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Abstract. Rice cultivation is of great importance worldwide, due to its nutritional properties and because it is part of many plates of the inhabitants of all continents. Weeds are part of the factors that affect rice production, which is why it is necessary to apply herbicides, including the modality of the presence of herbicides in irrigation. This paper aims to carry out a statistical study on the effectiveness of different treatments to eliminate the weeds of the INDIA SFL 11 rice variety in Babahoyo, Ecuador. The evaluation of some results of the treatments was carried out visually based on both weed control and herbicide toxicity by using linguistic terms that are associated with an indeterminate scale of percentages, where the data are given in the form of intervals and not in crisp values. Additionally other seven criteria are also utilized. Thus, we decided to apply neutrosophic statistics as a study tool for this problem. Neutrosophic statistics extends classical statistics theory to the framework of neutrosophy, where intervals are used instead of analyzing crisp values. Specifically, Tukey's test is applied in comparing some data in form of intervals that denotes the imprecision of the obtained measurement.

Keywords: Weed, herbicides, rice, neutrosophic statistics, Tukey's test.

1. Introduction

Rice (*Oryza sativa L*) is the most consumed grass in the world due to its high caloric content, which has led it to become the backbone of the economy of countries that depend directly on its production. According to the Food and Agriculture Organization (FAO), world production will be 514.9 millions of tons, surpassed by wheat with 757.4 millions of tons. ([1]).

Due to its characteristics, rice can be cultivated in different environments and areas. In Ecuador, it is carried out almost entirely on the coast, with 97% of the production, distributed mainly in three provinces: Guayas, Los Ríos and Manabí ([2]).

In Ecuador, rice cultivation is the largest, representing a third of the total area devoted to transitory products. During 2017, approximately 370,406 hectares were allocated ([3]).

Weeds in rice cause severe yield losses, affecting the number of tillers per plant, number of grains per panicle, and grain weight. In addition, they contribute to the survival of pests affecting the development of the crop and therefore increase production costs due to the necessary phytosanitary controls.

In Ecuador, the national average yield of rice in the first period 2018 was 4.81 t/ha, with the province of Loja being the one with the highest yield (9.10 t/ha), while in Los Ríos the lowest yield was obtained (3.64 t/ha). However, it represents an increase of 18% compared to the previous year.

According to the perspectives of the producers, there are many external factors that affect Ecuador's rice production, highlighting pests and/or diseases. 64% of farmers have been harmed by phytosanitary problems while 13% were affected by lack of water, weeds and salinity.

Due to the lack of knowledge, small farmers have used inappropriate techniques that are not optimal for the control of pests and diseases, allowing not only problems with their cultivation, but also to spreading of pests and diseases to other neighboring crops. Most rice producers do not coordinate planting, which results in having crops of different ages, facilitating the proliferation of pests. An incipient regulation and control of seeds, coming from abroad, by the State, facilitate the entry and proliferation of pests, [4].

Weeds are among the most limiting factors in rice production, as they cause direct and indirect damage to the crop through competition for light, water, and nutrients. They can reduce the quality of the harvest and are hosts for insects-pests and diseases. In addition, many weeds produce allelopathic compounds that are likely to affect normal crop growth.

The impact of weed damage is estimated to be between 15 and 20 percent of the production cost. The most important weeds in rice cultivation are grasses and within this group, *Echinochloa colona*, *Echinochloacrusgalli*, *Ischaemumrugosum* and *Leptochloaspp*. To this group of species must be added the non-commercial forms of *Oryza sativa* (black or red rice). The second group of weeds, in order of importance, are the sedges, among which *Cyperusesculentus*, *Cyperusferax*, *Cyperusiria* and *Fimbristilissp* stand out. These species are important since they are difficult to control and cause severe damage to the crop, [5].

There is a wide variety of herbicides used for weed control in rice cultivation. Among the recently introduced herbicides that inhibit protein synthesis through the inhibition of the enzyme acetolactate synthetase is halosulfuron-methyl, a sulfonylurea that is absorbed through the root system and the aerial part of the plant, and this is easily translocated within it, [5].

