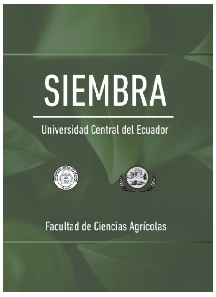
Effect of Organic Fertilizers Supplemented with Foliar Fertilizers on the Morphology of Hibiscus esculentus Linn in the Ecuadorian Amazon



Efecto de abonos orgánicos complementados con fertilizantes foliares químicos sobre la morfología del cultivo Hibiscus esculentus Linn en la Amazonía ecuatoriana

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Abstract

Okra (*Hibiscus esculentus*) is an annual herbaceous and non-traditional vegetable with high nutritional value and health benefits. Despite its importance, the lack of information on its cultivation in this region has led many Amazonian farmers to manage it empirically, combining foliar chemical fertilizers with organic fertilizers without a scientific basis for determining the most suitable combination. In this context, the objective of this research was to evaluate the impact of applying compost and chicken manure combined with foliar chemical fertilizers (Stimufol and Kristalon) on the development of aerial morphological traits of *Hibiscus esculentus* crops under field conditions in the Amazonian region of Ecuador. The experiment was conducted at the Experimental Center for Amazonian Research and Production of the Universidad Estatal Amazónica, using a completely randomized block design with two factors: organic fertilization and chemical foliar fertilization. Key morphological variables of the crop were evaluated, such as plant height, stem base diameter, number of leaves, petiole length, and leaf length and width. The results showed that plants treated with organic compost and chemical fertilizer Stimufol showed a significant increase in all morphological measurements compared to the other treatments. Finally, the combination of Stimufol and compost plays a crucial role in the development of okra's morphological attributes, while the absence of this treatment did not affect said attributes.

Keywords: okra cultivation, organic farming, chemical agriculture, *Abelmoschus esculentus*, Amazonia.

Resumen

La okra (*Hibiscus esculentus*) es una planta herbácea anual y hortaliza “no tradicional” de gran valor nutricional y beneficios para la salud. A pesar de su importancia, la falta de información sobre su cultivo en esta región ha llevado a muchos agricultores amazónicos a gestionarla de forma empírica, combinando fertilizantes químicos foliares con abonos orgánicos sin una base científica para determinar la combinación más adecuada. En este contexto, el objetivo de esta investigación fue evaluar el impacto de la aplicación de compost y gallinaza combinado con fertilizantes químicos foliares Stimufol y Kristalon en el desarrollo de los rasgos morfológicos aéreos del cultivo *Hibiscus esculentus,* en condiciones de campo, en la región amazónica de Ecuador. El experimento se llevó a cabo en el Centro Experimental de Investigación y Producción Amazónica de la Universidad Estatal Amazónica, utilizando un diseño de bloque completamente al azar con dos factores: fertilización orgánica y fertilización foliar química. Se evaluaron variables morfológicas clave del cultivo, como altura de la planta, diámetro en la base del tallo, número de hojas, longitud del peciolo, longitud y ancho de la hoja. Los resultados demostraron que las plantas tratadas con abono orgánico compost y fertilizante químico Stimufol mostraron un notable incremento en todas las mediciones morfológicas en comparación con los otros tratamientos. Finalmente, la combinación de Stimufol y compost juega un papel esencial en el desarrollo de los atributos morfológicos de la okra, mientras que la falta de este tratamiento no tuvo efecto en dichos atributos.

Palabras clave: cultivo de quingombó, agricultura orgánica, agricultura química, *Abelmoschus esculentus*, Amazonía.

1. Introduction

Okra, *Hibiscus esculentus* (*Abelmoschus esculentus*) (EEO), is a vegetable native to Africa (Purseglove, 1987), and annual herbaceous type. This vegetable is an important food to keep a good health, it has water (85 %), proteins (2.2 %), vegetable fat (0.2 %), carbohydrates (9.7 %), fiber (1.0 %) and ashes (0.8 %), which make the okra, a food with important nutritional value (Saifullah & Rabbani, 2009). Okra's parts are edible and offer a variety of benefits, as reported by Gemede et al. (2014). Okra seeds have edible oils (Oyolu, 1983), while the fruit is rich in fiber, vitamin C, folic acid and antioxidants (Adekiya et al., 2018). When okra is cooked, the mucilage can be obtained, and it can be used as a replacement of plasma or to expand the blood volume. The okra pods are source for minerals like potassium, sodium, magnesium, calcium, iron, zinc, manganese, and nickel, as well as vitamins A and C (Gemede et al., 2014; Moyin-Jesu, 2007). In addition, the fresh leaves, buds, flowers, and stems from the okra are edible and have a good acceptance by consumers (Adekiya et al., 2020).

