Revista Mexicana de Ciencias Agrícolas
REMEXCA

DOI: https://doi.org/10.29312/remexca.v17i6.4223

Article

Effects of Enerplant® concentrations on the nutritional efficiency of coffee seedlings

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Abstract

Establishing the proper use of the inputs that ensure the nutrition of coffee trees is essential to optimize their application. The objective was to investigate the effect of different concentrations of a biostimulant on the absorption and utilization efficiency of NPK by *Coffea arabica* L. seedlings. The experiment was conducted at the Tercer Frente Agroforestry Experimental Station, province of Santiago de Cuba, from December 2023 to July 2024. Concentrations of 0, 1, 2, 3 and 4 ml ha^{-1} of Enerplant® applied foliarly were studied. The absorption, utilization efficiency, absorption efficiency and translocation efficiency of nitrogen, phosphorus,and potassium were calculated. Data were processed using one-way analysis of variance, and means were compared using Tukey's test (α= 0.05). Enerplant® increased leaf contents and nutrient absorption. The biostimulant concentration of 4 ml ha^{-1} increased nitrogen absorption by 29%, phosphorus absorption by 59%, and potassium absorption by 63% compared to the control. Increasing Enerplant® concentrations increased nutrient utilization efficiency but reduced absorption and translocation efficiencies.

Keywords:

Coffea arabica L., absorption, biostimulant.

DOI: https://doi.org/10.29312/remexca.v17i6.4223

Introduction

Due to the high prices of mineral fertilizers and because their participation in production costs represents approximately 30% of the total (Fageria, 1988), it is necessary to obtain a coffee with low energy consumption; this has encouraged research to identify the mechanisms responsible for greater nutritional efficiency, in order to take advantage of them through selection and other plant breeding methods (Martins *et al*., 2015).

The term 'nutritional efficiency' is used to characterize the ability of plants to absorb and utilize nutrients and relates to nutrient absorption, translocation and utilization (Amaral *et al*., 2011).

Utilization efficiency reflects a cultivar's ability to produce well under conditions of low nutrient availability in the soil, while translocation efficiency depends on the transport of nutrients to the aboveground part and on its metabolic requirements (Amaral *et al*., 2011); however, Martin *et al*.(2013) note that there is no consensus on which of these indices has the greatest influence on plant growth.

Several factors affect nutritional efficiency: the extent of the root system, the root-to-shoot ratio, the distribution of roots in the soil (Föhse *et al*., 1988), a high photosynthetic rate (Tomaz *et al*., 2009), varieties (Martins *et al*., 2015), soil fertility and plant size (Amaral *et al*., 2011), and nutrient demand at the cellular level.

Compartmentalization, utilization in the aboveground part, short and long-distance transport, affinity of the absorption system, minimum concentration and modifications of the rhizosphere (Tomaz *et al*., 2011) are other factors that affect nutritional efficiency; nevertheless, the literature offers little reference to the possible effects that different levels of fertilizers or biostimulants could have on these indices.

Enerplant® is a plant-based growth stimulator made from different types of oligosaccharides. It is certified for organic agriculture and its benefits include higher yields, improved fruit quality, enhanced germination, increased resistance to diseases and increased resistance to postharvest management, among others (Biotec International, 2026).

In Cuba, the production of coffee seedlings has been promoted and information is available (Viñals *et al*., 2017; Bustamante-González *et al*., 2019; Valverde-Luco *et al*., 2020) on the positive effects of biostimulants as an alternative to enhance seedling growth and increase nutrient utilization efficiency; nonetheless, resources are not available to ensure their application in production.

It is known that Enerplant® increased height by 37%, leaf area by 35%, and biomass of coffee seedlings by 69% (Díaz-Medina *et al*., 2023); however, it is necessary to evaluate the effects of concentrations of this bioproduct on the absorption and efficiency of nutrient utilization by seedlings of this species, which is why this research was carried out.

Materials and methods

The research was conducted under the shade of zarán mesh in the nursery of the Tercer Frente Agroforestry Experimental Station (20° 09' north latitude, 76° 16' west longitude, 135 masl), province of Santiago de Cuba, from December 2023 to July 2024.

