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Interacción entre el estado nutricional y el patrón de crecimiento en jamaica (*Hibiscus sabdariffa L.*) bajo diferentes niveles de fertilización

Interaction between nutritional status and growth patterns in Roselle (*Hibiscus sabdariffa* L.) under different fertilization levels.

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RESUMEN

La investigación evaluó el efecto de diferentes niveles de fertilización (nitrógeno, potasio, y calcio) en el crecimiento y absorción de nutrientes en el cultivo de jamaica (*Hibiscus sabdariffa*) en la Granja Experimental Santa Inés de la Universidad Técnica de Machala. Se implementó un diseño de bloques completamente al azar con cuatro tratamientos (0%, 100%, 150% y 200% de la dosis recomendada) y cuatro repeticiones. Se analizaron variables de crecimiento y la concentración de nutrientes en diferentes órganos de la planta mediante extracción total en laboratorio. Los resultados mostraron efectos de la fertilización, principalmente en la tercera etapa fenológica, donde la dosis del 200% maximizó parámetros como altura, diámetro del tallo y producción de botones florales. La dosis del 150% resultó más efectiva para la extracción de NO_3^- en peciolos y hojas, mientras que el 200% optimizó la extracción de NH_4^+ y K^+ en tallos y frutos. Sin embargo, dosis superiores al 100% no mostraron beneficios significativos en las primeras etapas fenológicas y, en algunos casos, redujeron la eficiencia de absorción de nutrientes. Las dosis de fertilización deben ajustarse de manera precisa para maximizar la absorción de nutrientes sin incurrir en un exceso de fertilización, lo que podría afectar negativamente la eficiencia y la sostenibilidad del cultivo.

Palabras clave: manejo nutricional; absorción de nutrientes; productividad; fertilización; extracción; eficiencia.

ABSTRACT

This study evaluated the effect of different fertilization levels (nitrogen, potassium, and calcium) on the growth and nutrient absorption of roselle (*Hibiscus sabdariffa*) at the Santa Inés Experimental Farm of the Technical University of Machala. A completely randomized block design was implemented with four treatments (0%, 100%, 150%, and 200% of the recommended dose) and four replications. Growth variables and nutrient concentrations in different plant organs were analyzed through total extraction in the laboratory. Results showed fertilization effects, mainly during the third phenological stage, where the 200% dose maximized parameters such as plant height, stem diameter, and flower bud production. The 150% dose was more effective for NO_3^- extraction in petioles and leaves, while the 200% dose optimized NH_4^+ and K^+ extraction in stems and fruits. However, doses higher than 100% showed no significant benefits during early phenological stages and, in some cases, reduced nutrient absorption efficiency. Fertilization doses must be precisely adjusted to maximize nutrient uptake without causing excessive fertilization, which could negatively affect the crop's efficiency and sustainability.

Keywords: nutritional management; nutrient absorption; productivity; fertilization; extraction; efficiency.

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INTRODUCCIÓN

Roselle (*Hibiscus Sabdariffa*), a member of the Malvaceae family, is a medicinal plant known for its therapeutic properties (Mohamed, 2021). Recognized as a nutraceutical due to its health benefits, it plays an important role in traditional medicine (Mahgoub et al., 2024; Essiedu et al., 2022). Its genetic diversity and adaptability to warm climates allow its cultivation in various tropical and subtropical regions (Koley et al., 2024; Meftahizadeh et al., 2022), including countries like Brazil, India, Saudi Arabia, as well as Southeast Asian nations such as Malaysia, Indonesia, Thailand, the Philippines, and Vietnam, and African territories like Sudan and Egypt, in addition to Mexico (Mendonça et al., 2024).

Hibiscus sabdariffa has a high rate of soil nutrient absorption, requiring optimized fertilization protocols to enhance agronomic performance (Mwasiagi & Phologolo, 2021; Pérez et al., 2023). Research indicates that mineral nutrition systems must be based on the integration of the physical-chemical analysis of the substrate and the diagnosis of the plant material's nutritional status (Pérez-Díaz et al., 2023).