Okra, also known as quimbombo or gombo, is a plant that grows in the wild in some regions, but it is also intentionally cultivated in the warm weather of tropical and subtropical countries of the world. This crop produces all year-round and requires well-drained soils, rich in organic matter, with a pH between 5.8 and 6.5 (Tejada & Núñez, 2019), or between 6 and 7.5 (Lozano & Artinian, 2018). According to Tejada & Núñez (2019), even if this crop does not demand nutrients, it is recommended to apply nitrogen [N] and phosphorous [P] to the sowing and after the fourth week of harvesting. However, to define the fertilization in this crop is important to define the nutritional deficiencies of the soil where it is cultivated (Díaz-Franco et al., 2007). In this sense, Díaz-Franco & Ortegón (1999), in Mexico, reported low yield of the crop while using low doses (3.9 t ha^{-1}) and high fertilization (8.0 t ha^{-1} – 8.6 t ha^{-1}), better yield, revealing the importance of the fertilization in poor or deficient soils. Yields have been reported in intensive cultivation in optimal conditions of 40 t ha^{-1}, while in non-intensive cultivation systems of 2 or 4 t ha^{-1} (Lozano & Artinian, 2018). FAOSTAT (2023) and Adekiya et al. (2019) reported yields of approximately 2 t ha^{-1} and 2.7 t ha^{-1} in Nigeria, respectively. However, in another study of soil with and without fertilization, the foliar fertilization did not have any effect on fruit yield or plant height (Díaz-Franco & Ortegón, 1999).

Despite the existence of some studies about the crop in different countries with distinct edaphoclimatic conditions, like Mexico (Díaz-Franco et al., 2007; Díaz-Franco & Ortegón, 1999), Brazil (Coutinho-Miranda et al., 2019) and Cuba (Vilches-León et al., 2023), among others (Adekiya et al., 2019; Cuata Natte & Manzaneda Delgado, 2018; Funke Salami et al., 2023), okra continues being considered a "small" or "no traditional" vegetable in terms of consumption, and there is a lack of information about its cultivation and management (Charrier, 1984). This is the case of the context of the Ecuadorian Amazon region, where no research has been published about the management of this crop in particular, and the communities perceive that the weather in the last few years have changes, affecting the production systems (León Alvear et al., 2020). This represents a valuable opportunity to generate new knowledge that could take advantage of the potential of the okra as an alternative of productive diversification in this area and be able to produce plants with agroecological foundations that could support families' economy and the conservation of ecosystems (Muñoz-Rengifo et al., 2021).

In any case, the nutrition of the crop plays a crucial role in the production systems because the correct application influences in the characteristics and properties of fruits (Muñoz-Rengifo et al., 2018), as demonstrated by Cavalcante et al. (2010) with the use of organic fertilizers in okra plantations, and as it has been studied by other researchers (Adekiya et al., 2018, 2020; Agbede and Adekiya, 2017; Bertino et al., 2015; Díaz-Franco & Ortegón, 1999; Santos et al., 2019). In this sense, even if conventional agriculture, based on the intensive use of chemical fertilizers, was a rapid solution to the hunger problem, the expansion of the agricultural frontier generally detrimental to the forests, has brought negative effects to the soil health (Bedolla-Rivera et al., 2023), to the quality of the crop (Yang et al., 2020) and to food security (Reyes-Palomino & Cano Ccoa, 2022).

On the other hand, sustainable agriculture plays a significant role in the conservation and restauration of ecosystems (Álvarez et al., 2013; Rosset et al., 2014). As a result, other sustainable alternatives have been promoted to cultivate the land and reduce the partial or complete dependency on chemical fertilizers. The use of organic fertilizers complemented with chemical fertilizers could be a strategy to improve soil fertility, increase productivity of the crop and reduce the use of harmful chemical fertilizers for the environment (Tahat et al., 2020). On one side, compost is an organic fertilizer produced from plant-based materials and decomposed animals (Rivero et al., 2004). Another product, the "gallinaza", is an organic fertilizer produced from chicken manure (Hue & Silva, 2000) that has had an effect on okra production. Both fertilizers are recognized by their ability to improve soil structure, with capability of increasing water retention and providing essential nutrients for plant growth, supporting sustainable agriculture (Tahat et al., 2020). On the other hand, foliar fertilizers Stimufol and Kristalon are generally used by local farmers for their nutritional composition and their capacity to be quickly absorbed by the plant leaves, which could improve nutrient absorption and promote a vigorous growth. These fertilizers have a combination of macronutrients and micronutrients that are essential for an adequate development of the plant (Moghazy, 2007), and their preference is based on availability and capacity to improve soil fertility.

In the Amazon region of Ecuador, the lack of information about production, management and fertilization of okra, a crop considered as "small" or "no traditional", have taken most of farmers to manage this crop in an empirical manner. Because okra is not widely cultivated in the Amazon region, there is the opportunity to use organic fertilizers in combination with chemical one to keep a sustainable production. In this context, the goal of this research is to evaluate the impact of using a combination of compost and gallinaza with the foliar chemical fertilizers Stimufol y Kristalon in the development of the aerial morphological characteristics of the crop *Hibiscus esculentus* in field conditions of the Amazon region of Ecuador.

This study tackles the need of producing okra in the Ecuadorian Amazon in a more sustainable way, reducing the environmental impact by using organic fertilization combined with foliar chemical fertilizers. The results of this study provide significant data for both farmers and researchers involved in the promotion of okra crop in the Amazon region of Ecuador. The results support the diversification of crops as a strategy to increase family income, highlighting the benefits of the application of organic fertilizers due to their positive impact in the analyzed morphological variables.

