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Optimizing Pest Management in Sugarcane Cultivation: An Integrative Approach using Neutrosophic Statistics and Plithogenic Analysis

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Abstract. Pest management in modern agriculture, particularly in sugarcane cultivation, faces the challenge of balancing efficacy, costs, and environmental sustainability. Among the notable pests, the spittlebug (Mahanarva andigena) emerged as a significant threat that reduced yields of sugar and other derivatives. Traditionally, it was controlled with chemical pesticides, which posed environmental and human health risks. Consequently, the study conducted analyzed alternatives by using neutrosophic statistics and plithogenic analysis. The results included evaluating factors such as product concentration, application frequency, environmental conditions, and pest resistance to determine the efficacy of treatments with entomopathogenic microorganisms. Eficax stood out as the best treatment, showing significant improvements in plant growth and a high mortality rate of spittlebugs. In conclusion, the neutrosophic statistical analysis provided an efficient and economically viable solution for responsible agricultural management.

Keywords: Integrated pest management, neutrosophic plithogenic statistics, agricultural sustainability, biological control.

1 Introduction

Sugarcane (Saccharum officinarum L.) is widely cultivated in tropical and subtropical regions around the world. In Ecuador, this crop extends to several provinces including Guayas, Cañar, and Loja. It is a crop of great global relevance, as it provides sugar, an essential energy source for households and the food industry. Globally, approximately 20.42 million hectares are allocated to this cultivation, with more than 110,000 hectares in Ecuador dedicated not only to sugar production but also to ethanol and other derivatives.

However, sugarcane production faces significant challenges, such as a reduction of 40% to 60% in agricultural yields due to pests, particularly the spittlebug Mahanarva andigena, an insect that severely affects the crop [1]. The nymphs and adults of this insect cause substantial damage by sucking the sap and transmitting toxins that necrose the plant, which can lead to complete loss of the plant and significantly reduce the sucrose content.

Traditionally, control of this pest has been carried out using chemical pesticides such as Carbaryl and Acephate. Despite their effectiveness, these compounds have disadvantages such as high costs, difficulties in application due to the dense growth of the cane, and risks to human health and the environment. Additionally, pollution and the development of resistance to pests are concerns.

Given these issues, there has been growing interest in more sustainable alternatives, such as entomopathogenic fungi [2]. Recent studies have demonstrated the efficacy of species like Beauveria bassiana and Metarhizium spp. in controlling different life stages of the spittlebug [3], offering a promising and environmentally friendly alternative [4].

This study focuses on evaluating three commercial products based on these microorganisms in order to identify the most effective one for controlling the spittlebug in sugarcane [5]. It also aims to determine and evaluate factors in product formulation and environmental conditions that affect the efficacy and costs of entomopathogenic treatments against the spittlebug in sugarcane. For this purpose, neutrosophic statistics and phylogenetic analysis are employed to optimize the management of indeterminate data associated with pests and environmental impacts.

2 Materials and methods

2.1 Neutrosophic Statistics

Neutrosophic probabilities and statistics are a generalization of classical and imprecise probabilities and statistics [6]. The neutrosophic probability of event E is the probability that event E occurs, the probability that event E does not occur, and the probability of indeterminacy (not knowing whether event E occurs or not). In classical probability, nsup≤1, while in neutrosophic probability, nsup≤3+. The function that models the neutrosophic probability of a random variable x is called the neutrosophic distribution: $NP(x) = \big(T(x), I(x), F(x)\big)$

Where T(x) represents the probability that the value x occurs, F(x) represents the probability that the value x does not occur, and I(x) represents the indeterminate or unknown probability of the value x. Neutrosophic statistics is the analysis of neutrosophic events and deals with neutrosophic numbers, neutrosophic probability distribution, neutrosophic estimation, and neutrosophic regression.

It refers to a data set, which is formed totally or partially by data with some degree of indeterminacy and to the methods for analyzing them. Neutrosophic statistical methods allow interpreting and organizing neutrosophic data (data that can be ambiguous, vague, imprecise, incomplete, or even unknown) to reveal underlying patterns [7].

