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SCIENTIFIC ARTICLE

Effect of fertilizer doses and sources on the yield and profitability of the cassava cultivar INIAP P-652 "La Rendidora"

Efecto de dosis y fuentes fertilizantes en el rendimiento y rentabilidad del cultivar de yuca INIAP P-652 "La Rendidora"

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ABSTRACT

Fertilization is fundamental for efficient root formation and high yield in cassava. The objective of this study was to evaluate the effect of fertilizer doses and sources on the yield and profitability of the cassava cultivar INIAP P-652 "La Rendidora" in Ecuador. Factorial treatments of two fertilizer sources (chemically blended compound fertilizer – CBCF and bulk physically blended fertilizer – BPBF) and three fertilization doses (200, 400, and 600 kg ha^{-1}), plus a control treatment, were evaluated using a randomized complete block design in an A × B + N arrangement. The main variables recorded were root yield (RY), agronomic efficiency of fertilization (AEF), and economic profitability (EP). The results showed that RY was significantly affected ($p < 0.05$) by the fertilization treatments compared with the control. The CBCF produced the highest RY, with an average increase of 11.22 and 42.95% over the BPBF and the control treatment, respectively. No significant differences ($p > 0.05$) were detected among doses for RY; therefore, 200 kg ha^{-1} may be the most convenient dose. The AEF was significantly higher ($p < 0.05$) with CBCF than with BPBF. The 200 kg ha^{-1} dose achieved an AEF significantly higher ($p < 0.05$) than the 400 and 600 kg ha^{-1} doses. Finally, fertilization with CBCF at a dose of 200 kg ha^{-1} was the most economically viable alternative, with an average EP of 1.41 dollars per dollar invested and an average net economic benefit of 2,651.5 USD ha^{-1}.

Keywords: *Manihot esculenta* Crantz, Economic benefit, Fertilization, Productivity.

RESUMEN

La fertilización es fundamental para una eficiente formación de raíces y alto rendimiento en yuca. El objetivo del trabajo fue evaluar el efecto de dosis y fuentes fertilizantes en el rendimiento y rentabilidad del cultivar de yuca INIAP P-652 "La Rendidora" en Ecuador. Se evaluaron tratamientos factoriales de dos fuentes fertilizantes (fertilizante complejo de mezcla química - FCMQ y fertilizante de mezcla física al granel - FMFG) y tres dosis de fertilización (200, 400 y 600 kg ha^{-1}) más un tratamiento control, utilizando un diseño de bloques completos al azar en arreglo A × B + N. Las principales variables registradas fueron rendimiento de raíces (RR), eficiencia agronómica de la fertilización (EAF) y rentabilidad económica (RE). Los resultados evidenciaron que el RR fue afectado significativamente ($p<0,05$) por los tratamientos de fertilización con respecto al tratamiento control. El FCMQ produjo el mayor RR, con un incremento promedio del 11,22 y 42,95% sobre FMFG y el tratamiento control. No se detectaron diferencias significativas ($p>0,05$) entre dosis para el RR, por lo que 200 kg ha^{-1} puede ser la dosis más conveniente. La EAF fue significativamente mayor ($p<0,05$) con FCMQ frente al FMFG. La dosis de 200 kg ha^{-1}, alcanzó una EAF significativamente superior ($p<0,05$) a 400 y 600 kg ha^{-1}. Finalmente, la fertilización con FCMQ y una dosis de 200 kg ha^{-1} fue la alternativa económica más viable, con una RE promedio de 1,41 dólares por cada dólar invertido y un beneficio económico neto promedio de 2.651,5 USD ha^{-1}

Palabras clave: *Manihot esculenta* Crantz, Beneficio económico, Fertilización, Productividad.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is the second most important starch-producing crop in the tropics after maize and constitutes an essential source of food and income for more than 800 million people in Africa, Asia, and Latin America (Borku, Tora, & Masha, 2025). In Ecuador, its economic and social importance lies in its broad adaptation to different agroecological conditions and in its contribution to food security, particularly in the provinces of Manabí, Los Ríos, and Guayas, where most of the production is concentrated (Paredes et al., 2022).

Among the main advantages of this crop are its tolerance to drought, low-fertility soils, and high temperatures—traits that give it strategic relevance in the face of climate change (Howeler, 2017). In Ecuador, where a substantial proportion of the agricultural area is constrained by seasonal drought, cassava represents a productive alternative for strengthening food security and the livelihoods of rural communities (Castro-Landín, Navarro-Salto, Pardo-Reyes, & Gras-Rodríguez, 2025).