2. Materials and Methods

2.1. Study area

The research was carried out inside the program of production of the Experimental Center of Research and Amazon Production of the Amazon Statal University [$CEIPA_{UEA}$], located between the provinces of Pastaza and Napo, Ecuador, coordinates -1.2362666496116077 -77.88478682402508 (Figure 1). $CEIPA_{UEA}$ has an extension of 2848.20 hectares, it is found in a tropical environment where the annual precipitation can reach ≈4.000 mm, relative humidity is 80%, temperature varies between 15 and 25 °C, ≈3 sun hours^{-1} day^{-1}; and height varies between 580 and 990 m a.s.l.

2.2. Experimental Design

This research adopts an experimental approach, combining quantitative and qualitative methods, according to the classification of Hernández Sampieri et al. (2014). The experimental design consists in a randomized complete block [RCBD] that evaluates the interaction of two key factors: organic fertilization, through the use of gallinaza and compost, and through the use of synthetic foliar fertilization, comparing the effects of two commercial products: Stimufol (Agripac; Ecuador), an inorganic fertilizer NPK 25-16-12 enriched with micronutrients such as Boron [B], Cobalt [Co], Copper [Cu], Iron [Fe], Manganese [Mn], Molybdenum [Mo] and Zinc [Zn], recommended for foliar application and fertigation, and Kristalon (Yara; Ecuador), a fertilizer

with formula of N13% - P40% - K13%, that has micronutrients such as Cu, Mn and Zn in form of EDTA.
In this study, the results from two treatments derived from the analyzed factors are presented: treatment one [T1], that consisted of gallinaza complemented with the foliar fertilizer Kristalon, and treatment two [T2], that consisted of compost complemented with the foliar fertilizer Stimufol. Each treatment was evaluated in three replicates, in comparison with a control that did not receive any fertilizers [T3].

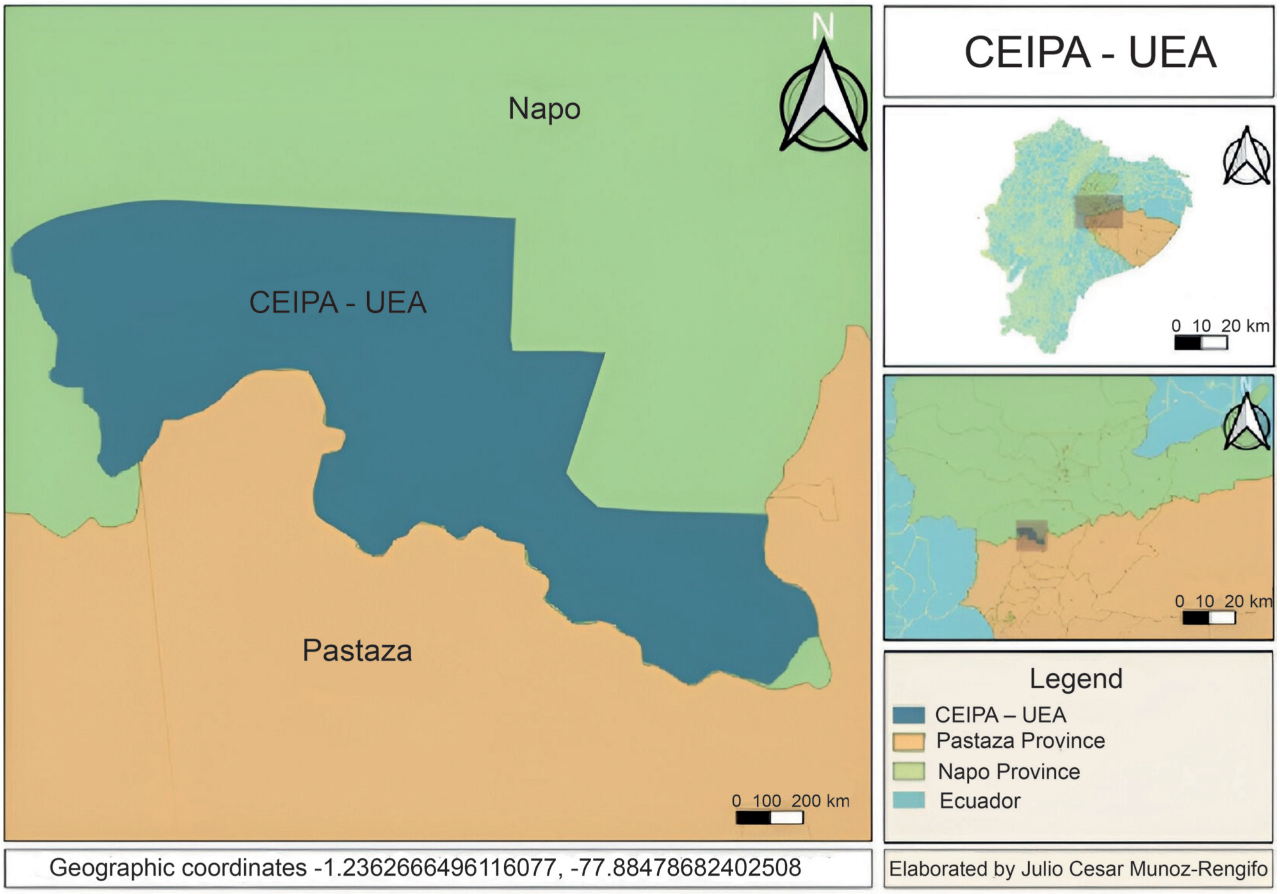

Figure 1. Location of the $\text{CEIPA}_{\text{UEA}}$ on the amazon region of Ecuador.