The development and growth of roselle are linked to the agronomic practices implemented throughout its life cycle (Caballero et al., 2024). Among these practices, fertilization plays a key role by supplying the essential mineral nutrients the plant needs for growth and productivity (Latorre et al., 2024). Proper fertilization not only ensures better yields but also contributes to the sustainability of the agricultural system in which the crop is produced (Abou-Sreea et al., 2021).

In Ecuador, there is a significant lack of data on the specific nutritional requirements of roselle, which limits the optimization of agricultural production systems. This lack of information restricts farmers' ability to make precise adjustments to fertilization doses, potentially resulting in nutrient deficiencies or excesses, affecting both crop productivity and the economic and environmental sustainability of production systems across different regions of Ecuador.

METHODOLOGY

Location and characterization of the study area

This study was conducted at the "Santa Inés" experimental farm of the Faculty of Agricultural Sciences of the Technical University of Machala, located in El Oro province, Machala canton, at Km 5½ on the Machala-Pasaje road, situated at latitude 3°17'37.98'' S and longitude 79°54'48.43'' W, at an altitude of 6 meters above sea level.

Experimental design

A Completely Randomized Block Design (CRBD) was used, with four treatments and four replications, for a total of 16 experimental units. Each unit consisted of four plants, totaling 64 plants for the experiment. Treatments were defined as follows: Treatment 1 was the unfertilized control (SF); Treatment 2, full fertilization (F. 100%); Treatment 3, 50% more than the recommended dose (F. 150%); and Treatment 4, 100% more than the recommended dose (F. 200%).

Planting material

Seeds were sourced from Tena canton, Napo, north-central Amazon of Ecuador. The variety used was "African," known for its favorable characteristics and adaptability in the country. Inert sand was used as a substrate to avoid interference from soil nutrients in the fertilization treatments.

Fertilization management

A nutrient balance was performed for the fertilizers used: urea (46% N), potassium muriate (60% K2O), DAP (46% P2O5), agricultural gypsum (24.64% CaO), and magnesium sulfate (20% MgO). Based on roselle's nutritional demands, fertilizer balances were calculated for the increasing dose levels (F.100%, F.150%, F.200%). The fertilization schedule was based on the balance, planting distance, and the crop's phenological stages. First stage, 50% of the fertilizer was applied; Second and third stages, 30% and 20%, respectively (Table 1).

Table 1
Fertilization schedule for the Jamaica crop (*Hibiscus Sabdariffa*) trial under different doses

Treatments	Fertilizer	Dose (ha^{-1})	Dose ($plant^{-1}$)	Stage		
				1	2	3
T1	Absolute control with no fertilizer application					
T2	Urea	425	35.4	283.33	170.0	113.33
	DAP	130.43	10.9	86.95	52.17	34.78
	MOP	175	14.6	116.67	70.00	46.67
	$CaSO_4$	211.04	17.6	140.69	84.42	56.28
	$MgSO_4$	130	10.8	86.67	52.00	34.67
T3	Urea	637.50	53.12	425	255	170.
	DAP	195.64	16.30	130.43	78.26	52.17
	MOP	262.50	21.87	175	105	70
	$CaSO_4$	316.56	26.38	211.04	126.6	84.42
	$MgSO_4$	195	16.25	130	78	52
T4	Urea	850	70.83	566.67	340	226.67
	DAP	260.86	21.74	173.91	104.3	69.56
	MOP	350	29.17	233.33	140	93.33
	$CaSO_4$	422.08	35.17	281.39	168.8	112.55
	$MgSO_4$	260	21.67	173.33	104	69.33

DAP, MOP: Diammonium phosphate (DAP); Muriate of potash (MOP).

Statistical analysis

Before statistical analysis, the date obtained was verified to assess assumptions and determine whether to use parametric or non-parametric statistics. Analysis of variance was conducted to identify significant differences among treatments and measured variables. When significant differences were found, means were compared using Tukey's test. The statistical analysis was performed using the AgroEstat software.

RESULTS AND DISCUSSION

Total nutrient extraction

Nutrient extraction in roselle leaf tissue under different fertilization levels was complex (Figure 1). The 100% dose resulted in the highest extraction of NO_3^-, NH_4^+, and K^+, while higher doses (150% and 200%) showed reduced extraction. Ca^{++} was an exception, peaking at the 150% dose. These results suggest that increasing fertilization beyond 100% may not be beneficial and could signal a saturation point or negative effects due to over-fertilization (Gibson & Waring, 1994). The importance of finding an optimal fertilization balance to maximize nutrient uptake efficiency in roselle cultivation has been emphasized (Okebalama & Marschner, 2023).