To use pre-emergent herbicides has been limited, because their effectiveness is conditioned by the moisture content and the preparation of the soil. However, with the early post-emergence application of residual herbicides, the advantage is that with a single application, emerged weeds can be controlled, while avoiding new weed emergencies. Therefore, it is considered that a good alternative for the control of rice weeds could be the application of herbicides in early post-emergence, [6].

We compare the results of applying eight herbicide treatments in the irrigated rice production system in Babahoyo. The evaluation of the results is carried out using the ALAM scale [2], where the evaluator associates a linguistic term with the effectiveness of the treatment. Each linguistic term is in turn associated with a percentage range of treatment effectiveness. Because visual inspection is indeterminate, intervals are taken as data rather than numerical values. This poses the challenge of conducting a statistical study based on intervals rather than crisps values. Also, the herbicide toxicity is evaluated using intervals. It is an opportunity to use neutrosophic statistics. The advantage of performing statistical processing using intervals is to obtaining greater accuracy at the cost of having greater indeterminacy.

Neutrosophic statistics is an extension of the classical statistics. While in classical statistics the data is known, formed by crisp numbers or parameters, in neutrosophic statistics the data has some indeterminacy[7-9]. In the neutrosophic statistics, the data may be ambiguous, vague, imprecise, incomplete, even unknown. Instead of crisp numbers used in classical statistics, one uses sets (that respectively approximate these crisp numbers) in neutrosophic statistics. Neutrosophic set theory has been used in agriculture and food problems, see [10-12].

This article is divided into the following sections. Section 2 is dedicated to recalling the main concepts of neutrosophic statistics and others necessaries concepts. Section 3 contains the study carried out in this research on the effectiveness of eight herbicide treatments on the INDIA SFL 11 rice variety, through the application of neutrosophic statistics and the Tukey's test, [13, 14]. Section 3 is dedicated to giving the conclusions of the paper.

2. Neutrosophy and Neutrosophic Statistics

This section is dedicated to describe some basic concepts of neutrosophy and neutrosophic statistics[9, 15-18].

Definition 1: ([19]) Let X be a universe of discourse. A *Neutrosophic Set* (NS) is characterized by three membership functions, $u_A(x), r_A(x), v_A(x) : X \rightarrow]^{-}0, 1^{+}[$, 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 the membership functions of truthfulness, indeterminacy and falseness of x in A, respectively, and their images are standard or non-standard subsets of $]^{-}0, 1^{+}[$.

Definition 2: ([19]) Let X be a universe of discourse. A *Single-Valued Neutrosophic Set* (SVNS) A on X is a set of the form:

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

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 the membership functions of truthfulness, indeterminate and falseness of x in A, respectively. For convenience a *Single-Valued Neutrosophic Number* (SVNN) will be expressed as $A = (a, b, c)$, where $a, b, c \in [0,1]$ and satisfy $0 \leq a + b + c \leq 3$.

Neutrosophic Statistics extends the classical statistics, such that we deal with set values rather than crisp values, [20].

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

Neustrosophic Inferential Statistics consists of methods that permit the generalization from a neutrosophic sampling to a population from which it was selected the sample.

Neutrosophic Data is the data that contains some indeterminacy. Similarly to the classical statistics it can be classified as:

- *Discrete neutrosophic data*, if the values are isolated points.
- *Continuous neutrosophic data*, if the values form one or more intervals.

Another classification is the following:

- *Quantitative (numerical) neutrosophic data*; for example: a number in the interval (we do not know exactly), 47, 52, 67 or 69 (we do not know exactly);
- *Qualitative (categorical) neutrosophic data*; for example: blue or red (we don't know exactly), white, black or green or yellow (not knowing exactly).

The *univariate neutrosophic data* is a neutrosophic data that consists of observations on a neutrosophic single attribute.

Multivariable neutrosophic data is neutrosophic data that consists of observations on two or more attributes.

A *Neutrosophical Statistical Number* N has the form $N = d + i$, [21], where d is called *determinate part* and I is called *indeterminate part*.