The treatments of the study were distributed in plots of 6 meters of long and 4 meters wide, with an area of 24 m^2 by plot and a total area of 216 m^2 for these treatments. The nine plots were separated longitudinally and transversely by a 1-meter line. In each plot, four grooves were created, and in each one 10 plants were sown following a planting frame of 1 meter x 0.6 meters, which resulted in a total of 40 plants per plot and 360 plants in total for the experiment. For the data collection, five randomly experimental units were selected in each plot, coming from the two internal grooves to avoid the border effect (Figure 2).

The organic fertilizers gallinaza and compost, considered as independent variables, were applied into the soil following the recommendations from Durán Ramírez (2013), fertilizing 600 g $plant^{-1}$. In contrast, the synthetic foliar fertilizers Kristalon and Stimufol, also independent variables, were applied onto the foliage of plants using a manual bomb Jacto HD 550 (Jacto Group; Brazil). Stimufol was administered in one dose of 20 g in five liters of water, 10 days after the emergence of the true leaves, with the two first applications done each five days and the following ones each 15 days. On the other hand, Kristalon was applied with the same doses and frequency. This strategy of application combined the organic fertilizers to satisfy the nutritional needs of the crop, following common practices of fertilization in the region.

In each treatment, diverse aerial morphological characteristics were evaluated and considered like independent variables: 1. Plant height [HS; cm], measured from the organic soil to the apex of the main stem; 2. Diameter of the base of the stem [DBS; cm], measured at 10 cm of the organic soil with a gauge Vernier (Insize Co. Ltd.; Mexico). In plants with multiple stems (multicaules), only the diameter of the main stem was recorded; 3. Leaf length [SL; cm], measured from the base until the apex of the leaf; 4. Leaf width [SW; cm], measured in the center of the leaf; 5. Petiole length [PL; cm], measured from the axillary bud until the base, and

6. Total number of effective leaves [NS; u] counted in each plant. For the length measurements, a flexometer was used Stanley Black & Decker model 030697 (SB&D; USA). The evaluation started five days after the transplant, and it was repeated every 15 days.