Despite its importance, national productivity remains low. The average yield is only 5.16 t ha^{-1} (Instituto Nacional de Estadística y Censo, 2025), a value significantly lower than the averages for South America (12.8 t ha^{-1}) and Asia (21.9 t ha^{-1}), where the yield potential of improved varieties can exceed 25 t ha^{-1} under adequate management conditions (Ferguson, Shah, & Kulakow, 2019; Cobeña Ruiz et al., 2020; Paredes et al., 2022). This productivity gap is associated with multiple factors, including the predominant use of traditional varieties with low genetic potential, the limited adoption of fertilization practices, and the scarce use of soil analysis for crop nutritional planning (Corozo et al., 2020; INEC, 2025).

Edaphic constraints also contribute to this problem. In the main production systems of Manabí, low contents of organic matter, nitrogen, sulfur, zinc, and boron are frequent, as well as imbalances in cationic bases—conditions that, together with the limited availability of irrigation, reduce the yield potential of the crop (Motato & Pincay, 2015; INEC, 2025). Consequently, fertilization is a fundamental practice for improving the yield and profitability of cassava, as it allows the replenishment of nutrients removed by harvests and optimizes the use of soil resources (Cadavid, 2011; Ezui et al., 2016; Howeler, 2017). Several studies have shown that adequate fertilization plans make it possible to attain yields exceeding 20 t ha^{-1} (Chua et al., 2020; Mulualem, Neim, & Getachew, 2021; Pimentel et al., 2021; Konan, Kouassi, Kouamé, & Bonny, 2024).

Producers commonly use simple fertilizers such as urea, diammonium phosphate, and muriate of potash (Ministerio de Agricultura y Ganadería, 2024); however, cassava requires a balanced supply of macro- and micronutrients to fully express its yield potential (Ezui et al., 2016; Howeler, 2017). In this context, compound fertilizers, particularly chemically blended compound fertilizers (CBCF), could offer advantages over bulk physically blended fertilizers (BPBF), owing to a more uniform distribution of nutrients within each granule and a more homogeneous release in the soil (Finch, Samuel, & Lane, 2014; Hasler, Bröring, Omta, & Olfs, 2015; Li et al., 2022). Recent studies have reported higher yields with compound fertilizers compared with bulk physical blends (Li et al., 2022; Pierre & Regmi, 2026). Nevertheless, there is little information on the response of cassava to these fertilizer sources under Ecuadorian conditions. Therefore, the present study aimed to evaluate the effect of different fertilizer doses and sources on the yield and profitability of the cassava cultivar INIAP P-652 "La Rendidora."

MATERIALS AND METHODS

Location

The study was carried out during the 2023 and 2024 seasons at the experimental campus of the Escuela Superior Politécnica Agropecuaria de Manabí Manuel Félix López, located in the Carrizal River valley, Bolívar canton, Manabí province, Ecuador, at an altitude of 15 m and geographically between the coordinates 00°49′23″ South latitude, 80°11′01″ West longitude.

Soil and climatic conditions

The climatic characteristics of the experimental site were as follows: mean annual temperature of 26.1 °C, annual precipitation of 1,003.80 mm, relative humidity of 83%, and 1,084.4 hours of sunshine. The ombrothermic diagram of the study area from January to June of 2023 and 2024 is presented in Figure 1.

The soil of the experimental site is classified within the Fluvisol group, according to Vera et al. (2019). The soil characteristics, based on the analysis performed at a depth of 0.20 m prior to the start of the experiment, were as follows: clay-loam texture (32% sand, 34% silt, and 34% clay), pH of 7.1, and an organic matter (OM) content of 2.8%. The nutrient concentrations were N-NH_4^+ (22 mg kg^{-1}), P (51 mg kg^{-1}), K (315 mg kg^{-1}), Ca (1,048 mg kg^{-1}), Mg (380 mg kg^{-1}), S (14.1 mg kg^{-1}), Zn (2.1 mg kg^{-1}), Cu (3.5 mg kg^{-1}), Fe (31 mg kg^{-1}), Mn (14 mg kg^{-1}), and B (0.47 mg kg^{-1}). The extractant used to determine N, P, K, Ca, Mg, Cu, Fe, Mn, and Zn was modified Olsen, whereas for B and S it was monobasic calcium phosphate. The methods used were colorimetry for N, P, and B; atomic absorption for K, Ca, Mg, Cu, Fe, Mn, and Zn; turbidimetry for S; soil:water ratio (1:2.5) for pH; and Walkley-Black titration for organic matter.