In stems, nutrient extraction patterns varied (Figure 2). For NO_3^-, all fertilization treatments (100%, 150%, and 200%) significantly exceeded the control. NH_4^+ extraction was highest with 100% and 200%, while 150% showed a drop. K^+ and Ca^{++} extraction peaked at 200%, though Ca^{++} did not significantly differ from the control or 100%. The 150% dose had the lowest K^+ and Ca^{++} extraction. The F.150% treatment showed the lowest extraction for K^+ and Ca^{++}. These data suggest that the stem's response to fertilization is complex and not always linear, with the F.200% dose generally producing the best results, except for NH4+, where F.100% was equally effective.

The variability in responses highlights the importance of considering each nutrient individually when determining optimal fertilization strategies for roselle cultivation (Al-Baik & Alamery, 2024).

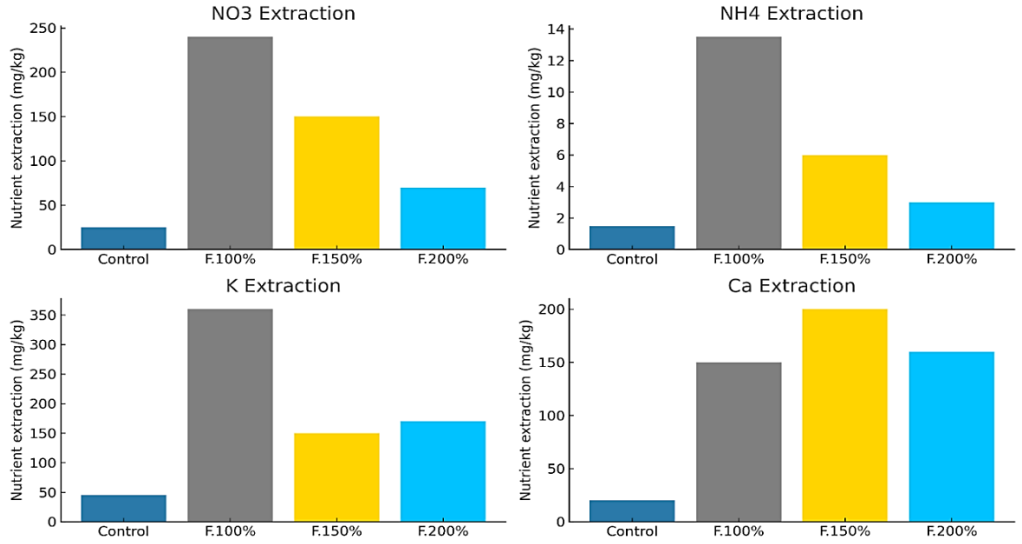

Figure 1. Total nutrient extraction in leaf tissue. Stage 3.

