 | M | 55.5 | M | 31.8 | B | 21.2 | M | 43.1 | B | 28.8 |
| P | Ppm | A | 50 | A | 330 | A | 231 | A | 94 | A | 418 | A | 183 |
| K | meq/100 g | A | 1.8 | A | 1.9 | A | 1.9 | A | 3.7 | A | 1.7 | A | 1.5 |
| AC | meq/100 g | A | 10 | A | 14 | A | 19 | A | 20 | A | 12 | A | 14 |

| FO2: Poultry manure | | Start | | End of the 1st Cycle | | End of the 2nd Cycle | | Start | | End of the 1st Cycle | | End of the 2nd Cycle | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mg | meq/100 g | A | 1.1 | A | 2.7 | A | 3.9 | A | 1.6 | A | 4 | A | 2.4 |
| Cu | Ppm | A | 10 | M | 2 | M | 3 | A | 13 | M | 2 | M | 2 |
| Mn | Ppm | M | 5 | M | 5 | M | 9 | M | 10 | M | 10 | M | 5 |
| Zn | Ppm | M | 3 | A | 7 | M | 6 | M | 3 | A | 11 | M | 3 |
| Ca/Mg | meq/100 g | TO | 9 | O | 5 | O | 5 | TO | 12 | O | 3 | TO | 6 |
| Mg/K | meq/100 g | B | 1 | B | 1 | B | 2 | B | 0.4 | B | 2 | B | 2 |
| Ca+Mg/K | meq/100 g | B | 6 | B | 9 | O | 13 | B | 6 | O | 10 | O | 11 |

On the other hand, bovine manure reduced the soil pH from 9.6 to 9.04 and the electrical conductivity from 0.34 to 0.2 mmhos/cm after two cycles, by increasing organic matter and available nutrients. Therefore, this fertilizer improves soil properties, reduces the need for chemical fertilizers, and contributes to a more sustainable and efficient management of agricultural resources (see Table 8).

**Table 8:** Yield of bovine manure from the soil analysis over two crop cycles. Source: Own elaboration.

| FO3: Bovine manure | | Start | | End of the 1st Cycle | | End of the 2nd Cycle | | Start | | End of the 1st Cycle | | End of the 2nd Cycle | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analysis | Unit | Level | | Level | | Level | | Level | | Level | | Level | |
| pH | | AL | 9.6 | AL | 9.39 | Me AL | 8.34 | A | 9.57 | AL | 9.44 | AL | 9.04 |
| EC. | mmhos/cm | NS | 0.34 | NS | 0.6 | NS | 0.2 | AL | 0.67 | NS | 0.7 | NS | 0.5 |
| MO | % | B | 2.9 | A | 6.1 | M | 4.2 | A | 7.8 | A | 7.4 | A | 5.2 |
| TOTAL N | Ppm | B | 21.4 | M | 45.7 | M | 31.4 | M | 58.7 | M | 55.5 | M | 39 |
| P | Ppm | A | 83 | A | 134 | A | 65 | A | 99 | A | 125 | A | 99 |
| K | meq/100 g | A | 0.6 | A | 1.4 | A | 2.1 | A | 1 | A | 1.7 | A | 2.2 |
| AC | meq/100 g | A | 22 | A | 13 | A | 17 | A | 17 | A | 13 | A | 16 |
| Mg | meq/100 g | A | 1.1 | A | 1.9 | A | 3.4 | A | 1.3 | A | 2.1 | A | 2.1 |
| Cu | Ppm | A | 10 | M | 2 | M | 1 | A | 10 | M | 2 | M | 3 |
| Mn | Ppm | M | 5 | B | 3 | B | 3 | B | 3 | B | 1 | B | 4 |
| Zn | Ppm | M | 3 | B | 1 | B | 1 | M | 3 | B | 1 | B | 1 |
| Ca/Mg | meq/100 g | A | 20 | A | 7 | O | 5 | A | 13 | A | 6 | A | 7 |
| Mg/K | meq/100 g | B | 2 | B | 1 | B | 2 | B | 1 | B | 1 | B | 1 |
| Ca+Mg/K | meq/100 g | 0 | 37 | O | 11 | O | 10 | O | 18 | B | 9 | B | 8 |

### 3.5 Yield of the treatments in relation to crop development.

The use of organic fertilizers significantly influenced the variables evaluated in two crop cycles of Lupinus mutabilis. According to the results obtained, the humus treatment stood out with the highest germination percentage (89%), followed by bovine manure (83.62%), poultry manure (78.98%), and the control treatment (73.39%). On average, the plant height reached 86.81 cm, with 11.63 branches, 21.59 flowers, and 21.75 pods per plant. These values reflect that treatments with organic matter, especially humus, improved yield compared to the untreated soil (see Table 9).