Using a completely randomized experimental design, the study examined the effects of Enerplant® concentrations [0 (control), 1, 2, 3 and 4 ml ha^{-1}] on NPK content, absorption, and utilization efficiency in seedlings of *Coffea arabica* L., variety 'Isla 6-14', grown in a brown earth-cow manure substrate in a 3:1 ratio with 8.2% organic matter, pH H_2O 7, 38; phosphorus and potassium values 279.5 and 282.7 mg of P_2O_5 and K_2O in 100 g of soil, respectively.

Black polypropylene bags measuring 12.5 cm in width and 25 cm in length were utilized.

Each treatment consisted of 35 plants, of which 15 were evaluated at the end of the experimental period.

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Enerplant® applications were made before 10:00 am using a Matabí 16 L backpack sprayer at constant pressure. The product was applied to the second through the fifth pairs of leaves. Water was applied to the control treatment on the same day as the other treatments. To ensure correct application of the different concentrations, the plants were separated with metal sheets when applying the bioproduct.

When the seedlings developed the sixth pair of leaves, the plants were separated into vegetative and root systems. They were washed with water and then dried in a forced-air circulation oven at 70 °C to a constant weight. They were then ground and sieved to 0.2 mm.

Mineralization was performed in a mixture of sulfuric acid and selenium, and the nitrogen concentration was determined by the Kjeldahl method, the phosphorus concentration by the molybdenum blue method, and the potassium concentration by flame photometry.

Nutrient absorption (mg), utilization efficiency (UE) in g mg^{-1} (Siddiqi and Glass, 1981), absorption efficiency in mg g^{-1} (Swiader *et al*., 1994), and translocation efficiency (TE) in % (Li *et al*., 1991) were calculated based on dry mass and nutrient contents.

The normality of the data was assessed using the Kolmogorov-Smirnov test, and the homogeneity of variance was assessed using the Levene test. An analysis of variance was performed, and Tukey's test was used to compare differences (Ruesga *et al*., 2005).

Results and discussion

Enerplant® applications significantly increased NPK levels in the leaves and phosphorus and potassium levels in the roots (Table 1).

Table 1. Concentration of nutrients in leaves and roots of coffee seedlings (g kg^{-1}).

Concentration (ml ha^{-1})	Leaves			Root		
	N	P	K	N	P	K
0 (control)	28.5 b	1.29 d	18.43 d	23.7 a	1 d	13.6 e
1	25.26 c	1.93 a	20.56 c	21.3 c	1.3 a	18.68 b
2	30 a	1.78 b	21.6 b	21.6 b	1.13 c	15 c
3	28.5 b	1.5 c	20.8 bc	15 d	0.92 e	13.7 d
4	28.83 ab	1.7 b	22.77 a	21.6 b	1.25 b	19 a
SE, x#	0.33*	0.03*	0.22*	0.07*	0.007*	0.01*

*= letters indicate significant differences (α= 0.05).

No definite pattern was found of the effect of biostimulant concentrations on N values. The highest leaf content was observed when applying 2 ml ha^{-1}, whereas for phosphorus, it was with 1 ml ha^{-1}. For potassium, an increasing trend in its values was observed when applying the different concentrations.

In the roots, the applications of Enerplant® led to significant increases in phosphorus and potassium (Table 1). For nitrogen, concentrations decreased significantly with the application of the biostimulant.

In general, the concentration of the three nutrients was higher in the leaves than in the roots (Table 1). A similar result was reported by Bustamante *et al*. (2022) when investigating doses of Osmocote in coffee seedlings.

Leaf nitrogen concentrations (Table 1) were higher than the critical values (2.26-2.62%) found for seedlings produced in cone-tainers (Gonçalves *et al*., 2009). Phosphorus values were lower than those reported as critical (2.2-2.5%) by Gonçalves *et al*. (2009), as were potassium values (2.59-2.92%). This difference in results may be related to the differing experimental conditions reported by the cited authors and to the varieties used.

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In this sense, Silva *et al*. (2007) are of the opinion that genetic factors may cause differences in foliar nutrient concentrations, indicating that there is a greater or lesser efficiency of nutrient absorption, translocation, and utilization by plants among varieties and lines.