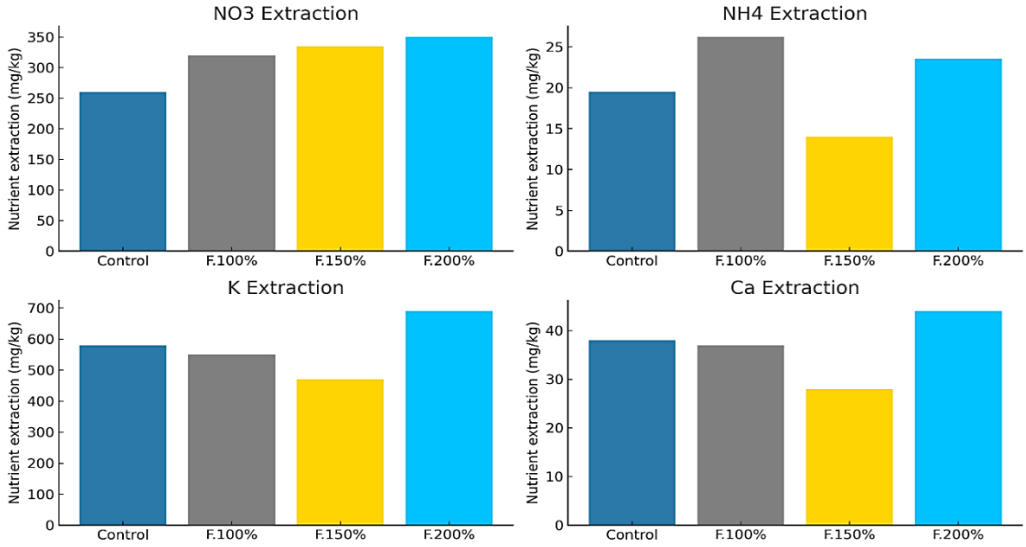

Figure 2. Total nutrient extraction in stem tissue. Stage 3.

The nutrient extraction levels in the petiole show that for NO_3^-, the F.150% dose has the highest extraction, while for NH_4^+, a progressive increase is observed with the dose, reaching its maximum at F.200%. Figure 3 also shows that for K^+, both F.150% and F.200% result in significantly higher extractions. These results indicate that the petiole's response to fertilization is nutrient-specific, suggesting that there is no single optimal dose for all nutrients. The F.150% dose appears to be an important inflection point, showing positive effects for all the nutrients analyzed, while F.200% shows additional benefits for NH_4^+ and K^+. This variability highlights the importance of considering each nutrient individually when determining fertilization strategies to optimize the nutrition of the Jamaica crop, emphasizing the importance of these nutrients in the vegetative development of the crop (Baigts-Allende et al., 2023). Total nutrient extraction in the fruit during the final stage of the crop shows that 200% fertilization maximizes NO_3^- extraction, while 100% fertilization is more effective for the extraction of NH_4^+, K^+, and Ca^{++}, as shown in Figure 4. This result is consistent with the findings of Deng et al. (2023), who observed that different types of potassium fertilizers significantly improve nutrient absorption in grape crops, suggesting that effective potassium application in Hibiscus sabdariffa could result in similar absorption patterns. The high coefficients of variation (CV%) indicate notable variability in the data. In contrast, the studies by Khalofah et al. (2024) and Alam et al. (2016) suggest that excessive fertilization, particularly with nitrogen, can reduce fruit quality due to nutritional imbalances and physiological stress in Hibiscus plants. This imbalance can affect the absorption of essential nutrients (Rashki & Khamari, 2022) and overall plant productivity (Rashki & Khamari, 2022). Additionally, water stress in Hibiscus further affects morphological characteristics (Besharati et al., 2022).

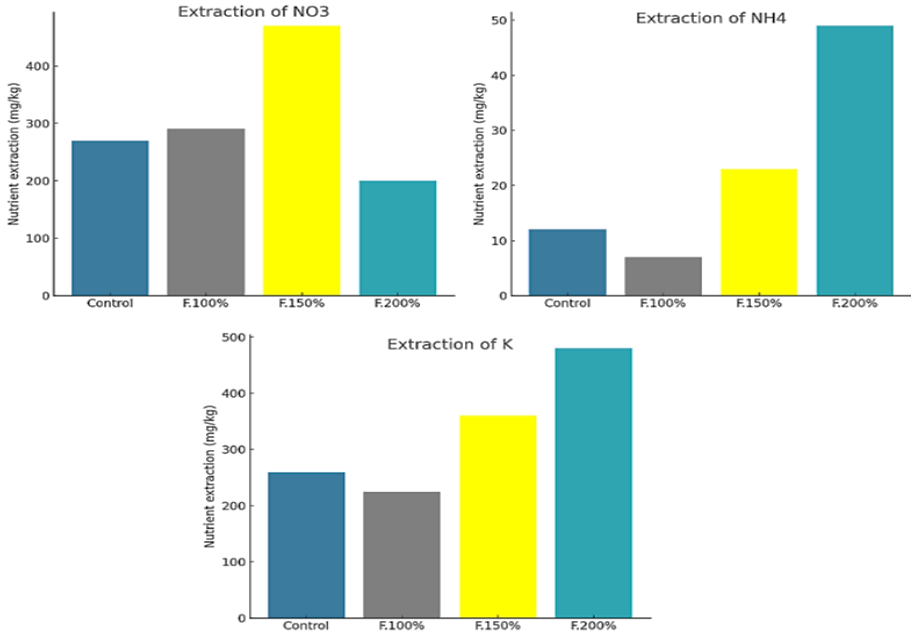

Figure 3. Total nutrient extraction in petioles. Stage 3.