Ultimately, neutrosophic logic, neutrosophic sets, and neutrosophic probabilities and statistics have wide applications in various research fields and constitute a novel area of study in full development [8] [9]. Neutrosophic descriptive statistics comprise all techniques for summarizing and describing the characteristics of neutrosophic numerical data.

Neutrosophic numbers are numbers of the form where a and b are real or complex numbers, while "I" is the indeterminacy part of the neutrosophic number N. The study of neutrosophic statistics refers to a neutrosophic random variable where X_l and $X_u I_N$ represent the lower and upper levels respectively that the studied variable can reach, in an indeterminate interval $[I_l, I_u]$. Thus, the neutrosophic mean of the variable $(\bar{x}_N)$ is followed by formulating:

$$X_N = X_l + X_u I_N;\ I_N \in [I_l, I_u] \tag{1}$$

Where, $\bar{x}_a = \frac{1}{n_N}\sum_{i=1}^{n_N} X_{il},\quad \bar{x}_b = \frac{1}{n_N}\sum_{i=1}^{n_N} X_{iu},\quad n_N \in [n_l, n_u],$ (2)

it is a neutrosophic random sample. However, for the calculation of neutrosophic squares (NNS), it can be calculated as follows [10, 11]:

$$\sum_{i=1}^{n} N(X_i - \bar{X}_{iN})^2 = \sum_{i=1}^{n} N\left[\begin{matrix} \min\begin{pmatrix} (a_i + b_i I_L)(\bar{a} + \bar{b} I_L), (a_i + b_i I_L)(\bar{a} + \bar{b} I_U) \\ (a_i + b_i I_U)(\bar{a} + \bar{b} I_L), (a_i + b_i I_U)(\bar{a} + \bar{b} I_U) \end{pmatrix} \\ \max\begin{pmatrix} (a_i + b_i I_L)(\bar{a} + \bar{b} I_L), (a_i + b_i I_L)(\bar{a} + \bar{b} I_U) \\ (a_i + b_i I_U)(\bar{a} + \bar{b} I_L), (a_i + b_i I_U)(\bar{a} + \bar{b} I_U) \end{pmatrix} \end{matrix}\right], I \in [I_L, I_U] \tag{3}$$

Where $a_i = X_l b_i = X_u$. The variance of the neutrosophic sample can be calculated by

$$S_N^2 = \frac{\sum_{i=1}^{n_N}(X_i - \bar{X}_{iN})^2}{n_N};\ S_N^2 \in [S_L^2, S_U^2] \tag{4}$$

The neutrosophic coefficient (NCV) [12] measures the consistency of the variable. The lower the NCV value, the more consistent the performance of the factor compared to other factors. The NCV can be calculated as follows:

$$CV_N = \frac{\sqrt{S_N^2}}{\bar{x}_N} \times 100;\ CV_N \in [CV_L, CV_U] \tag{5}$$

The Neutrosophic Argumentation coefficient evaluates the criteria through Linguistic Terms with SVNN of consensus of justification of the expert opinion, (see Table 1).

Table 1: Linguistic Expression to Determine the Level of Importance of the Factor on the Variable. Source: Own elaboration.

Linguistic Expression	Scale	Plithogenic number (T, I, F)	$S([\mathbf{T}, \mathbf{I}, \mathbf{F}])$	Description
Very low importance (VLI)	0	(0.05, 0.90, 0.95)	0.07	The factor has a negligible impact on the effective control of spittlebugs.
Low importance (LI)	1	(0.15, 0.75, 0.85)	0.18	The factor has a reduced impact, not critical for the effective control of spittlebugs.
Moderately low (MLI)	2	(0.25, 0.65, 0.75)	0.28	Moderate impact but considered low priority in the control of spittlebug.
Moderately important (MI)	3	(0.50, 0.50, 0.65)	0.45	Factor with a medium level of importance; significant but not decisive impact.
Important (I)	4	(0.65, 0.35, 0.50)	0.60	An important factor that considerably influences the control of spittlebugs.
Very important (VI)	5	(0.80, 0.20, 0.30)	0.77	A very important factor, whose proper management is key to the effective control of spittlebug.