**Table 9:** Yield of the treatments over two cycles of Lupinus mutabilis cultivation. Source: Own elaboration.

| Treatments | Germination (%) | Number of plants | Height (cm) | Number of branches | Number of Flowers | Number of Pods |
|---|---|---|---|---|---|---|
| | CH average | CH average | CH average | CH average | CH average | CH average |
| FO1: Humus | 89 | 73 | 87 | 12 | 22 | 22 |
| FO2: Bovine manure | 83.62 | 67.63 | 87.28 | 11.83 | 21.55 | 20.90 |
| FO3: Poultry manure | 78.98 | 63.79 | 85.54 | 11.48 | 21.55 | 21.32 |
| S1: Control treatment | 73.39 | 59.88 | 87.08 | 11.25 | 21.30 | 22.40 |

| Treatments | Germination (%) | Number of plants | Height (cm) | Number of branches | Number of Flowers | Number of Pods |
|---|---|---|---|---|---|---|
| Total | 325.47 | 263.83 | 347.23 | 46.52 | 86.37 | 87.00 |
| **Average** | **81.37** | **65.96** | **86.81** | **11.63** | **21.59** | **21.75** |

For its part, the yield in Pisum sativum also showed a favorable response to the use of organic fertilizers. Humus was the most efficient treatment, with an average germination of 84.47%, while the other treatments (bovine manure, poultry manure, and control) showed decreasing values. The average plant height was 99.78 cm, with 11.64 branches, 21.19 flowers, and 18.79 pods per plant. The observed improvements are associated with the ability of organic fertilizers to stabilize the chemical and physical properties of the soil by optimizing fertility (see Table 10).

**Table 10:** Yield of the treatments over two cycles of Pisum sativum cultivation. Source: Own elaboration.

| Treatments | Germination (%) | Number of Plants | Height (cm) | Number of branches | Number of Flowers | Number of pods |
|---|---|---|---|---|---|---|
| | CH average | CH average | CH average | CH average | CH average | CH average |
| FO1: Humus | 84.47 | 68.25 | 100.39 | 12.18 | 21.32 | 19.13 |
| FO2: Bovine manure | 81.06 | 64.25 | 99.49 | 11.12 | 21.02 | 20.63 |
| FO3: Poultry manure | 77.65 | 61.50 | 99.73 | 11.32 | 21.25 | 18.38 |
| S1: Control treatment | 74.81 | 59.58 | 99.49 | 11.95 | 21.18 | 17.00 |
| Total | 317.99 | 253.58 | 399.10 | 46.57 | 84.77 | 75.15 |
| Average | 79.50 | 63.40 | 99.78 | 11.64 | 21.19 | 18.79 |

In terms of average yield, Pisum sativum showed a net yield of 1,080.67 kg/ha over the two crop cycles, equivalent to 90.06% of the probable yield (1,200 kg/ha). In contrast, Lupinus mutabilis presented a net yield of 746.32 kg/ha, reaching only 54.73% of the probable yield. These results reflect significant differences in the response of both crops to soil conditions and fertilization sources (see Table 11).

**Table 11:** Average yield of two crop cycles of Pisum sativum and Lupinus mutabilis. Source: Own elaboration.

| Indicators | Total yield Pisum sativum | Total yield Lupinus mutabilis |
|---|---|---|
| Total, in kg. | 11.67 | 16.12 |
| Average in kg/Terrace | 0.97 | 0.67 |
| Total, land use | in 108 m2 | in 216 m2 |
| kg/ha Probable Yield | 1 200 | 1 363.64 |
| Net yield obtained from the crop per hectare | 1 080.67 | 746.32 |
| Production percentage | 90.06 | 54.73 |

**Neutrosophic membership degree:** The neutrosophic membership degree of each intersection of the sets of $P(T_i)$ is determined as shown in Table 12 (intersections within the scope of the study). For this, the $t_{norm}$ and $t_{conorm}$ were used to determine the intersection through the aggregation operation, which is the value $\left(min_j\{\mathrm{T}_{ij}\}, max_j\{\mathrm{I}_{ij}\}, max_j\{\mathrm{F}_{ij}\}\right)$. Each resulting value is defined by a single-valued neutrosophic number (SVNN) that reflects the level of membership of this element or set within $P(T_i)$.