Plant material

The cassava variety P-652 "La Rendidora" was used as planting material; it was released by the Portoviejo Experimental Station of the National Institute of Agricultural Research (INIAP). It exhibits good sensory characteristics such as sweet flavor and a firm, soft texture, and it also has potential for agro-industry owing to its high dry matter content (36%). For these reasons, it is considered a dual-purpose variety, suitable both for fresh consumption (7 to 8 months after planting) and for starch production at 12 months after planting, with an average conversion of 5.5 to 6.0 kg of fresh roots to obtain 1.0 kg of starch. It has a

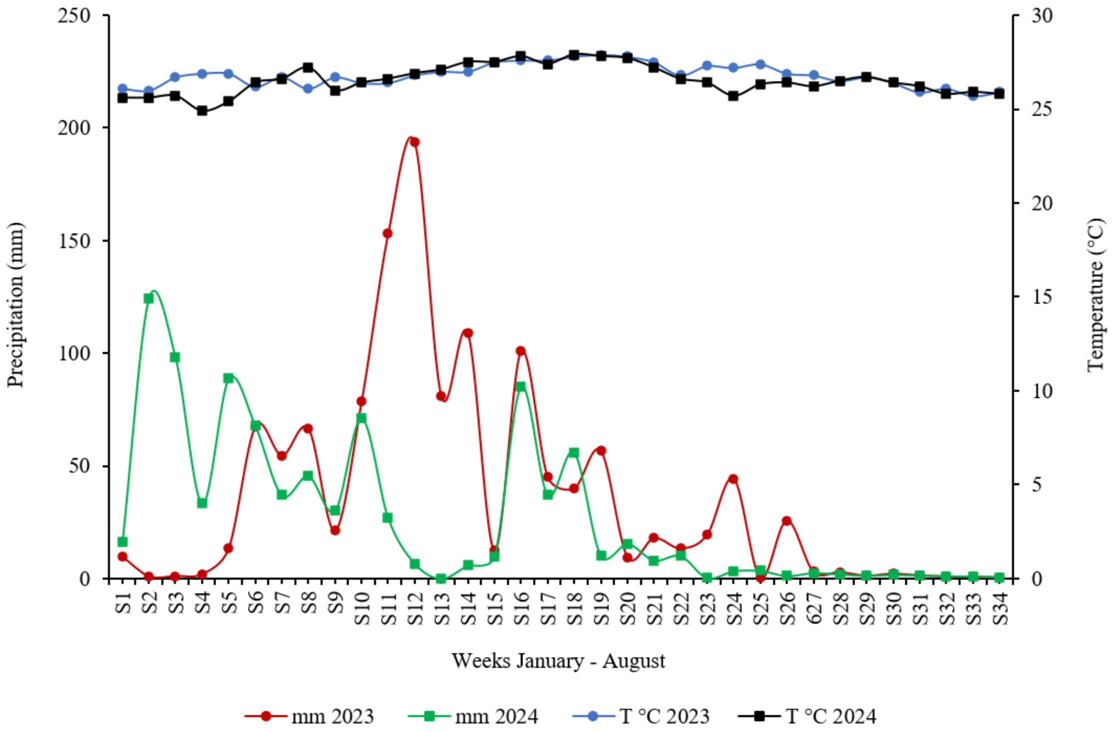

Figure 1. Ombrothermic diagram of the cropping seasons from January to August of 2023 and 2024. Bolívar, Manabí, Ecuador. The weekly mean temperature and total precipitation data were obtained from the meteorological station of the National Institute of Meteorology and Hydrology (INAMHI) installed in the study area.

yield potential greater than 20 t ha^{-1} and tolerance to the main phytosanitary problems (Cobeña Ruiz et al., 2020).

Experimental design and treatments

Factorial treatments of two fertilizer sources (chemically blended compound fertilizer – CBCF and bulk physically blended fertilizer – BPBF) and three doses (200, 400, and 600 kg ha^{-1}) were evaluated, plus a fertilization-omission treatment (control). In both cases, commercial fertilizers with the same nutritional composition were used (15% N, 5% P_2O_5, 20% K_2O, 10% S, 4% MgO, 0.02% Zn, and 0.02% B).

A randomized complete block design was used, with an A × B + 1 factorial arrangement, comprising seven treatments, three replicates, and 21 experimental units. The experimental unit consisted of 5 × 8 m plots (40 m^2). Plants were established at a spacing of 1.0 m between rows and 1.2 m between plants, with 54 plants per plot, of which 26 were border effect and 28 made up the useful plot. The stem cuttings used as seed consisted of five nodes and came from a 12-month-old plantation.

Agronomic management

Planting was carried out at the onset of the rainy season (January), with the stem cuttings previously disinfected by immersing them for five minutes in a solution composed of the insecticide Malathion 57 at a dose of 2 mL L^{-1} of water plus the fungicide Vitavax 300 at a dose of 5 g L^{-1} of water. Pre-emergence weed control was carried out with the herbicide mixture alachlor 2.5 L ha^{-1} + diuron 0.6 kg ha^{-1}, complemented by post-emergence control with ammonium glufosinate at a dose of 1.5 L ha^{-1}. During the experiment, root damage caused by *Phyllophaga* sp. occurred, making it necessary to apply control measures at 30 and 45 days after planting. Control was carried out with the insecticide chlorpyrifos at a dose of 5 mL L^{-1} of water, applied in combination with a biostimulant based on carboxylic, humic, and fulvic acids, amino acids, phosphorus, and zinc, at a dose of 5 mL L^{-1} of water, in order to stimulate new roots. This application was directed to the soil as a surface drench.