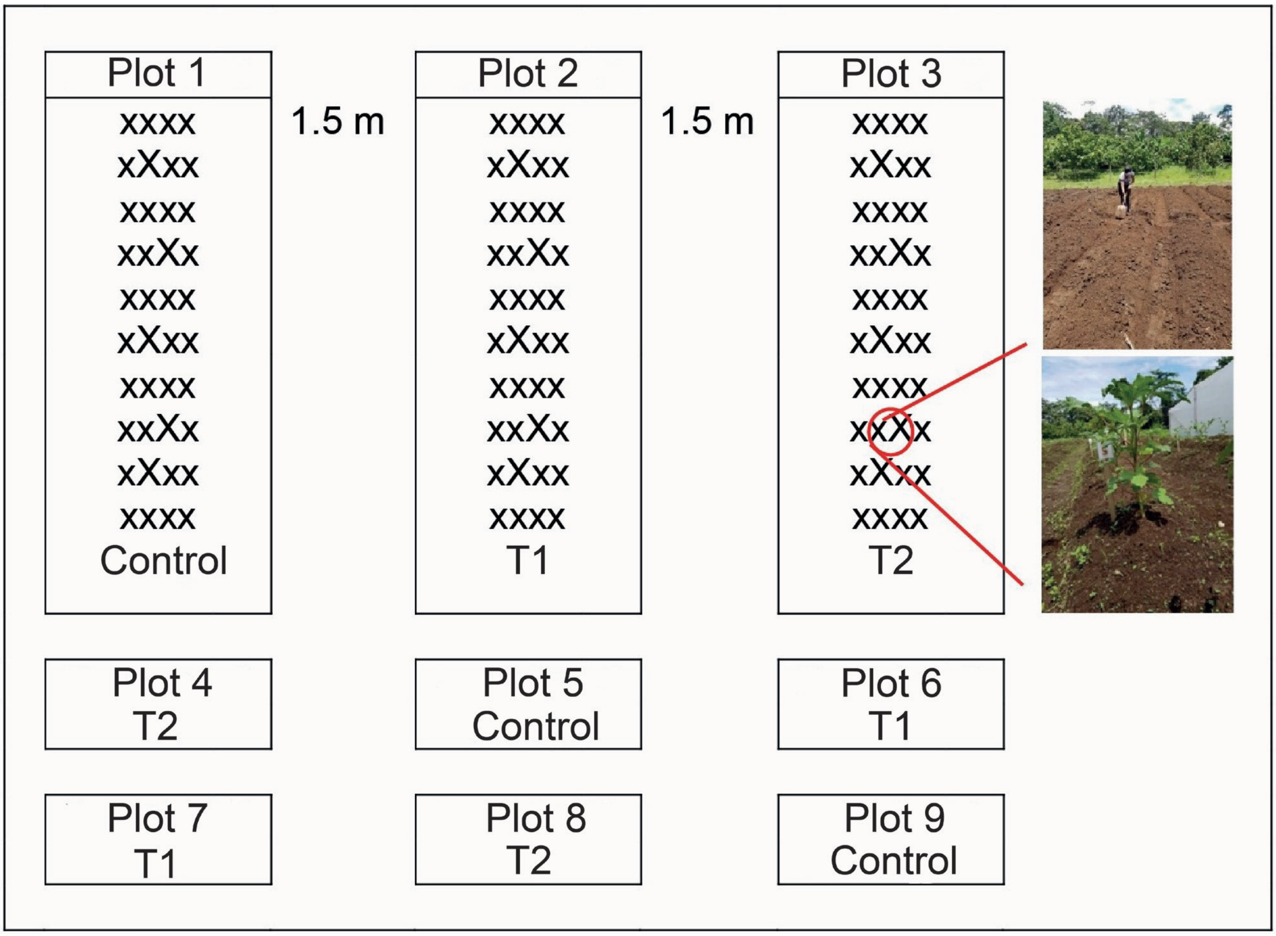

Figure 2. Representation of the experiment area.

2.3. Crop management

2.3.1 Soil Preparation

Crop management started with the soil preparation during the first week of September 2019. A mechanical roadheader attached to a tractor of caterpillars was used to leave the field fluffy and at the optimal depth. Later, the ground was furrowed leaving a distance of 1 meter between the vertical organs of the plants.

2.3.2 Seedlings and transplant

The plot layout and sowing in seedbed were done in a month previous to the field preparation, in August 2019. Peat substrate was used in four drawers of 128 cells. The seeds were placed in the center of each cell at a depth of 0.5 cm, and they were watered until the field capacity was reached. Considering the temperature of the place, the plants were watered every two days. The seed emergence was monitored continuously, obtaining the germination of 126 seeds (98.4 %).

The transplant was carried out in October 2022 (approximately 23 days after the sowing date), when the plants reached between two and three true leaves (approximately seven cm of height). Before the transplant, the seedbed was moistened and the plants that fulfilled the following criteria were selected: 1) good size, 2) good stem wide, 3) straight stems, 4) good coloration in their different fractions of aerial biomass. Later, with a lot of care, the cells were extracted and were placed in a permanent place.

2.3.3 Weed control

Weed control was done manually using rake and hoe, applying the technique of soil removal to eliminate the superficial scab. This improved the soil characteristics, like aeration, microbial activity, nutrient content, humidity and percolation.

2.4. Data Analysis

The data of the morphological variables: HS (cm), DBS (cm), NS (u), PL (cm), SL (cm) and SW (cm), were processed and analyzed using the statistic software SPSS v.22 (IBM, USA), through a General Linear Model [GLM] Univariate analysis with two factors (time and treatments) for each variable. To confirm the results of the evaluated variables more than two times in the study time, an analysis of repeated measurements in the time [GLM] was done using the same statistic software (SPSS v.22). In all the analysis, a *Tukey* test was done with a significant level of 0.05 % and confidence intervals of 95 %. The descriptive statistics were determined, and homogeneity tests of variance were done, and in the cases that the data did not meet the assumptions of ANOVA, logarithmic transformations were done. ANOVA of one factor was carried out when it was necessary to confirm the results.

3. Results

3.1. Plant Height and diameter of the base of the stem

The results of this research revealed that the okra crop, under the edaphoclimatic conditions of the $CEIPA_{UEA}$ presented important growth rates in HS and DBS through the study. The height of the plant during the research ranged between 8.82±0.38 cm (T3) and 31.40±1.49 cm (T2), during the first and seventh monitoring, respectively (Figure 3). The results of the statistical analysis gave a significant growth between measurements (time factor) and treatments ($p < 0.001$) (Table 1). The treatment with the highest HS was T2 ($F = 14.831$; $p < 0,001$) (Table 1), reaching a height of 31.40±1.49 cm at the seventh evaluation. In the case of T1, 27.87±1.46 cm was reached, and for T3, 25.73±1.67 cm was reached (Figure 3).

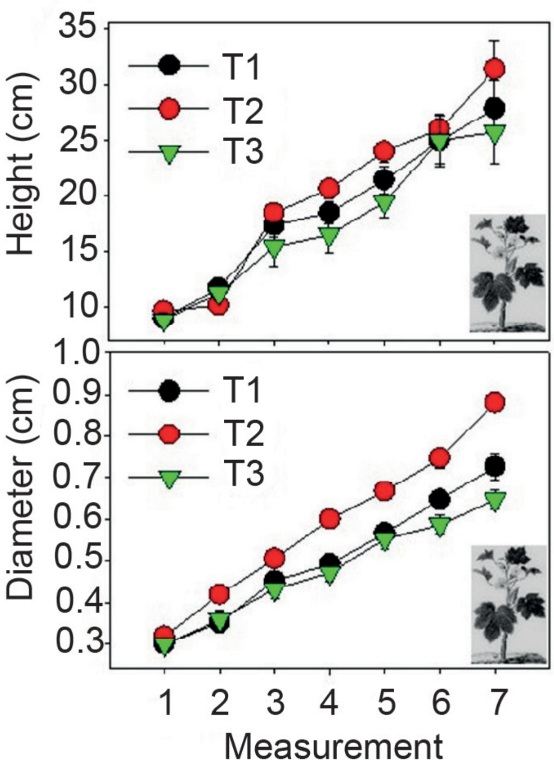

Figure 3. Height and diameter (HS y DBS; mean ± standard error) of the treatments throughout the study time.