A *Neutrosophic Frequency Distribution* is a table displaying the categories, frequencies, and relative frequencies with some indeterminacy. Most often, indeterminacies occur due to imprecise, incomplete or unknown data related to frequency. As a consequence, relative frequency becomes imprecise, incomplete, or unknown too.

Neutrosophic Survey Results are survey results that contain some indeterminacy.

A *Neutrosophic Population* is a population not well determined at the level of membership (i.e. not sure if some individuals belong or do not belong to the population).

A *simple random neutrosophic sample* of size n from a classical or neutrosophic population is a sample of n individuals such that at least one of them has some indeterminacy.

A *stratified random neutrosophic sampling* the pollster groups the (classical or neutrosophic) population by a strata according to a classification; afterwards the pollster takes a random sample (of appropriate size according to a criterion) from each group. If there is some indeterminacy, we deal with neutrosophic sampling.

Additionally we describe some concepts of interval calculus, which shall be useful in this paper.

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, [22, 23]:

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

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

$N_1 \times N_2 = a_1a_2 + (a_1b_2 + b_1a_2 + b_1b_2)I$ (Product),

$\frac{N_1}{N_2} = \frac{a_1+b_1I}{a_2+b_2I} = \frac{a_1}{a_2} + \frac{a_2b_1-a_1b_2}{a_2(a_2+b_2)}I$ (Division).

A de-neutrosophication process gives an interval number $I = [a_1, a_2]$ for centrality, [24].

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

3. Results

This section is dedicated to provide the results of the present study. We use the Tukey's test, which is a type of ANOVA process, [13, 14, 25]. The inputs are N assessment divided in K groups each of them have the same number of elements. The null hypothesis test consists in asserting that the means of the groups are equal. It is sufficient that the mean of two groups are not significantly equal for rejecting the null hypothesis. The main Equation of the test is the following:

$$q_{observed} = \frac{M_{i.} - M_{j.}}{\sqrt{MS_{error}\left(\frac{1}{S}\right)}} \quad (3)$$

Where $M_{i.}$ and $M_{j.}$ are the group means to compare, MS_{error} is the mean square error from the previously computed ANOVA test, and S is the number of observations per group.

$q_{observed}$ is compared with a $q_{critical}$ value calculated from a table of values (see [14]), which depends upon the α-level and the degrees of freedom $\nu = N - K$.

If $q_{observed} \leq q_{critical}$ we consider there is not a significant difference between ith and jth groups means, otherwise there exists a difference.

The present research was carried out in the town of San Pablo, Los Ríos province, located at 12 km of the Babahoyo-Montalvo road, with the geographical coordinates X = 672,825 Y = 979,717,5 and at 9 meters above sea level. Average annual precipitation is 2329.8 mm; 82 percent relative humidity; 998.2 hours of heliophany and temperature of 25.6 °C.

The place has a humid tropical climate, according to the Köppen climate classification with an average annual temperature of 25.5 °C. The average annual precipitation is 2,177.8 mm/year, relative humidity of 80.9 percent and 908.4 hours of heliophany on an annual average (UTB-2017 meteorological station).

The INDIA SFL 11 rice variety was used as sowing material, whose characteristics are presented in Table 1.

Plant height	126 cm
Tillering	Intermediate
Crop cycle	127–131 days
Yield potential	6 to 8 t/ha
Shelling	Intermediate
Weight of 1000 grains in shell	29 g
Pile rate	67 percent
Shelled grain size	7.52 mm
White center	None

Table 1: Characteristics of the INDIA SFL 11 rice variety.

Rice sowing was carried out on June 18, 2018 at a sowing density of 100 kg/ha. Eight treatments were evaluated, including one without any weed control (Table 2). The design used was that of complete random blocks with four repetitions and experimental units made up of 4x5 m plots, equivalent to 20 m^2 each of them, with a distance of 25 cm between rows and 25 cm between plants. For the evaluation and comparison of means of the treatments, the Tukey's test was used at 95 percent probability.