Linguistic Expression	Scale	Plithogenic number (T, I, F)	$\mathcal{S}([\mathbf{T},\mathbf{I},\mathbf{F}])$	Description
Extremely Important (EI) or Critical (C)	6	(0.95, 0.05, 0.10)	0.93	Critical factors whose improper management could completely fail the control of spittlebug.

Mathematical modeling using neutrosophic logic to plithogenic logic is a methodology that focuses on including indeterminacy and contradiction in the evaluation of sets and systems [13,14]. Plithogenic logic has the following characteristics according to the methodology analyzed in the study materials [15, 16].

3 Results

3.1 Case study. Preliminary results in classical statistics.

Study Site: The research was conducted in an area of 7140 m² in the Palo Quemado parish, located along the Toachi River and part of the Sigse mountain range, in the Sigchos canton, Cotopaxi province. This area has an altitude ranging from 990 to 1270 meters above sea level and records temperatures between 23°C and 24°C, with annual precipitation ranging from 105 to 306 mm.

Implementation: A completely randomized block design with a factorial arrangement of seven and four repetitions was adopted. Each experimental unit occupied 25 m², totaling 28 units.

Construction of cages: Cages of 1m x 1m x 1m, lined with 2mm mesh fabric, were constructed. These cages included a sleeve on the front for the insertion of spittlebugs.

Isolation and infestation: A sugarcane plant between 3 and 4 months old was selected in each plot, after previously weeding and defoliating. After ensuring the absence of spittlebugs for seven days of isolation, 14 spittlebugs per cage were introduced using an entomological net.

Application of commercial products: Products were applied according to the specifications of their technical sheets, with two application frequencies: every 15 days for 2 and 3 weeks. The treatments are detailed below:

- T1-T6: Varied in product and number of applications. Combinations of Beauveria bassiana, Metarhizium anisopliae, Lecanicillum lecanii, and Purpureocillium were used.
- T7: Control without treatment.

Identification with iNaturalist: The spittlebugs captured at various life stages were preserved in 70% alcohol and transported to the laboratory at the Technical University of Cotopaxi. Photographs of various parts of the insect were taken and uploaded to the iNaturalist app for taxonomic identification.

Context: In the study of biological pest control in agriculture, specifically the management of spittlebugs in sugarcane crops through the use of entomopathogenic microorganisms, a model was developed to analyze the effects of different treatments on the health and growth of the crop.

Plant Growth: The results show that treatments T1 and T4 (Eficax), and T3 and T6 (Biometarhizium) demonstrated greater plant growth in the first 15 days. After 30 days, T1 and T4 reached maximum heights of 1.13 m and 1.17 m respectively. At 45 days, T4 showed the highest heights, with maximums of 1.22 m and minimums of 1.19 m. By day 60, T4 significantly stood out by reaching an average height of 1.44 m, followed by T6 with 1.23 m (see Figure 1).

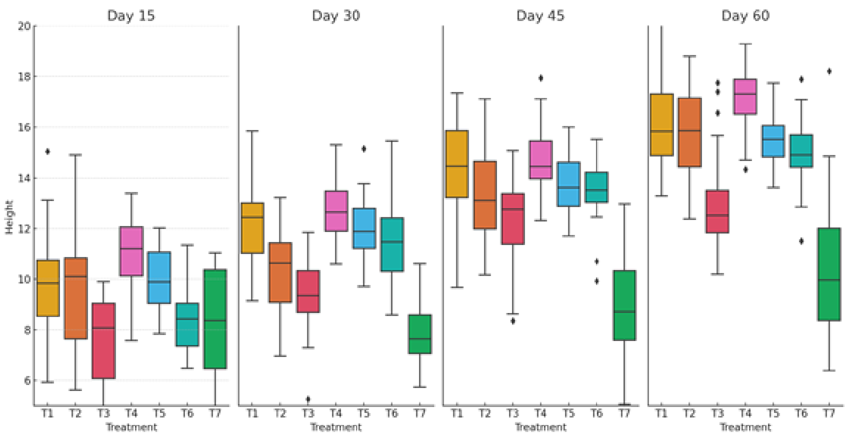

Figure 1: Boxplot graph for sugarcane plant height (cm). Source: Own elaboration.