Enerplant® concentrations increased nutrient absorption (Table 2). The concentration of 4 ml ha^{-1} significantly increased the absorption of nitrogen (29%) and potassium (63%) by the coffee seedlings compared to the control. For phosphorus, a similar effect of a significant increase relative to the control was observed at biostimulant concentrations of 2 and 4 ml.

Table 2. Effect of Enerplant® concentrations on nutrient absorption (mg seedling^{-1}).

(ml ha^{-1})	Aboveground system			Root system			Total		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
0	82.08 b	4.93 c	125.52 c	9.5 d	0.84 c	12.49 D	91.59 bc	5.77 d	138 c
1	76.47 b	6.51 b	129.88 c	12 c	0.88 c	24.14 B	88.5 bc	7.4 b	154 b
2	80.38 b	6.45 a	141.25 b	13.9 b	1.27 b	22.04 b	94 b	7.72 ab	163.29 b
3	76.19 b	5.5 a	131.85 bc	8.9 d	1.12 b	18.71 C	85.13 c	6.62 c	150.56 bc
4	92.35 a	6.73 a	172 a	26.3 a	1.52 a	52.99 A	118.65 a	8.26 a	225 a
SE, x#	2.17*	0.16*	3.41*	0.44 *	0.04*	0.78*	2.27*	0.17*	3.55*

*= letters indicate significant differences (α= 0.05).

The N:P ratio in plant tissues is a limiting indicator of growth. Ratios greater than 16 indicate that growth is limited by P, whereas ratios lower than 14 indicate that the limiting element is N (Bündchen *et al*., 2013). The ratio of nitrogen absorption in the aboveground system to that in the root system showed a tendency to decrease significantly with increasing concentration (Table 3).

Table 3. Ratio of aboveground system absorption to root system absorption.

(ml ha^{-1})	N	P_2O_5	K_2O
0	8.82 a	6.05 b	10.3 a
1	6.53 b	7.6 a	5.53 c
2	5.95 b	5.23 bc	6.57 bc
3	8.69 a	5.02 bc	7.18 b
4	3.52 c	4.43 c	3.25 d
SE, x#	0.31*	0.27*	0.32*

*= letters indicate significant differences (α= 0.05).

A similar behavior was observed for phosphorus, although no differences were found among concentrations of 2 to 4 ml ha^{-1}. This low ratio reflects that nitrogen was the element limiting the growth of coffee seedlings.

The decrease in the ratios indicates changes in nutrient absorption when applying the biostimulant. Gonçalves *et al*. (2018) explained that the ideal balance for the growth of plant organs is variable, with a specific endogenous nutrient concentration being able to favor the growth of one organ and inhibit the growth of another.

Enerplant® applications in cocoa significantly increased the evaluated morphological variables, including leaf area (Bustamante-González *et al*, 2022b). This increase in the variable could have increased photosynthetic activity, decreased nitrogen concentration, and increased phosphorus, resulting in a consequent variation in the N:P ratio. It should be noted that the efficiency of phosphorus utilization was higher than that of nitrogen and potassium (Table 4).

DOI: https://doi.org/10.29312/remexca.v17i6.4223

Table 4. Effect of Enerplant® concentrations on the efficiency of nutrient utilization and absorption in coffee seedlings.

Concentration (ml ha^{-1})	Utilization efficiency (g DM mg^{-1})			Absorption efficiency (mg g^{-1})		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
0	0.111 c	1.78 b	0.074 b	232.71 a	14.72 a	351.97 a
1	0.135 b	1.61 cd	0.077 b	161.62 b	13.43 ab	279.57 b
2	0.127 b	1.55 d	0.073 b	150.08 b	12.3 bc	260.31 b
3	0.138 b	1.76 bc	0.077 b	145.34 b	11.28 c	256.83 b
4	0.191 a	2.75 a	0.105 a	97.59 c	6.79 d	176.72 c
SE, x#	0.003*	0.04*	0.01*	6.4*	0.5*	10.36*

*= letters indicate significant differences (α= 0.05).

Authors such as Tomaz *et al*. (2008) explain that different plant species differ in their response depending on the availability of nutrients in the soil and differ in their nutrient absorption capacity and utilization efficiency.