Pre-emergent	Dose/ha	Post-emergent	Dose / ha
T1. clomazone + butaclor	0.850 +1.4L	propanil + (picloram + 2.4-D amina)	2.3 + 0.4L
T2. clomazone + butaclor	0.850 +1.4L	manual weeding	3 weeds
T3. pendimentalin + butaclor	2.8 + 2.8L	cyhalofop	1.0L
T4. pendimentalin + butaclor	2.8 + 2.8L	manual weeding	3 weeds
T5.oxadiazon + butaclor	1.5 + 2.8L	(propanil + triclopyr)	5.0L
T6. oxadiazon + butaclor	1.5 + 2.8L	manual weeding	3 weeds
T7. clomazone + benti-ocarbo	0.850 + 4.0L	bispiribacsodium + (picloram + 2,4-D amina)	0.4 + 0.7L
T8. clomazone + benti-ocarbo	0.850 + 4.0L	manual weeding	3 weeds

Table 2: Treatments under study.

The application of the pre-emergency treatments was carried out on July 8th, 30 days after transplantation (dat). On both occasions, a 20-liter manual knapsack pump with a TEEJET 15004 flat fan nozzle was used, whose water consumption was 333 l/ha, after calibration. It was fertilized with urea (46% N), divided into equal parts 65.5 kg/ha at 15 dat and 65.5 kg/ha at 35 dat. Sulfur (ammonium sulfate 21% N and 24% S) was fractionated in equal parts, 10 kg/ha at 15 dat and 10 kg/ha at 35 dat. Phosphorus (DAP 18% N and 46% P_2O_5) in doses of 30 kg/ha and potassium 50 kg/ha (muriate of potassium 60% K_2O) were applied together in their entirety at 15 dat.

For preventive control of insects, thiamethoxam + lambdacyhalothrin was used, in doses of 250 cc/ha at 25 dat and then chlorpyrifos was used in doses of 750 cc/ha at 43 dat. In addition, for the preventive control of diseases, trifloxystrobin + tebuconazole was used, in doses of 600 cc/ha at 48 dat.

During the cultivation cycle the following variables were quantified:

1. Weed control. At 20 and 40 days after application (daa), the effect of the treatments on the weeds present was visually evaluated. For this, the scale proposed by ALAM ([2]) was used in which the value 0 indicates that the weeds were not affected and 100 that they were completely destroyed, Table 3.

Rating	Description
100 %	Full control
80-99 %	Excellent or very good
60-79 %	Good or sufficient

40-59 %	Doubtful or mediocre
20-39 %	Bad or lousy
0-19 %	Bad or null

Table 3: ALAM scale for weed control evaluation.

2. Toxicity to rice. The evaluation of the selectivity of the herbicide treatments to the crop was carried out on the same dates as the weed control evaluations, using the scale from 0 to 10, where 0 means that the rice did not suffer damage and 10 that all the plants are dead, see Table 4.

Rating	**Description**
0	No damage
1-3	Little damage
4-6	Moderate damage
7-9	Severe damage
10	Total Death

Table 4: Scale for herbicide toxicity evaluation.

3. Plant height. It was recorded at the moment of harvest, measuring in centimeters from the base of the plant to the apex of the most prominent panicle in 10 plants taken at random.

4. Number of tillers per m². It was randomly evaluated in 1.0 m² within the useful area of each experimental plot, counting the tillers at the time of harvest.

5. Panicles per m². For this variable, the number of panicles present in the same m² was determined that was used to count the tillers.

6. Panicle length. It was determined by measuring the distance between the ciliary node and the apex of the panicle, excluding the edges, in 10 random panicles.

7. Grains per panicle. In the same 10 panicles used in the previous variable, the number of grains in each panicle was counted.

8. Weight of 1000 grains. In the same 10 panicles used in the previous variable, the number of grains in each panicle was counted.