Table 1. Morphological characteristics of seedlings (mean ± standard error) in the early months of crop establishment. The Univariate GLM Analysis results are presented along with statistical significance, and Tukey Test[2] was applied to the treatments.

Variables†*		N	Treatments				Data		
			F[1]	p-value[2]		*Tukey Test*	F[1]	p-value[2]	
HS		105	14.831	0.000	***	T1<T2>T3	186.421	0.000	***
DBS		105	6.147	0.002	*	T1=T2>T3=T1	85.322	0.000	***
Ns		102	1.878	0.155	ns	T1=T2=T3	132.194	0.000	***
Pl		105	3.763	0.024	*	T1=T2>T3=T1	68.244	0.000	***
Sl		105	8.560	0.000	***	T1=T2>T3=T1	54.038	0.000	***
Sw		105	9.154	0.000	***	T2>T1=T3	58.264	0.000	***

†* HS = Plant Heigh; DBS = Diameter at the base of the stem; NS = Number of effective leaves; PL = Petiole length; SL = leaf length; SW = leaf width. N: Sample size of the harmonic mean of the treatments.
[1] F: F-score.
[2] (***): p < 0,001; (**): p < 0,01; (*): p < 0,05; (ns): not significative.

About the DBS in the base of the stem, a higher DBS was observed in T2 in comparison to the one in T1, which was kept in an intermediate range, and T3 presented a shorter basal diameter during all the research phases. At the end of the study, the DBS at T2 was higher than the one at T1 and T3 (Figure 3). A further analysis revealed statistical differences among treatments through time ($p < 0.01$ and $p < 0.001$, respectively) (Table 1). The *Tukey test* grouped the treatments in two homogenous subgroups, in one side, T2 and T1 ($p = 0.332$), and on the other T1 and T3 ($p = 0.99$).

3.2. Total number of effective leaves

NS per plant among the treatments through study time ranged between 2.1±0.2 at the beginning of the research (T1) and 7.9±0.8 until the measurement number seven at the T2 (Table 2). The results of the statistical analysis did not reveal differences among treatments ($p > 0.05$), but among measurements, the increment in NS plant in all the treatments was significant ($p < 0.05$) (Table 1).

3.3. Petiole length

Okra plants with the different treatments presented an important variability in petiole length [PL]. There were statistical differences among treatments, and through time this variable presented a significant growth ($p < 0.05$) (Table 1). At the end of the research, the average PL was longer in T2 (10.2±1.0 cm) (Table 2) in comparison to T1 and T3 (8.8±1.1 cm and 7.6±0.9 cm, respectively) (Table 2). These treatments were grouped by the *Tukey test* in two homogeneous subgroups ($p < 0.05$) (Table 1). On one side, T2 and T1 (4.5 cm and 4.3 cm, respectively; $p = 0.60$), and by the other with 4.3 cm in T1 and in T3 with 3.8 cm (Table 1).

3.4. Leaf length

The average leaf length [SL] presented oscillations in T1 ranging 3.4±0.2 cm and 11.0±1.5 cm; in T2 between 3.5±0.2 cm and 11.2±1.9 cm; while in T3, between 3.5±0.2 cm and 9.3±1.7 cm, between the start and the evaluation number seven, respectively, for all treatments (Table 2). During the study time (time factor), and as expected, the SL showed a significant growth ($p < 0.001$) (Table 1). At the end of the study, T2 presented longer SL (11.2±1.9 cm), and T3 presented shorter SL (9.3±1.7 cm), while T1 was kept in intermediate ranges (Tables 1 y 2). Despite the significant differences among treatments ($p < 0.001$) (Table 1), the *Tukey test* grouped in the same homogeneous subgroup T2 and T1 ($p = 0.149$), while T1 and T3 (6.4 cm and 5.7 cm, respectively) in another subgroup, where T1 was observed to have a superior tendency ($p = 0.063$).

3.5. Leaf width

Trying the different treatments during the study time, SW presented an important growth in T2, T1 and T3 (Table 2). The results of the statistical analysis revealed differences among treatments and time ($p < 0.001$) (Table 1). In the seventh measurement, the leaves of T2 reached 14.3± 2.5 cm, T1 12.7±1.9 cm and T3 11.1±2.5 cm (Table 2). The treatment that presented wider leaves was T2, while the less width was presented in T3, and T1 was kept in intermediate ranges (Table 1).

Table 2. Morphological characteristics of okra's seedlings (NS, PL, SL, y SW) for each treatment. The values are mean ± standard error from the seven monitoring sessions conducted during the study period. Tukey test results from the Univariate General Linear Model (GLM) analysis are presented.