At 120 and 150 days after planting, the acaricide hexythiazox was applied at a dose of 0.5 mL L^{-1} of water to control infestation by the phytophagous mite complex *Mononychellus* sp., *Tetranychus* sp., and *Oligonychus* sp. Fertilization was applied in a surface band and was split into three applications carried out at the beginning (January), middle (March), and end (May) of the rainy season. In addition, with each fertilization, a foliar application of a biostimulant based on 99.58% pure *Ascophyllum nodosum* seaweed extract was carried out at a dose of 1 L ha^{-1} + 0.5 kg ha^{-1} of a fertilizer product based on titanium (0.3%), boron (2%), iron (4%), manganese (2%), zinc (5%), magnesium (2%), copper (0.5%), molybdenum (0.1%), and cobalt (0.1%).

Evaluated variables

Data were recorded at harvest, which was carried out eight months after planting. The number of commercial and reject roots per plant was recorded; for this purpose, five plants were randomly selected from the center of the experimental unit, where roots with a minimum length and diameter of 15 cm and 8 cm, respectively, were counted as commercial. This is based on a commercial criterion established by the local market for fresh cassava consumption. The remaining roots, with smaller dimensions and unfavorable characteristics such as constrictions and damage from pests and diseases, were considered rejects.

The weight of commercial and reject roots was determined in kg for each evaluated plant, using a TMA-model electronic balance with a precision of 5 g. The commercial root yield (t ha-¹) was estimated from the weight of commercial roots of each experimental unit.

The agronomic efficiency of fertilization – AEF (kg of roots kg-¹ of applied fertilizer) was estimated using equation proposed by Senkoro et al. (2018).

$$AEF = \frac{\text{Yield with fertilization (kg ha}^{-1}) - \text{Yield without fertilization (kg ha}^{-1})}{\text{Dose of applied fertilizer (kg ha}^{-1})}$$

Statistical analysis

Prior to data analysis, the homogeneity of variance was examined with Bartlett's test and the normality of the dataset with the Shapiro-Wilk test. Once compliance with the assumptions was verified, a two-way analysis of variance (ANOVA) was performed, in which the main effects of fertilizer sources and doses and their respective interaction were analyzed. Mean separation was carried out with Tukey's test ($p \leq 0.05$). In addition, the comparison of the effect of fertilization versus the unfertilized treatment was analyzed by orthogonal contrasts. Data analysis was performed using the InfoStat professional software, version 2020.

Economic analysis

The economic analysis of the treatments was estimated using the algebraic expressions applied by Ayvar-Serna et al. (2020), where the total cost (TC) is estimated by adding the fixed costs (FC) plus the variable costs (VC) (TC = FC + VC). The fixed costs were derived from all crop management operations that were not influenced by the fertilization treatments (land preparation, planting, and phytosanitary management). In contrast, the variable costs were derived from the expenses influenced by the fertilization treatments (fertilizers, fertilizer application, and harvesting labor). To quantify the total income (TI), the income obtained from the sale of fresh roots was calculated using the formula: TI = SP × YLD, where SP is the sale price (USD $ kg-¹ of roots) and YLD is the yield of fresh roots per hectare (kg ha-¹). The net income (NI) is the result of subtracting the total cost from the total income (NI = TI − TC). The profit per dollar invested (PDI) was obtained by dividing the net income by the total costs (PDI = NI/TC). The net economic benefit of fertilization (NEBF) was estimated by subtracting the net income of the control treatment (NIC) from the net income of the fertilization treatments (NIT).

RESULTS AND DISCUSSION

The main effect of the fertilizer source had a significant influence ($p < 0.05$) on most of the variables evaluated in both planting seasons (2023–2024), except for reject roots and reject root weight, which were not significantly affected ($p > 0.05$). The main effect of the fertilization doses, in turn, had a significant influence ($p < 0.05$) only on the agronomic efficiency of fertilization in both evaluated seasons (2023–2024), whereas the opposite occurred for the remaining variables. The source × dose interaction was not significant ($p > 0.05$) for any of the analyzed variables,

Table 1. Results of the analysis of variance (ANOVA) for the main effects (fertilizer sources and fertilization doses), the source × dose interaction, and the orthogonal contrast between fertilization treatments vs. control.