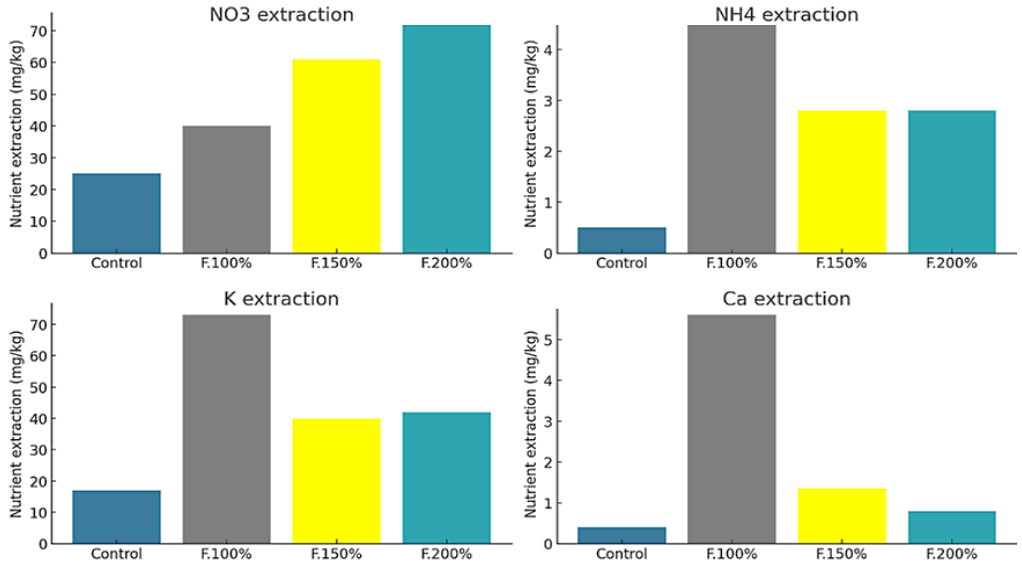

Figure 4. Total nutrient extraction in fruit. Stage 3.

Biometric data

In the first phenological stage, the data showed that fertilization at levels of F.100%, F.150%, and F.200% had a significant impact during the first month of cultivation. The fertilized treatments presented statistically significant improvements compared to the control in all evaluated parameters: plant height, stem diameter, number of leaves, and chlorophyll intensity. These differences are highly significant ($p < 0.01$), and the relatively low coefficients of variation indicate good precision in the data. However, it is noteworthy that no significant differences were observed between the different fertilization levels during this initial phenological stage, suggesting that applying doses above the recommended 100% may not be necessary, as no additional significant benefits were observed under the conditions of this study. More detailed data are presented in Table 2. These results are consistent with previous research on crop nutrition and growth. Owen (2019) reported that roselle plants showed optimal growth with fertilizer concentrations ranging from 100 – 300 mg L^{-1} of nitrogen.

In the second phenological stage, the data obtained showed that fertilization at levels of F.100%, F.150%, and F.200% significantly improved all the evaluated parameters. The fertilization treatments showed significant improvements compared to the control: plant height, stem diameter, number of leaves, and chlorophyll intensity (Table 3). These differences are highly significant ($p < 0.01$), and the low coefficients of variation indicate a clear improvement in growth and development. However, in this second phenological stage, no significant differences were observed between the different fertilization levels, suggesting that it may not be necessary to apply doses higher than 100% of the recommended amount, as no significant additional benefits were observed with higher doses under the conditions of this study.

The chlorophyll intensity peaked at the 100% dose, in line with Jin et al. (2023), who observed significant improvements in the quality and growth of Jamaica flower (Hibiscus Sabdariffa) with optimal fertilization, including a 27.5% increase in chlorophyll content compared to the control.