**Table 12:** Neutrosophic membership degree of each set of $P(T_i)$. Source: Own elaboration.

| $P(T_i)$ | $x(d^0)$ | $P(T_i)$ | $x(d^0)$ |
|---|---|---|---|
| $\{S_1, A_i\}$ | (0.38,0.54,0.63) | $\{\{\{S1, A_i\}, C_i\}, \{B_i, Z_1\}\}$ | (0.38,0.54,0.63) |
| $\{FO1, A_i\}$ | (0.98,0,0.03) | $\{\{\{FO1, A_i\}, C_i\}, \{B_i, Z_1\}\}$ | (0.88,0.04,0.13) |
| $\{FO2, A_i\}$ | (0.78,0.14,0.23) | $\{\{\{FO2, A_i\}, C_i\}, \{B_i, Z_1\}\}$ | (0.78,0.14,0.23) |
| $\{FO3, A_i\}$ | (0.68,0.24,0.33) | $\{\{\{FO3, A_i\}, C_i\}, \{B_i, Z_1\}\}$ | (0.68,0.24,0.33) |
| $\{C_1\}$ | (0.68,0.24,0.33) | $\{\{\{S1, A_i\}, C_i\}, \{B_i, Z_2\}\}$ | (0.38,0.54,0.63) |
| $\{C_2\}$ | (0.88,0.04,0.13) | $\{\{\{FO1, A_i\}, C_i\}, \{B_i, Z_2\}\}$ | (0.78,0.14,0.23) |
| $\{C_1, C_2\}$ | (0.88,0.04,0.13) | $\{\{\{FO2, A_i\}, C_i\}, \{B_i, Z_2\}\}$ | (0.78,0.14,0.23) |
| $\{B_i\}$ | (0.88,0.04,0.13) | $\{\{\{FO3, A_i\}, C_i\}, \{B_i, Z_2\}\}$ | (0.68,0.24,0.33) |
| $\{Z_1\}$ | (0.88,0.04,0.13) | $\{\{\{S1, A_i\}, C_i\}, \{B_i, \{Z_1, Z_2\}\}\}$ | (0.38,0.54,0.63) |
| $\{Z_2\}$ | (0.78,0.14,0.23) | $\{\{\{FO1, A_i\}, C_i\}, \{B_i, \{Z_1, Z_2\}\}\}$ | (0.88,0.04,0.13) |
| $\{Z_1, Z_2\}$ | (0.88,0.04,0.13) | $\{\{\{FO2, A_i\}, C_i\}, \{B_i, \{Z_1, Z_2\}\}\}$ | (0.78,0.14,0.23) |
| | | $\{\{\{FO3, A_i\}, C_i\}, \{B_i, \{Z_1, Z_2\}\}\}$ | (0.68,0.24,0.33) |

The results of the neutrosophic membership degrees have highlighted two points of interest within $P(T_i)$. For example, the intersections between the set groups $\{\{\{FO1, A_1\}, C_2\}, \{B_1, Z_1\}\}$, as well as $\{\{\{FO1, A_1\}, C_2\}, \{B_1, \{Z_1, Z_2\}\}\}$, are defined by a membership degree of (0.88, 0.04, 0.13). Therefore, vermicompost emerges as the most efficient organic source, due to its consistent effects on the soil, regardless of the management used, confirming its positive impact compared to other treatments.

On the other hand, the correlation analysis revealed that the weight and number of grains of Lupinus mutabilis correlate 1, with weight being a key indicator of yield. Parameters such as electrical conductivity (0.96), organic matter (0.69), and nitrogen (0.71) showed significant positive correlations with yield. Meanwhile, phosphorus (1) and zinc (0.83) influenced germination, which correlated 0.60 with production. Consequently, the use of organic fertilizers consolidates as a key strategy to optimize agricultural productivity and preserve the quality of the degraded soils of Salache.

## 4 Conclusion

The study confirmed that the use of vermicompost as an organic fertilizer source significantly improves soil properties such as pH, electrical conductivity, organic matter, and essential nutrients, which positively impacts the yield of Pisum sativum and Lupinus mutabilis. The applied dose (30 tons per hectare) achieved outstanding results, reaching 90% and 55% of the average for each crop, respectively, demonstrating its effectiveness in degraded soils. Furthermore, the analysis using Neutrosophic SuperHyperSoft Sets allowed for the identification of set groups corresponding to chemical and physical properties ($a_i$), as well as plant indicators ($b_i$) and crop cycles ($c_i$). This enabled the design of a structure for evaluating multiple attributes, with neutrosophic membership degrees inherent in sustainable agricultural practices. Lastly, it is suggested to explore new organic sources and promote the use of decomposed fertilizers in eroded areas, to encourage sustainable soil management for resilient agriculture.