Variables	Fertilizers (F)	Doses (D)	F x D	Treatments vs. control	C.V. %
Year 2023					
Commercial roots per plant	0,0001***	0,7140NS	0,9472NS	0,0001***	5,38
Reject roots per plant	0,9945NS	0,8931NS	0,0762NS	0,0005***	13,37
Commercial root weight (kg)	0,0053**	0,2739NS	0,7058NS	0,0001***	8,04
Reject root weight (kg)	0,4129NS	0,6013NS	0,1269NS	0,0001***	14,12
Yield (t ha-¹)	0,0052**	0,2725NS	0,7080NS	0,0001***	8,02
Agronomic efficiency of fertilization (kg kg-¹)	0,0090**	0,0001***	0,5012NS	-----	11,15
Year 2024					
Commercial roots per plant	0,0001***	0,3231NS	0,1462NS	0,0001***	3,99
Reject roots per plant	0,5877NS	0,1205NS	0,1851NS	0,0001***	12,14
Commercial root weight (kg)	0,0021**	0,1950NS	0,7603NS	0,0001***	3,10
Reject root weight (kg)	0,0525NS	0,0530NS	0,7800NS	0,0001***	8,06
Yield (t ha-¹)	0,0021**	0,1888NS	0,7525NS	0,0001***	3,09
Agronomic efficiency of fertilization (kg kg-¹)	0,0036**	0,0001***	0,2194NS	-----	10,56

C.V. = coefficient of variation; * Significant at $p < 0.05$; ** Significant at $p < 0.01$; *** Significant at $p < 0.001$; NS: Not significant, $p > 0.05$.

which indicates the independence of the effects of each factor (Table 1). Furthermore, the orthogonal comparison between the mean of the fertilization treatments and the mean of the control treatment was statistically significant ($p < 0.05$), which denotes that fertilization is a determining factor affecting the yield components of cassava, regardless of the fertilizer and doses evaluated (Table 1).

Fertilization with CBCF produced a greater increase in commercial roots in 2023 (+16.33%) and 2024 (+11.32%) relative to fertilization with BPBF. With respect to the control treatment, fertilization with CBCF achieved an increase in commercial roots of 30.10 and 35.66% in 2023 and 2024, respectively (Table 2). A similar situation occurred for commercial root weight, where fertilization with CBCF produced an increase of 0.79 and 0.48 kg plant^{-1} relative to BPBF in 2023 and 2024, respectively. With respect to the unfertilized control treatment, CBCF caused an increase of 2.74 and 2.84 kg plant^{-1} in root weight for the 2023 and 2024 seasons, respectively (Table 2).

Table 2. Comparative effect among chemically blended compound fertilizers (CBCF), bulk physically blended fertilizers (BPBF), and the control treatment on the yield components of cassava INIAP P-652.

Fertilizer sources	Commercial roots per plant	Reject roots per plant	Commercial root weight (kg plant^{-1})	Reject root weight (kg plant^{-1})
		Year 2023		
CBCF	9,37 a[1/]	2,81 a	6,29 a	0,44 a
BPBF	7,84 b	2,82 a	5,50 b	0,46 a
Control	6,55 c	3,94 b	3,55 c	0,89 b
		Year 2024		
CBCF	10,60 a	3,06 a	8,20 a	0,74 a
BPBF	9,40 b	2,97 a	7,72 b	0,76 a
Control	6,82 c	5,41 b	5,36 c	1,86 b

[1] Means within columns with different letters differ significantly according to Tukey›s test ($p \leq 0.05$). CBCF = chemically blended compound fertilizer; BPBF = bulk physically blended fertilizer.

Table 3. Comparative effect among fertilization doses and the control treatment on the yield components of cassava INIAP P-652.

Fertilization dose	Commercial roots per plan	Reject roots per plant	Commercial root weight (kg plant^{-1})	Reject root weight (kg plant^{-1})
		Year 2023		
200 kg ha^{-1}	8,52 a[1/]	2,76 a	5,63 a	0,43 a
400 kg ha^{-1}	8,73 a	2,86 a	6,01 a	0,46 a
600 kg ha^{-1}	8,56 a	2,79 a	6,06 a	0,47 a
Control	6,55 b	3,94 b	3,55 b	0,89 b
		Year 2024		
200 kg ha^{-1}	9,79 a	2,75 a	7,92 a	0,77 a
400 kg ha^{-1}	10,09 a	3,23 a	8,11 a	0,75 a
600 kg ha^{-1}	10,12 a	3,07 a	7,84 a	0,74 a
Control	6,82 b	5,41 b	5,36 b	1,86 b

[1] Means within columns with different letters differ significantly according to Tukey›s test ($p \leq 0.05$).

No statistically significant differences were detected between fertilization with CBCF and BPBF for the number and weight of reject roots per plant in either of the planting seasons (2023–2024) analyzed. However, the orthogonal comparison showed that fertilization reduced the production of reject roots by 28.43 and 44.18% in 2023 and 2024, respectively, relative to the control treatment. On average, fertilization reduced reject root weight by 49.44 and 59.68% in the 2023 and 2024 seasons, respectively, relative to the control treatment (Table 2).