Statistical Analysis: The variability in the data was acceptable with a variation coefficient of 11.86% (see Table 2). The analysis of variance revealed a significant difference between the treatments ($p < 0.0001$), indicating significant effects of the studied factors on the treatments. The interaction between factors did not show statistical significance, except in the direct comparison of the treatments with the control.

Table 2: Variance Analysis for spittlebug mortality. Source: Own elaboration.

F.V.	GL	SC	CM	F	p-value	
Block	3	5.79	1.93	1.87	0.1775	ns
Treatments	6	433.86	72.31	68.25	0.0001	**
Factor A	2	64.33	32.17	31.21	0.0001	**
Factor B	1	57.04	57.04	55.35	0.0001	**
A x B Factor	2	0.33	0.17	0.16	0.8521	ns
Factors vs. Witness	1	312.15	312.15	294.61	0.0001	**
Error	18	22.25	1.06			
Total	27	0.56				
CV	11.86					

Spittlebug Mortality: The Tukey test at 5% indicated that T4 was the most effective treatment for controlling Spittlebugs, followed by T6, with statistically significant differences between the groups (see Table 3).

Table 3: Tukey Test at 5% for Mortality of Sugarcane Spittlebugs Caused by Entomopathogens. Source: Own elaboration.

Factors vs. Witness	Mean					
T4	13.75	A				
T6	11.25		B			
T1	10.5		B	C		
T5	9.75		B	C		
T3	8.5			C	D	
T2	6.5				D	
T7	0.5					E

Control Costs: The control costs varied among the treatments, with T4 being the most expensive at $77.00, followed by T6 at $76.15 and T5 at $76.03 (see Table 4). The costs were calculated by adding up the costs of the product, labor, and the frequency of applications.

Table 4: Control Costs of the 3 Commercial Products Based on Entomopathogenic Microorganisms. Source: Own elaboration.

Product	Unit price	Treatment cost	Labor ($25 per day)	Cost/treatment
T1 (Eficax 2 applications)	20.6	1.5	50	51.5
T2 (Solubiomix 2 applications)	13.75	0.68	50	50.68
T3 (Biometarhizium 2 applications)	15.39	0.77	50	50.77
T4 (Eficax 3 applications)	20.6	2	75	77
T5 (Solubiomix 3 applications)	13.75	1.03	75	76.03
T6 (Biometarhizium 3 applications)	15.39	1.15	75	76.15
T7 (No application)	0	0	0	0
	Total study cost			382.13

In conclusion, treatment T4 with three applications of Eficax proved to be the most effective both in terms of plant growth and Spittlebug mortality, although it was also the most costly. However, factors that were not considered or were quantified as of low importance due to their complexity need to be analyzed. For this, it is necessary to apply neutrosophic statistics.

3.2 Extension to Neutrosophic Statistics.

When analyzing the results obtained from classical statistics, the following factors in the analyzed sample should be reconsidered for this analysis:

- Concentration and formulation of the products (F1): The effectiveness of treatments with entomopathogenic microorganisms largely depends on the concentration and the way these biological agents are formulated.
- Frequency and timing of application (F2): The timing and frequency of applying the treatments can significantly affect the effectiveness of Spittlebug control.