9. Crop yield. It was obtained based on the weight of the grains from the useful area of each experimental plot, standardizing at 14% humidity and transformed into kg/ha. To standardize the weights, the Azcon-Bieto formula was used, [26]:

$$Pu = Pa\frac{100 - ha}{100 - hd} \qquad (4)$$

Where:

Pu = uniform weight,

Pa = current weight,

ha = current humidity,

hd = desired humidity.

10. Economic Analysis. It was carried out based on the level of grain yield in kg/ha, with respect to the economic cost of the treatments.

Note that for the processing of the results that take values from Tables 3 and 4, the operations of the Tukey's test are generalized to the domain the interval values. The final results are converted into a single crisp value with the help of formula 2 using the de-neutrosophication process.

In Table 5, the averages of weed control at 20 and 40 daa of the products are recorded. In the analysis of variance, highly significant differences were obtained for both evaluations and the coefficients of variation were 2.88% and 5.38%, where the interval results were converted into crisp values by using Equation 2.

At 20 daa, the best weed control was reported in the mixture of clomazone + benthiocarb, in doses of 0.850L + 4.0L and bispyribacsodium + (picloram + 2,4-D amine) in doses of 0.4L + 0.7L with 95.8 percent weed control, being statistically superior to the other treatments.

At 40 daa, the mixture of clomazone + benthiocarb, in a dose of 0.850L + 4.0L and bispyribacsodium + (picloram + 2,4-D amine) in a dose of 0.4L + 0.7L presented the best weed control with 99 percent, being statistically equal to the mixtures of clomazone + butachlor in doses of 0.850L +1.4L and (propanil + picloram + 2,4-D amine) in doses of 2.3L + 0.4L.

Treatments	**20 daa**	**40 daa**
T1	[86.5, 88.5]b	[92.8, 94.8] ab
T2	[75.5, 77.5] d	[80.3, 82.3] c
T3	[82, 83] b	[85.7, 86.6] bc
T4	[79.6, 81.4] cd	[80.9, 81.7] c
T5	[86.79, 88.81] b	[89.5, 90.5] abc
T6	[77.95, 78.65] cd	[82.3, 82.7] c
T7	[95.3, 96.1] a	[98.5, 99.5] a
T8	[76.4, 76.6] d	[79.9, 80.1] c
General mean	[82.505, 83.820] (83.2)	[86.237, 87.275] (86.8)
Statistical significance	**	**
VC (%)	2.88	5.38

Means with the same letter do not differ significantly, according to the Tukey's Test.

Ns= not significant

*= significant

**= highly significant

Table 5: Percentage of control at 20 and 40 daa. The general means given between parenthesis is the de-neutrosophied value.

Herbicide selectivity

None of the treatments showed symptoms of phytotoxicity at 20 and 40 daa. That is to say, the specialists determined that no damage exists with respect to toxicity, based on the linguistic terms in Table 4.

Plant height

No differences were detected with a VC of 3.48% (Table 6).

With the mixture of clomazone + benthiocarb, in doses of 0.850L + 4.0L most weeds, the highest plant height (107.8 cm) was presented. The lowest height (99.5 cm) was obtained with the mixture of clomazone + benthiocarb in doses of 0.850L + 4.0L and with bispyribacsodium + (picloram + 2,4-D amine) in doses of 0.4L + 0.7L.

Number of tillers per m²

The means for this variable are observed in Table 6. The analysis of variance did not reach significant differences and its VC was 17.92%.

With the mixture of oxadiazon + butachlor in doses of 1.5L + 2.8L and (propanil + triclopyr) in doses of 5.0L, the highest number of 326.8 tillers/m² (326.8) was recorded. The lowest number (215.8) was obtained with the mixture of clomazone + benthiocarb, in doses of 0.850L + 4.0L and three manual weeds.

Panicles per m²

The means for this variable are presented in Table 6, not reaching significant differences and with a variation coefficient of 18.28%.

With the mixture of oxadiazon + butachlor in doses of 1.5L + 2.8L and (propanil + triclopyr) in doses of 5.0L, the highest number of panicles/m² (325.8) was achieved. The lowest number (210) was obtained with the mixture of clomazone + benthiocarb, in doses of 0.850L + 4.0L and three weeds.