Variables*	T	MLG	Average of each monitoring						
		Tukey test	**1**	**2**	**3**	**4**	**5**	**6**	**7**
NS (cm)	T1	a	2.1±0.2	3.1±0.2	4.1±0.3	4.9±0.7	5.9±0.9	6.9±0.6	7.4±0.7
	T2	a	2.7±0.4	3.4±0.3	4.1±0.2	4.6±0.4	5.2±0.4	7.1±0.9	7.9±0.8
	T3	a	2.4±0.2	3.1±0.2	4.0±0.2	4.5±0.5	5.4±0.8	6.2±0.7	7.0±0.9
PL (cm)	T1	ab	1.1±0.1	1.9±0.3	2.8±0.6	4.1±0.5	6.5±1.0	7.9±1.1	8.8±1.1
	T2	ab	1.2±0.2	1.9±0.4	3.2±0.4	4.7±0.7	7.2±0.9	8.1±0.9	10.2±1.0
	T3	bc	1.1±0.1	1.9±0.3	2.4±0.3	4.0±0.7	5.6±0.9	6.6±0.9	7.6±0.9
SL (cm)	T1	ab	3.4±0.2	4.0±0.2	5.0±0.5	5.8±0.7	7.5±1.7	8.7±1.6	11.0±1.5
	T2	ab	3.5±0.2	4.2±0.2	6.5±0.7	7.3±0.6	7.6±0.7	9.0±1.2	11.2±1.9
	T3	bc	3.5±0.2	3.9±0.2	5.0±0.7	5.3±0.7	6.0±0.9	7.6±1.1	9.3±1.7
SW (cm)	T1	b	3.8±0.3	4.3±0.3	5.6±0.5	6.8±0.8	7.8±1.1	9.7±1.3	12.7±1.9
	T2	a	3.7±0.2	4.8±0.3	7.2±0.8	8.5±0.7	8.9±0.9	10.7±1.9	14.3±2.5
	T3	b	3.7±0.2	4.3±0.4	6.1±0.9	6.3±0.9	6.7±0.9	9.2±1.5	11.1±2.5

* NS = Number of effective leaves; PL = Petiole length; SL = leaf length; SW = leaf width; Tukey test: different letters indicate statistical differences.

4. Discusion

The organic fertilizers have the capacity to improve the morphological characteristics of the plants contributing the necessary resources for the crop (Tahat et al., 2020). In this study, the use of organic fertilizer had a positive effect on the morphological behaviour of the plants, which could be observed by the differences found among the treatments in study (T1 and T2) with the control treatment (T3). The organic fertilizer improves the fertility of the soil by improving the edaphic conditions that improve the development of the root system (Calderín García et al., 2018), promoting a higher development of the root biomass of the plants in the seedling stage. This allows a better development of the plant and secured the establishment and performance of the plant in the field (Muñoz-Rengifo et al., 2020).

In the study done by Sousa et al. (2020), the plants *Abelmoschus esculentus* (L.) Moench were observed to be taller and with wider basal diameter when organic fertilizers of bovine origin were used. This result, together with the results from this research, confirm the significant impact that organic fertilizers have in the morphological development of the plants. Despite of the combination of organic fertilizers with chemical fertilizers during this study, the combination of the compost treatment with the foliar fertilizer Stimufol (T2) resulted in a higher growth rate (31.40 cm) and basal diameter (1 cm) in comparison to the other evaluated treatments (T1 and T3). These results coincide with the reported by Adekiya et al. (2019), who found that the organic amendments favored the growth of okra plants (with moringa leaves 39 cm, papaya leaves 41 cm, mesquite leaves 55 cm, neem leaves 48 cm plus fertilizer NPK 15-15-15, 33 cm) in comparison to the control treatment.

In another study, Cuata Natte and Manzaneda Delgado (2018) observed plant height of (62.5 cm) and stem diameter (3.0 cm) higher than the ones obtained in this research at 90 days. Also, Alam and Hossain (2008) reported okra heights of 70.20 cm, while Adekiya et al. (2020) got heights of 37 cm to 56 cm with different kinds of amendments at 45 days after sowing. All higher than the ones reached during this study at 85 days. These results highlight the importance in the selection and adequate combination of fertilizers to optimize growth and development of okra plants.

According to the results of morphological characteristics, such as leaf number, petiole length, leaf length, and leaf width at 80 days show an important range of variability among treatments and growth during the expected time. In other studies, variability ranges have also been found between okra genotypes (Dash & Misra, 1995; Hazra & Basu, 2000; Martin & Rhodes, 1983; Saifullah & Rabbani, 2009). In these results, the range of each of the variables reached at 80 days, for the petiole length was between 7.6 and 10.2 cm, leaf length between 9.3 and 11.2 cm, leaf width between 11.1 and 14.3 cm, and leaf number per plant between 7 and 8. These results were inferior to the ones recorded by Saifullah and Rabbani (2009), who at the end of the harvest (approximately at 135 days), got values ranging from 19.1 and 32.4 cm for petiole length, between 14.7 and 23.7 cm for leaf length, and between 16.0 and 30.1 cm for leaf width, using manure and conventional fertilization, according to the indications of Bangladesh Agricultural Research Council (BARC, 1997). On the other hand, in the study by Alam and Hossain (2008), using conventional fertilization recommended by BARC (1997), petiole length ranged between 8.4 and 19.2 cm, leaf length between 7.1 and 15.5 cm, leaf width between 10.8 and 18.0 cm, and the number of leaves per plant between 27.4 and 26.6 at 80 days.