In both planting seasons (2023–2024), no statistically significant differences were detected among the fertilization doses of 200, 400, and 600 kg ha^{-1} for the analyzed yield components, which suggests that the 200 kg ha^{-1} dose may be the most economically convenient for enhancing root yield per plant and reducing losses due to rejects (Table 3). On average, the three fertilization doses caused an increase of 23.84 and 31.80% in commercial root production and of 39.83 and 32.66% in commercial root weight per plant in 2023 and 2024, respectively, with respect to the control treatment. In contrast, the three fertilization doses, on average, contributed to reducing the number of reject roots by 28.43 and 44.18% in the

2023 and 2024 seasons, while the weight of rejected roots decreased by 49.44 and 59.68% for the same seasons, relative to the unfertilized control treatment (Table 3).

Fertilization improved the nutritional status of the plants, increasing yield and reducing the proportion of defective or low commercial-quality roots compared with the control treatment, an effect that was more pronounced with CBCF. These results are consistent with previous studies that reported increases in cassava root production and yield due to fertilization, with increases ranging between 8 and 50% per plant and between 16 and 39% in total yield relative to unfertilized treatments (Chua et al., 2020; Rosa, Fernandes, Gazola, Nunes, & Soratto, 2021; Mulualem et al., 2021; Pimentel et al., 2021; Konan et al., 2024).

Fertilization with CBCF produced root yields significantly higher ($p < 0.05$) than those obtained with BPBF in both seasons, with increases of 9.63–12.82% relative to this source and of 34.62–51.30% compared with the control treatment (Figure 2A). In turn, the 200 kg ha^{-1} dose showed yields statistically similar ($p > 0.05$) to those attained with 400 and 600 kg ha^{-1}, exceeding the control by more than 30% and making it possible to obtain commercial yields greater than 40 t ha^{-1} in both evaluated seasons (Figure 2B). These results suggest that the application of the lowest dose constitutes the most efficient alternative from an agronomic and economic standpoint.

Fertilization with CBCF showed agronomic efficiencies of fertilization (AEF) of 55.12 and 55.63 kg of roots kg^{-1} of applied fertilizer in 2023 and 2024, which were significantly higher ($p < 0.05$) than those obtained with BPBF in both seasons. This demonstrated a greater capacity to convert the applied fertilizer into root yield (Figure 2C). Likewise, the 200 kg ha^{-1} dose recorded the highest AEF, with averages of 74.80 and 82.02 kg of roots kg^{-1} of applied fertilizer in 2023 and 2024, significantly exceeding ($p < 0.05$) the 400 and 600 kg ha^{-1} doses, with increases greater than 40% in both evaluation years. These results indicate that the lowest dose evaluated optimizes fertilizer use and maximizes the productive efficiency of the crop (Figure 2D).

The higher yields and AEF values obtained with CBCF (Figures 2A and 2C) could be attributed to its homogeneous chemical composition, in contrast to BPBF, which favors a more uniform distribution of nutrients in the rhizosphere, optimizing their absorption and use by the crop. Moreover, this characteristic reduces segregation processes during transport and application, improving distribution uniformity, decreasing nutrient losses, and favoring greater synchronization between nutrient supply and crop demand (Hasler et al., 2015; Thaper, Fulton, McDonald, & Fasina, 2022; Pierre & Regmi, 2026).