- Environmental conditions (F3): Entomopathogenic microorganisms are sensitive to environmental conditions such as temperature, humidity, and UV radiation. Suboptimal conditions can reduce the efficacy of the microorganisms by decreasing their viability or activity.
- Pest resistance (F4): As with any control method, there is a risk that the Spittlebug may develop resistance to certain entomopathogenic microorganisms if these are used repeatedly and exclusively.
- Compatibility with other control methods (F5): The interaction of entomopathogenic microorganisms with other control methods (chemical, cultural, mechanical) can influence the overall effectiveness of Spittlebug management.

These factors must be considered in integrated pest management to ensure effective control of the Spittlebug in sugarcane crops. This approach aims to maximize the efficacy of biological treatments and minimize negative impacts on the environment and agricultural economy. These factors are common due to the complexity of ecological systems and variations in biological responses in pest control and management. Therefore, given the variability of the data and criteria obtained, the use of neutrosophic statistics is conditioned by experts to denote the indeterminate random components within the plithogenic set.

Development of the modeling: A group of experts analyzed the data obtained during the information collection phase. Through consensus, the following categorizations for the modeling were defined, as well as the relationship between subset and factor:

Plithogenic Set:	Spittlebug Control
Subsets or Dimensions:	• Efficacy of treatments (F1, F2, F4, F5) • Impact on plant growth (F3, F5) • Cost-effectiveness (F1,F5)
Variable:	Effectiveness in the control of Spittlebug. Code (ECS)
Factors (F):	F1, F2, F3, F4 and F5.
Sample:	60 days
Scale	[0, 6] (See Table 1)

Neutrosophic statistical analysis: When modeling the variable using neutrosophic statistics, absolute frequencies are obtained to determine the level of effectiveness in controlling the Spittlebug over a sample of 60 days of analyzed research (Table 5). To determine the level of incidence of each factor in its dimension, an indeterminacy measure for modeling was set with a scale of $0 \leq F_{V_n} \geq 1$, to determine the relative level of membership within the subset, as well as within the plithogenic set based on the analyzed frequency.

Table 5: Neutrosophic frequency for each plithogenic subset in the development of education. Source: Own elaboration.

Days	F1	F2	F3	F4	F5
1	(0 ; 2)	(2 ; 4)	(3 ; 5)	(1 ; 2)	(3 ; 5)
2	(3 ; 4)	(1 ; 3)	(0 ; 3)	(3 ; 6)	(3 ; 3)
3	(2 ; 4)	(1 ; 3)	(2 ; 3)	(1 ; 3)	(0 ; 3)
4	(2 ; 3)	(3 ; 5)	(0 ; 3)	(0 ; 1)	(3 ; 5)
5	(3 ; 6)	(1 ; 4)	(0 ; 3)	(1 ; 1)	(0 ; 1)
6	(3 ; 4)	(2 ; 3)	(0 ; 0)	(3 ; 5)	(2 ; 2)
7	(1 ; 4)	(1 ; 2)	(3 ; 4)	(1 ; 1)	(1 ; 1)
8	(3 ; 6)	(1 ; 4)	(3 ; 5)	(0 ; 1)	(0 ; 2)
9	(3 ; 4)	(0 ; 2)	(2 ; 5)	(1 ; 4)	(3 ; 6)
10	(3 ; 5)	(2 ; 3)	(2 ; 2)	(0 ; 1)	(2 ; 4)
11	(0 ; 0)	(3 ; 5)	(0 ; 1)	(2 ; 5)	(2 ; 5)
12	(3 ; 3)	(3 ; 6)	(1 ; 1)	(2 ; 2)	(2 ; 2)
13	(1 ; 1)	(2 ; 5)	(0 ; 3)	(0 ; 1)	(1 ; 1)
14	(1 ; 2)	(2 ; 3)	(0 ; 2)	(2 ; 3)	(3 ; 5)
15	(0 ; 2)	(1 ; 4)	(2 ; 5)	(1 ; 3)	(0 ; 3)
16	(0 ; 3)	(0 ; 1)	(0 ; 0)	(0 ; 2)	(3 ; 3)
17	(2 ; 4)	(2 ; 5)	(3 ; 6)	(0 ; 0)	(0 ; 2)
18	(3 ; 6)	(2 ; 4)	(0 ; 2)	(1 ; 3)	(0 ; 2)
19	(1 ; 4)	(2 ; 4)	(3 ; 6)	(2 ; 5)	(0 ; 3)
20	(3 ; 6)	(3 ; 6)	(3 ; 6)	(1 ; 1)	(2 ; 4)
0-60	(93; 186)	(92; 191)	(76; 169)	(75; 167)	(102; 189)