## References

[1] R. A. Mihai, E. J. Melo Heras, V. A. Terán Maza, I. A. Espinoza Caiza, E. A. Pinto Valdiviezo, and R. D. Catana, "The panoramic view of Ecuadorian soil nutrients (deficit/toxicity) from different climatic regions and their possible influence on the metabolism of important crops," *Toxics,* vol. 11, no. 2, p. 123, 2023.

[2] L. Jiménez, W. Jiménez, L. González, P. Quichimbo, N. Fierro, and D. Capa-Mora, "Rescuing local knowledge with regards to soil management and fertility in the Amazon Region of Ecuador," *Environmental Development,* vol. 50, no. June, pp. 1-3, 2024/06/01/ 2024.

[3] E. M. Bouchtaoui, M. Fahr, A. Smouni, K. Azim, R. Lahlali, and F. Mokrini, "Harnessing compost and vermicompost for sustainable and effective management of plant-parasitic nematodes in agricultural systems: A critical review," *Physiological and Molecular Plant Pathology,* vol. 133, no. September, pp. 2-5, 2024/09/01/ 2024.

[4] A. Ierna and M. Distefano, "Crop Nutrition and Soil Fertility Management in Organic Potato Production Systems," *Horticulturae,* vol. 10, no. 8, p. 886, 2024.

[5] L. Jiménez, W. Jiménez, N. Ayala, P. Quichimbo, N. Fierro, and D. Capa-Mora, "Exploring ethnopedology in the Ecuadorian Andean highlands: A local farmer perspective of soil indicators and management," *Geoderma Regional,* vol. 36, no. March, pp. 2-10, 2024/03/01/ 2024.

[6] X. Chen *et al.*, "Enhancing Maize Yield and Nutrient Utilization through Improved Soil Quality under Reduced Fertilizer Use: The Efficacy of Organic–Inorganic Compound Fertilizer," *Agriculture,* vol. 14, no. 9, p. 1482, 2024.

[7] P. J. Bebeli *et al.*, "State and Progress of Andean Lupin Cultivation in Europe: A Review," *Agronomy,* vol. 10, no. 7, p. 1038, 2020.

[8] Y. Lu *et al.*, "Partial Substitution of Nitrogen Fertilizer with Biogas Slurry Increases Rice Yield and Fertilizer Utilization Efficiency, Enhancing Soil Fertility in the Chaohu Lake Basin," *Plants,* vol. 13, no. 15, pp. 1-14, 2024.

[9] A. Torres-García, E. F. Héctor-Ardisana, R. León-Aguilar, F. E. Zambrano-Gavilanes, and O. A. F. Téllez, "Vermicompost Leachate-Based Biostimulant and its Effects on Physiological Variables and Yield of Different Crops in Manabí, Ecuador," *Ciencia y Tecnología Agropecuaria,* vol. 25, no. 1, pp. 1-12, 2024.

[10] F. Smarandache, "Extensión de Soft Set a Hypersoft Set, y luego a Plithogenic Hypersoft Set," *Revista Asociación Latinoamericana de Ciencias Neutrosóficas. ISSN 2574-1101,* vol. 25, no. 2023, pp. 103-106, 2023.

[11] F. Smarandache, "Soft set product extended to hypersoft set and indetermsoft set cartesian product extended to indetermhypersoft set," *Journal of fuzzy extension and applications,* vol. 3, no. 4, pp. 313-316, 2022.

[12] Z. A. Ameen and M. H. Alqahtani, "Baire category soft sets and their symmetric local properties," *Symmetry,* vol. 15, no. 10, p. 1810, 2023.

[13] F. Smarandache, "Foundation of the SuperHyperSoft Set and the Fuzzy Extension SuperHyperSoft Set: A New Vision," *Neutrosophic Systems with Applications,* vol. 11, no. November, pp. 48-51, 2023.

[14] M. Mohamed, A. Elmor, F. Smarandache, and A. A. Metwaly, "An efficient superhypersoft framework for evaluating llms-based secure blockchain platforms," *Neutrosophic Sets and Systems,* vol. 72, no. 2024, pp. 1-21, 2024.

[15] E. González Caballero, M. Leyva Vázquez, and F. Smarandache, "On neutrosophic uninorms," *Neutrosophic Sets and Systems,* vol. 45, no. 2021, pp. 340-348, 2021.


Received: July 20, 2024. Accepted: September 21, 2024