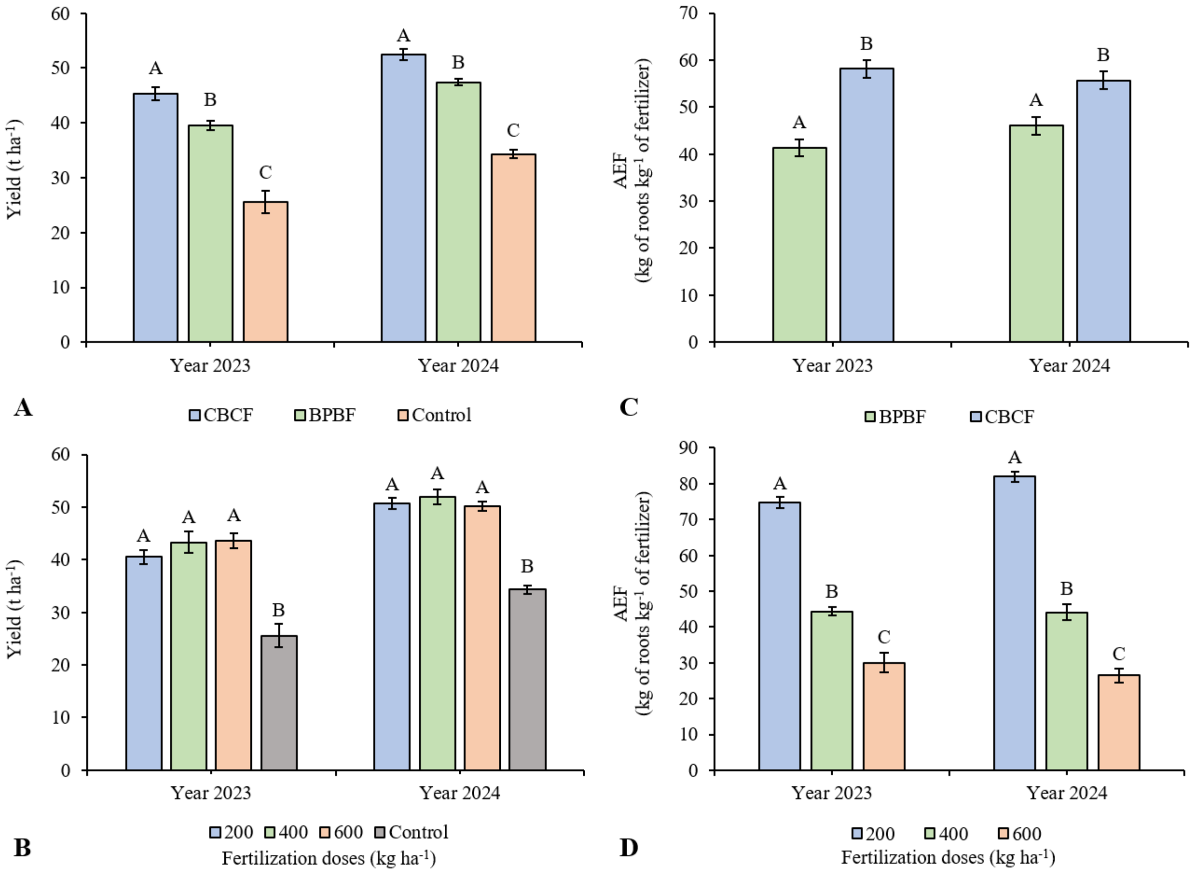

Figure 2. Yield and agronomic efficiency of fertilization (AEF) as a function of chemically blended compound fertilizers – CBCF and bulk physically blended fertilizers – BPBF (Figures 2A and 2C), fertilization doses (Figures 2B and 2D), and control treatments in cassava INIAP P-652. Bars with different letters indicate differences in means according to Tukey's test ($\alpha \leq 0.05$).

Although no previous studies compare the efficiency of CBCF and BPBF in cassava, research on cereals has shown that compound fertilizers with greater granulation homogeneity significantly increase yield (+12%) and nutrient use efficiency (+18%) compared with bulk physical blends and conventional fertilizers (Li et al., 2022; You et al., 2023; Liu et al., 2025). These antecedents support the agronomic superiority observed for CBCF in the present study.

The agronomic advantages of CBCF are particularly relevant in cassava, because root development and biomass accumulation in storage roots require a balanced and continuous supply of nutrients, especially during the stages of tuberization and root thickening (Howeler, 2017). A more homogeneous distribution of nutrients in the rhizosphere could favor their absorption, reducing localized deficiencies and contributing to greater agronomic efficiency and crop productivity.

Although the highest yield was obtained with 400 kg ha-¹, this did not differ statistically ($p > 0.05$) from the 200 kg ha-¹ dose, which suggests that the lower dose would be sufficient for the production of roots intended for fresh consumption (7 to 8 months after planting) under the conditions of the study (Figure 2B). These results are consistent with previous reports showing similar responses between 200 and 400 kg ha-¹ of fertilization, indicating that additional increases in the dose do not necessarily translate into proportional yield increases (Muojiama, Agbo, Eze, & Uba, 2018; Katuromunda, Ekwaro, & Wanaku, 2021). Nevertheless, higher doses could be more appropriate for systems oriented toward industrial starch production (> 12 months after planting), where the crop remains in the field longer and has greater nutritional requirements.

Unlike yield, AEF was significantly influenced ($p < 0.05$) by the fertilization dose, reaching its maximum value at 200 kg ha-¹ (Figure 2D). This suggests that this dose was sufficient to meet the nutritional requirements of the crop without generating significant nutrient losses or luxury consumption, whereas higher doses showed lower efficiency, in accordance with Mitscherlich’s law of diminishing returns (Ferreira, Zocchi, & Baron, 2017). The values obtained are within the AEF ranges reported for cassava in different environments in Africa, ranging from 20.5 to 162 kg of roots kg-¹ of applied nutrient (Byju & Haripriya, 2009; Ezui et al., 2016; Senkoro et al., 2018; Adiele et al., 2020).