In the third phenological stage, the data showed that fertilization at levels of F.100%, F.150%, and F.200% significantly improved plant growth in all the evaluated parameters. The F.200% treatment consistently produced the highest values in plant height, stem diameter, number of leaves, chlorophyll intensity, and number of flower buds, significantly surpassing the control and, in most cases, the F.100% and F.150% treatments. The latter showed intermediate values, generally similar to each other and higher than the control (Table 4). The differences are highly significant ($p < 0.01$), and the low coefficients of variation indicate a clear improvement trend with increasing fertilization. In this final phenological stage, it can be observed that Jamaica responds favorably to fertilization levels higher than the standard, showing a growth pattern that intensifies with increasing nutritional doses (Esmaeilian et al., 2024). In the results of the third phenological stage, we can observe that the plant height reached its maximum with the 200% dose (92.50 cm), which is consistent with the findings of Batool et al. (2020) & Abdou et al. (2022), who found that high fertilization doses significantly improved plant height growth under water stress conditions.

Table 2

Biometric data for the first phenological stage of roselle under increasing fertilization levels (100%, 150%, 200%)

Level fertilizer	Plant height (cm)	Stem diameter (cm)	Number of leaves	chlorophyll intensity
Control	14.25 **b**	1.07 **b**	8.75 b	14.44 **b**
F.100%	28.50 **a**	2.20 **a**	35.00 **a**	46.73 **a**
F.150%	27.75 **a**	1.86 **a**	32.00 **a**	41.55 **a**
F.200%	29.00 **a**	1.81 **a**	35.50 **a**	39.78 **a**
F-test	11.62**	10.07**	66.62**	16.48**
CV %	16.75%	17.17%	11.27%	19.95%

NS, *, ** = (NS) no significance, (*) 95% significance level, (**) 99% significance level.

Table 3

Biometric data for the second phenological stage of roselle under increasing fertilization levels (100%, 150%, 200%)

Level fertilizer	Plant height (cm)	Stem diameter (cm)	Number of leaves	Chlorophyll intensity
Control	40.10 **b**	1.90 **b**	8.50 **b**	29.00 **b**
F.100%	76.40 **a**	3.60 **a**	48.00 **a**	103.00 **a**
F.150%	76.92 **a**	3.32 **a**	47.00 **a**	85.50 **a**
F.200%	77.32 **a**	3.82 **a**	58.00 **a**	83.75 **a**
F-test	22.02**	19.68**	75.11**	33.55**
CV %	11.5%	12.34%	12.47%	14.70%

NS, *, ** = (NS) no significance, (*) 95% significance level, (**) 99% significance level.

Table 4

Biometric data for the third phenological stage of roselle under increasing fertilization levels (100%, 150%, 200%)

Level fertilizer	Plant height (cm)	Stem diameter (cm)	Number of leaves	Chlorophyll intensity	number of flower buds
Control	60.45 **b**	2.22 **b**	9.15 **c**	15.77 **c**	3.47 **c**
F.100%	82.95 **ab**	3.65 **a**	42.62 b	43.75 **b**	21.52 **b**
F.150%	89.75 **a**	3.50 **ab**	63.35 b	47.97 **ab**	24.55 **b**
F.200%	92.50 **a**	4.67 **a**	105.50 **a**	54,07 **a**	45.82 **a**
F-test	5.50**	10.21**	48.20**	146.49**	62.68**
CV %	15.22%	17.89%	21.04%	6.93%	18.39%

NS, *, ** = (NS) no significance, (*) 95% significance level , (**) 99% significance level.

CONCLUSIONS

The study on the nutritional status of the Roselle crop showed that fertilization significantly impacts nutrient absorption, especially in the third development stage. Considering that the recommended dose is 100% fertilization in Kg Ha^{-1} (425 Urea; 130.43 DAP; 175 MOP; 211.04 $CaSO_4$; 130 $MgSO_4$), the 150% dose optimized the extraction of NO_3^- in leaves and petioles, while the 200% dose maximized the extraction of NH4+ and K+ in stems and fruits. However, the research determines that the optimal dose corresponds to 100% of the recommendation, as higher levels do not show proportional improvements in total nutrient extraction. These results demonstrate the importance of maintaining balanced fertilization management, as excessive doses can cause nutritional imbalances and reduce absorption efficiency, compromising the sustainability of the crop.

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