From the neutrosophic frequencies observed in the application of the treatments, it is noted that for a sample of 60 days analyzed, there is a level of indeterminacy ranging from 46.03% to 55.09%. Among the impacting factors are environmental conditions and pest resistance with representativity levels of (76; 169) and (75; 167) respectively. Therefore, the application of these treatments must be analyzed by including these neutrosophic elements.

Comparative Analysis: The modeling of data on the level of ECS indicates that factors 3 and 4 require studies with a deeper level of investigation. To determine the level of incidence within each subset, it is necessary to analyze the means of the sampled data (see Table 6). To understand which factor is representative, neutrosophic mean values, $\bar{x} = \in [\bar{x}_L; \bar{x}_U]$, and variations in the values of the neutrosophic standard deviation, $S_N \in [S_L; S_U]$, are calculated. Therefore, to determine which factor requires a higher level of accuracy when diagnosing each subset, it is necessary to calculate the $CV_N \in [CV_L ; CV_U]$ values and the associated levels of indeterminacy.

Table 6: Neutrosophic Statistical Analysis of the ECS Level. Source: Own elaboration.

Factors	$\bar{x}_N$	S.N.	CVN	
F1	1.55 + 3.1 I	0.861 + 2.466 I	0.555 + 0.795 I	I ∈ (0,0.795)
F2	1,533 + 3,183 I	0.76 + 2.458 I	0.496 + 0.772 I	I ∈ (0,0.772)
F3	1,267 + 2,817 I	0.86 + 2.472 I	0.679 + 0.878 I	I ∈ (0,0.878)
F4	1.25 + 2.783 I	0.776 + 2.306 I	0.621 + 0.829 I	I ∈ (0,0.829)
F5	1.7 + 3.15 I	0.831 + 2.096 I	0.489 + 0.665 I	I ∈ (0,0.665)

The control of the Spittlebug in Ecuadorian regions does not only depend on choosing an effective treatment without considering the external factors which, due to their indeterminate characteristics, are analyzed or projected onto other studies. The neutrosophic variable analyzing the ECS level depends on the interaction and balance of these factors. From the analysis of Table 6, the factors influencing the ECS levels and the associated level of indetermination are observed. The results show that the CV_N values range from 0.489 to 0.679 with an indetermination measure of [0.665; 0.878] generated by a sample of [0; 60] questionnaires and statistical information obtained from the analyzed sample. From the comparative analysis between factors, it is observed that:

Factor F2 and F5: These are among the factors with the greatest importance and the least complexity in the group analyzed in the neutrosophic statistical studies [0.772; 0.665], classified within a neutrosophic area of MI and C. Therefore, key management should be carried out in the effective control of the Spittlebug when applying the optimal treatment. Additionally, it is considered that too-spaced applications may allow the pest population to recover, while very frequent applications can be economically unviable. Concurrently, applying treatments at key moments in the pest's life cycle can significantly increase the efficacy of the treatment. It is important to note that the use of chemical insecticides could negatively affect the entomopathogenic microorganisms applied, whereas appropriate cultural practices can enhance conditions for their effectiveness.

Factor F3 and F4: These are identified as factors of lesser complexity within the analyzed group with a classification of I and MI. These factors are seen in a neutrosophic area as influential and key in pest control. The levels of indetermination analyzed are above the analyzed group [0.878; 0.829] due to an evolutionary effect shared by living beings, which should be considered in the neutrosophic statistical analysis. Moreover, for environmental conditions, it is suggested to analyze whether extreme temperatures can deactivate or kill the microorganisms before they can infect the Spittlebug. Meanwhile, pest resistance suggests rotating different types of entomopathogenic microorganisms and combining them with other control methods to help mitigate this risk.