The high agronomic response of the INIAP P-652 variety to the lower fertilization dose could be explained by the adequate supply of nutrients from the soil, whose levels of organic matter and essential nutrients were within the ranges considered optimal for cassava cultivation (Howeler, 1996a, 1996b). This suggests that an important part of the crop’s nutritional requirements was met by the natural fertility of the soil.

Fertilization significantly increased the profitability of the cassava crop relative to the control treatment in both evaluation years (Table 4). The application of CBCF at 200 kg ha-¹ generated the highest net incomes (USD 4,852 and USD 6,241 ha-¹), returns per dollar invested (1.30 and 1.53), and net fertilization benefits (USD 2,788 and USD 2,815) in 2023 and 2024, respectively, making it the most economically efficient alternative. Although the 400 and 600 kg ha-¹ doses produced slight yield increases, these did not proportionally offset the increase in production costs, reducing the relative profitability of the system (Table 4).

Table 4. Economic analysis of fertilizer sources (CBCF and BPBF), fertilization doses, and the control treatment in cassava INIAP P-652.

Treatments	YLD	SP	TI = SP×YLD	TC = FC+VC	NI = TI−TC	PDI = NI/TC	NEBF = NIT−NIC
			Year 2023				
BPBF 200 kg ha-¹	40.010	0,20	8.002	3.583	4.419	1,23	2.055
BPBF 400 kg ha-¹	41.400	0,20	8.280	3.774	4.506	1,19	2.142
BPBF 600 kg ha-¹	41.550	0,20	8.310	3.914	4.396	1,12	2.032
CBCF 200 kg ha-¹	42.915	0,20	8.583	3.731	4.852	**1,30**	**2.488**
CBCF 400 kg ha-¹	44.305	0,20	8.861	4.068	4.793	1,18	2.429
CBCF 600 kg ha-¹	44.455	0,20	8.891	4.166	4.725	1,13	2.361
Control	25.550	0,20	5.110	2.746	2.364	0,86	-----
			Year 2024				
BPBF 200 kg ha-¹	50.060	0,20	10.012	3.975	6.037	1,52	2.611
BPBF 400 kg ha-¹	50.670	0,20	10.134	4.134	6.000	1,45	2.574
BPBF 600 kg ha-¹	49.709	0,20	9.942	4.244	5.698	1,34	2.272
CBCF 200 kg ha-¹	51.585	0,20	10.317	4.076	6.241	**1,53**	**2.815**
CBCF 400 kg ha-¹	52.195	0,20	10.439	4.289	6.150	1,43	2.724
CBCF 600 kg ha-¹	51.315	0,20	10.263	4.451	5.812	1,31	2.386
Control	34.300	0,20	6.860	3.434	3.426	1,00	-----

YLD: Yield (kg ha-¹); SP: Sale price (USD kg-¹); TI: Total income (USD ha-¹); TC: Total cost (USD ha-¹); FC: Fixed costs (USD ha-¹); VC: Variable costs (USD ha-¹); NI: Net income (USD ha-¹); PDI: Profit per dollar invested; NEBF: Net economic benefit of fertilization (USD ha-¹); NIT: Net income of fertilization treatments (USD ha-¹); NIC: Net income of the control treatment (USD ha-¹). BPBF: Bulk physically blended fertilizer; CBCF: Chemically blended compound fertilizer.

The importance of these results lies in the fact that investment in moderate fertilization doses can generate viable and attractive economic returns for cassava producers in the region, creating incentives to use technologically more advanced fertilizer sources, which would lead to increased efficient nutrient use and reduced crop yield gaps. In this context, the results obtained align with those described by Ezui et al. (2016), Senkoro et al. (2018), and Atalo, Rollon, & Jabagat (2025), who reported benefit-cost ratios > 2, with net economic returns greater than 100%, using nutritionally more balanced fertilizer sources.

CONCLUSIONS

In general, fertilization contributes significantly to increasing the number and weight of commercial roots per plant, reducing the losses associated with defective and malformed roots, and enhancing the yield of the INIAP P-652 variety under the conditions of the Carrizal River valley, Ecuador.

The chemically blended compound fertilizer (CBCF) was more effective in promoting a greater increase in root yield and agronomic efficiency of fertilization, achieving higher yield per unit of applied fertilizer.

Regardless of the fertilizer source, all doses produced statistically similar yields, whereas the agronomic efficiency of fertilization was significantly higher with 200 kg ha^{-1}; therefore, this dose is recommended for the Carrizal River valley locality, as it optimizes the production of root biomass per unit of applied fertilizer.

Fertilization with CBCF at 200 kg ha^{-1} constitutes the most economically viable alternative, with the highest return per dollar invested and the highest net economic benefit of fertilization.

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