The observed differences among the treatments were significant, but the results showed lesser values when compared to the ones obtained by other authors (Adekiya et al., 2020; Alam & Hossain, 2008; Cuata Natte & Manzaneda Delgado, 2018; Saifullah & Rabbani, 2009). According to Oliveira et al. (2014), the positive effect of the content of organic matter could be reduced when it is high, and it could be minimized when it is low (Muñoz-Rengifo et al., 2018). For example, when Díaz-Franco & Ortegón (1999) investigated the effect of different commercial fertilizers in the fruit yield of okra plants, found that foliar fertilizers applied to the soil, and in combination, did not have a significant impact on plant height and in yield, which were attributed to the lack of fertilization in the place. The foliar absorption of the fertilizers is a crucial factor, but it can be influenced by the interaction of environmental, physical-chemical factors of the fertilizers and metabolic factors of plants (Rodríguez, 1992), elements that had an effect on the okra plant response to the evaluated treatments in this study.

According to various authors (Ajimal et al., 1979; Arumuga et al., 1981; Olasantan & Salau, 2008), certain morphologic variables, such as the number of stems, fructification nodes per plant, days until the first flowering, and the first node of fructification, as wells as plant variety and the sowing density (Salau & Makinde, 2015), influence in yield. In this study, the combined treatment of compost and foliar fertilizer Stimufol showed an improved morphological state in comparison with other evaluated treatments. The fertilizer Stimufol, with its balanced composition of essential nutrients like nitrogen, phosphorous, and potassium, improves the root absorption, resulting in a higher foliar and root development (Moghazy, 2007). Besides, it provides key micronutrients such as iron, zinc and boron, fundamental for the metabolic and photosynthetic processes, increasing flower and fruit production (El-Nemr et al., 2015; Ismaeil & Youssef, 2008). On the other hand, the compost benefits plant growth because it provides organic matter that improves soil structure and water retention (Al-Dulaimi et al., 2015; Mahmoud et al., 2015). The combination of Stimufol and compost generates a synergetic effect, improving the absorption of nutrients, stimulating root and foliar growth, and increasing the production of fruits, promoting a balanced plant development and superior in our study.

However, the presence of a higher number of leaves per plant, beans and weight of these are not always translated into a higher yield (Salau & Makinde, 2015), which is important to bear in mind. It is necessary to consider that the observed results in the morphological variables of this study are significantly inferior to the ones reported in previous studies about okra crop, where the same variables were evaluated (Alam & Hossain, 2008; Gondane & Bhatia, 1995; Saifullah & Rabbani, 2009; Sousa et al., 2020). This difference is attributed to the environmental conditions of the experimental site, to the nutritional status and type of soil because these factors influence in the plant production as described by Díaz-Franco et al. (2007).

The present study was carried out in the Amazon region, characterized by dense fog that reduce the sun hours, influenced by the foothills of the Eastern Cordillera of Los Andes, at a height higher than 600 m.a.s.l and annual precipitation of approximately 4000 mm. In contrast, researchers in Bangladesh, at heights between 10 and 15 m.a.s.l, like in Alam and Hossain (2008) and Saifullah and Rabbani (2009), reported a higher number of sunlight during the study period. On the other hand, the study of Cuata Natte and Manzaneda Delgado (2018) reported a better morphological behaviour than the results from this study because the area of study was done in a fallow of 4 to 5 years, at 410 m a.s.l. These differences showed the influence of the environmental conditions in the results.

According to Alam and Hossain (2008), the coefficient of genotypic variation or phenotype on a morphological characteristic of the plant is relevant as in agreement with other studies (Dakahe et al., 2007; Lotilo, 1989; Singh et al., 1998). The importance of organic fertilizers is highlighted, although its effect could be limited by genotypic and phenotypic susceptibility in unfavorable environmental conditions, as observed in the expression of the morphological characteristics in this study, aspect to consider in future studies in the Amazon region.

5. Conclusions

The results from this research highlight the importance of using organic fertilizers as an effective strategy to promote the healthy and sustainable growth of plants. The okra crop, assimilated the synergetic effect of the combination of organic compost fertilizer complemented with foliar fertilization Stimufol (T2) in a better way, and promoted a better development of the morphological characteristics: plant height, diameter of the base of the stem, petiole length, leaf length, and leaf width, improving the quality of this treatment in comparison to the rest of treatments in this study. The organic fertilizer gallinaza complemented with the foliar fertilizer Kristalon (T1) showed intermediate results compared to the evaluated variables in okra crop. On the other hand, the lack of fertilization (Control-T3) had a negative impact in the phenological development and agronomic behaviour of the plants in comparison to the treatments containing fertilization. Although plants subjected to combined fertilization exhibited superior morphological attributes in comparison to the ones under analysed treatments in this study, they were still placed below the values obtained in regions with higher solar intensity, which is important to consider in future studies.

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Contributor roles

- Julio César Muñoz-Rengifo: conceptualization, investigation, data curation, methodology, validation, supervision, writing – review & editing.
- Jorge Luis Alba Rojas: investigation, project administration, writing – original draft, writing – review & editing.
- Jorge Freile Almeida: conceptualization, methodology, validation, writing – original draft.
- Marcos Gerardo Heredia Rengifo: conceptualization, methodology, writing – review & editing.
- Segundo Bolier Torres Navarrete: methodology, validation, writing – review & editing.

Ethical Implications

Ethics approval Not applicable.

Conflicts of interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

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