The final factor to be analyzed is *factor F1*, where the effectiveness of the treatments is analyzed with an indetermination level of [0.795] and a classification between a neutrosophic area of MI and C. This involves including neutrosophic elements related to the proper concentration, ensuring there are enough active microorganisms to infect and control Spittlebug populations. It also analyzes and proposes a suitable formulation that helps maintain the viability of these microorganisms in the field.

These neutrosophic factors have a particularly significant impact on the ECS level regarding the development of sugarcane in different regions of Ecuador. Hence, the neutrosophic variable depends on the interaction and balance of these factors, establishing the following hierarchy of neutrosophic importance F5, F2, F1, F4, and F3. Subsequently, the degrees of contradiction of these factors and the areas where they converge within the plithogenic set are identified.

3.3 Neutrosophic Statistical Analysis of the Dimension through Integration into Plithogenic Logic.

To determine where factors or elements converge within the plithogenic ECS set, it is necessary to identify the associated characteristics and their relationship with the development of sugarcane. For this purpose, Table 7 proposes the key elements to consider.

Table 7: Characteristics of the Plithogenic Set in the Control of the Spittlebug. Source: Own elaboration.

CODE	Dimension	CODE	Sub-dimension or factor	Scale	Plithogenic number (T, I, F)	d_n (x; V_n)	Attribute value
V1	Efficacy of treatments	v11	Spittlebug mortality.	[0 ; 6]	(0.95, 0.05, 0.10)	0.93	EI
		v12	Repellency.	[0 ; 6]	(0.65, 0.35, 0.50)	0.60	I
		v13	Reduction of infestation.	[0 ;6]	(0.80, 0.20, 0.30)	0.77	VI
V2	Impact on plant growth	v21	Plant height.	[0 ; 6]	(0.55, 0.50, 0.65)	0.45	I
		v23	General plant health.	[0 ; 6]	(0.80, 0.20, 0.30)	0.77	MI
V3	Cost-effectiveness	v31	Cost of treatment per hectare.	[0 ; 6]	(0.80, 0.20, 0.30)	0.77	VI
		v32	Cost-benefit relation.	[0 ; 6]	(0.95, 0.05, 0.10)	0.93	EI

The plithogenic set is defined for three subsets V1, V2, and V3. Therefore, a plithogenic set is defined as consisting of 7 attributes, each of these attributes containing possible values, with their respective plithogenic particularities and possible values in the linguistic expression to determine the level of importance of the factor on the variable.

The multi-attribute of dimension 3 has a cardinality of 3x2x2 = 12.

The degrees of contradiction among the values for each attribute are defined as follows:

- $c_N(v_{11}, v_{12}) = 0.33; c_N(v_{12}, v_{13}) = 0.16$
- $c_N(v_{22}, v_{21}) = 0.32$
- $c_N(v_{32}, v_{31}) = 0.16$

As can be seen, the dominant values for each attribute are: v_{11} and v_{32}.

When v_{11} and v_{32} are activated, all other nodes are activated, which means that the incidence value caused by the *effectiveness of the treatments* in the development of sugarcane influences the *cost-effectiveness* for producers and is in turn influenced by the predominant factors. Therefore, to propose potential solutions, it is necessary to determine the intersected area of the predominant attributes in the plithogenic set. Thus, it is proposed to evaluate the level of importance of the treatment v_{11} and v_{32} and how it affects the effectiveness of the control of Spittlebug.

Spittlebug mortality. (v_{11}) and Cost-benefit ratio. (v_{32})

Neutrosophic Plithogenic Intersection	$S([\mathbf{T}, \mathbf{I}, \mathbf{F}])$	Assessment
$(a_1, a_2, a_3) \wedge_p (b_1, b_2, b_3) = (a_1 \wedge_D b_{1,} \frac{1}{2}[(a_2 \wedge_D b_2) + (a_2 \vee_D b2)], a_3 \vee_D b3)$ $(a_1, a_2, a_3) \wedge_p (b_1, b_2, b_3) = (0.95; 0.05; 0.05)$	0.9633	It is located at a sublevel above EI and closer to 1 true.