Treatments	Plant height (cm)	Number of tillers/m²	Number of panicles/m²
T1	101.5	314.0	306.3
T2	105.9	302.5	290.8
T3	104.6	316.5	307.3
T4	107.4	301.8	290.5
T5	103.7	326.8	315.8
T6	104.7	255.8	241.5
T7	99.6	291.5	280.3
T8	107.8	215.8	210.0
General mean	104.4	290.6	280.3
Statistical significance	ns	ns	ns
Variation coefficient (%)	3.48	17.92	18.28

Table 6: Plant height, number of tillers, and panicles per m².

Crop yield

In Table 7 the averages for this variable are reported. The analysis of variance presented significant differences and the VC was 9.72%.

The mixture of oxadiazon + butachlor in doses of 1.5L+2.8L and (propanil + triclopyr) in doses of 5.0L reached the highest yield (4974.5 kg/ha), being statistically equal to the mixtures of clomazone + butachlor, in doses of 0.850 L +1.4L and propanil + (picloram + 2,4-D amine) in doses of 2.3L+ 0.4L; clomazone + butachlor, doses of 0.850L+1.4L and three weeds; pendimentalin + butacloren doses of 2.8L+2.8L and cyhalofopen doses of 1.0L; pendimentalin + butacloren doses of 2.8L+2.8L and three weeds; oxadiazon + butachloren doses of 1.5L +2.8L and three weeds; clomazone + benthiocarbo in doses of 0.850L+ 4.0L and bispyribacsodium + (picloram + 2,4-D amine) in doses of 0.4L+0.7L. All were statistically superior to the mixture of clomazone + benthiocarb in doses of 0.850L + 4.0L and three weeding, with a value of 3892.5 kg/ha.

Economic analysis

Table 7 presents the results of the economic analysis. The highest net benefit ($341.80) was registered with the mixture of clomazone + butachlor, in doses of 0.850L+1.4L and propanil + (picloram + 2,4-D amine), in doses of 2.3L+0.4L. The lowest value ($ -24.23) was obtained with the T8 clomazone + benthiocarb treatment, in doses of 0.850L+4.0L and three weeds.

Treatments	Yield (kg/ha)	Net benefit (USD)
T1	4917.5 ab	341.80
T2	4610.0 ab	237.20
T3	4944.8 ab	304.76
T4	4753.0 ab	254.50
T5	4974.5 a	181.71
T6	4532.5 ab	169.11
T7	4803.5 ab	236.49
T8	3892.5 b	-24.23
General mean	4678.5	
Statistical significance	*	
Variation coefficient (%)	9.72	

Table 7: Return and net profit.

Conclusion

This paper applied a statistical analysis to eight herbicides treatments in the irrigated rice production system in Babahoyo. We used the Tukey's test in a neutrosophic framework, because we preferred to maintain the imprecision obtained for indeterminate data for measuring the percentage of control at 20 and 40 days after application and the herbicide toxicity evaluation. We applied this test using intervals and later we de-neutrosiphied the final results. Thus we arrived to the following conclusions:

- The best weed control at 20 and 40 daa was obtained with the mixture of clomazone+benthiocarb, in doses of 0.850L+4.0L and bispyribacsodium + (picloram + 2.4 D amine) in doses of 0.4L+0.7L.

- Phytotoxicity was not observed with any of the treatments.
- Plant height and grains per panicle showed favorable results in the mixture of clomazone + benthiocarb in doses of 850L+4.0L and bispyribacsodium + (picloram + 2,4-D amine) in doses of 0.4L+ 0.7L.
- The mixture of oxadiazon + butachlor in doses of 1.5L+2.8L and (propanil + triclopyr) in doses of 5.0 L registered a greater number of tillers and panicles/m^2, panicle length, weight of 1000 grains and crop yield with 4974.5 kg/ha.
- The highest net benefit was registered with the mixture of clomazone + butachlor, in doses of 0.850L+1.4L and propanil + (picloram + 2,4-D amine), in doses of 2.3L+0.4L, with $341.80.

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