There is a stronger relationship between the subsets of *treatment efficacy* and *cost-effectiveness* [in their attributes (v_{11}) and (v_{32})] than between the previous ones and the *impact on plant growth*, consequently, to the most predominant factors. A relationship is obtained with a degree beyond EI according to the plithogenic neutrosophic union and intersection operator. Therefore, solutions should be focused on addressing the factors that converge in the attributes (v_{11}) and (v_{32}) that affect the control of Spittlebug and the development of sugarcane in Ecuador.

3.4 Partial solutions

To address the challenges identified in the neutrosophic statistical analysis of Spittlebug control in sugarcane crops, two integrative solutions are proposed that focus on improving the efficacy of treatments and their cost-benefit relationship:

1. Optimization of the formulation and concentration of entomopathogenic treatments (F1): Given the critical dependency of the effectiveness of entomopathogenic treatments on their concentration and formulation, a key strategy is to develop improved formulations that maximize stability and biological activity under a range of environmental conditions. This includes:
   - Research and development: Collaborate with agricultural research institutions to innovate in formulations that extend the viability of entomopathogens in the field, considering factors such as resistance to UV radiation and extreme temperatures.
   - Controlled field tests: Implement field trials to determine the optimal concentration and formulation that produces the best results against Spittlebug, adjusting doses according to the specific needs of

the crop and environmental characteristics.

2. Integration of environmental management and monitoring strategies (F3, F5): Incorporate an integrated pest management system that combines the use of entomopathogens with environmental and cultural monitoring strategies to adapt to changing conditions and minimize pest resistance:
    - Early warning systems: Use sensor technologies and predictive models to monitor environmental conditions that may affect the efficacy of biological treatments and adjust applications in real time.
    - Rotation of biological and chemical agents: Alternate between different entomopathogenic microorganisms and, when necessary, use selective chemical insecticides to reduce the risk of Spittlebug resistance. This should be complemented with cultural practices that improve plant health and reduce dependence on chemical interventions.

Implementation and Evaluation:

- Training and education of farmers: Conduct workshops to educate farmers on the importance of new formulations, integrated pest management, and the effective use of early warning system data.
- Ongoing evaluation: Establish a protocol for the continuous evaluation of the effectiveness of the implemented strategies, using neutrosophic statistics to adjust practices based on indeterminate outcomes and ensure an adaptive response to field conditions.

These solutions aim not only to improve the efficacy of Spittlebug control but also to ensure the sustainability and profitability of agricultural practices in the context of prudent environmental and economic management.

4 Conclusion

The study on the control of Spittlebug in sugarcane crops demonstrates how neutrosophic statistics, applied through analyses of indeterminacy and plithogenic variables, allow for a deeper understanding of the interaction between multiple agricultural and environmental factors. This methodology is crucial for assessing the efficacy, costs, and environmental effects of treatments with entomopathogenic microorganisms, considering both the variability and the inherent uncertainty in agricultural systems. Neutrosophic statistics facilitate more informed and adaptive agronomic decisions, thereby optimizing integrated pest management and promoting a sustainable approach to agriculture.

The use of Plithogenics in this study on Spittlebug control illustrates how interactions between different factors and treatments can be analyzed to select the best pest management strategy. The selection of Eficax as the most effective treatment, based on detailed plithogenic analysis, demonstrates its superiority in terms of plant growth and Spittlebug mortality, while also fitting into a sustainable economic model. This plithogenic approach, which incorporates variability and indeterminacy into decision-making, allows agricultural managers to optimize their resources and enhance the effectiveness of treatments. Thus, they focus on solutions that provide the best results both in agronomic and environmental terms.

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