In this context, Amaral *et al*. (2011) reported differences in nutrient uptake among coffee cultivars at different levels of soil fertility and found that efficiency was uneven for the formation of the aboveground part and roots.

Utilization efficiency (UE) connects the economy of carbon with that of a given mineral nutrient. For their part, Swiader *et al*. (1994) consider it to represent the capacity of plants to produce maximum amounts of dry matter with a minimum investment in the unit of nutrient applied.

For the efficiency of utilization of the three nutrients, significant differences were found among the applied concentrations (Table 4). The highest values that differed significantly from the rest were observed at the highest Enerplant® concentrations.

Due to the magnitude of efficiency, the nutrients were in the order P> N> K (Table 4). This result confirms the role of phosphorus in this phase of crop growth and its effect on seedling growth and metabolism.

Other research, such as that by Tomaz *et al*. (2009), indicates that higher utilization efficiency is related to a lower need for P for biochemical reactions and greater redistribution of nutrients to the growing zone.

NUE and PUE values were higher than those reported by Bustamante-González and Ferrás-Negrín (2019) when applying FitoMas E to coffee seedlings, whereas KUE values were lower.

For 18-month-old grafts of *Coffea arabica* on *Coffea canephora* rootstock in Brazil, Tomaz *et al*. (2009) reported similar behavior (PUE> NUE). Carvalho *et al*. (2015) also found PUE> KUE> NUE as behavior in grafts.

In coffee seedlings, Bustamante *et al*. (2022a) reported a similar order, PUE> NUE> KUE. For cocoa, Bustamante *et al*. (2022b) reported that nutrient utilization efficiency increased with Enerplant® doses.

Absorption efficiency (AE) decreased with the application of Enerplant® concentrations. The highest NPK values were found in the control, which differed significantly from the rest (Table 4). The highest absolute AE values were observed for K, followed by N and finally by P.

Results similar to those of this study were reported by Carvalho *et al*. (2015), who found absorption efficiency values ranging from 195 to 349 g kg^{-1} for N, from 124 to 236 for potassium and from 18.3 to 35.8 for phosphorus. This behavior could be related to greater root system development in a phosphorus-rich substrate. Similar absorption magnitudes were reported by Kamala-Bai *et al*. (2013) when studying the effects of phosphorus doses and sources in India.

When studying the effects of the concentrations of a biostimulant composed of algal extracts on the growth of grape seedlings, Ferreira *et al*. (2017) found that increasing the dose reduced shoot length, root length, and dry mass, thereby decreasing metabolic processes.

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The treatment that received 4 ml ha^{-1} of Enerplant® (Table 5) exhibited the lowest absolute translocation (TE) values (although, in some cases, these did not differ statistically from those observed in other treatments). The TE of the three nutrients fell within the range of the values found by Tomaz *et al*. (2009); Carvalho *et al*. (2015).

Table 5. Effect of Enerplant® concentrations on nutrient translocation efficiency in coffee seedlings.

Concentration (ml ha^{-1})	Translocation efficiency (%)		
	N	P_2O_5	K_2O
0	89.59 a	85.15 b	90.82 a
1	86.26 b	88.06 a	84.31 c
2	85.31 b	83.56 bc	86.49 bc
3	89.41 a	83.06 bc	87.49 b
4	77.84 c	81.56 c	76.89 d
SE, x#	0.48*	0.61*	0.65*

*= letters indicate significant differences (α= 0.05).

This reflects the increase in the efficiency of nutrient utilization by the coffee seedlings; as the highest concentration of Enerplant® promoted the lower values of absorption and translocation efficiencies, a greater amount of dry mass per gram of nutrient was produced.

By studying the translocation efficiency of *C. canephora* clones, it was concluded that increasing P in soil can suppress the rate of its transport in the xylem, which reduced the translocation efficiency (Martins *et al*., 2013).

The positive results of applying the biostimulant may be related to what Jiménez-Arteaga (2013) reported: Enerplant® optimizes the assimilation of macro- and micronutrients and intensifies vegetative development processes by increasing leaf area and photosynthesis.

Conclusions

Applying Enerplant® increases nutrient absorption by coffee seedlings and utilization efficiency, while absorption and translocation efficiencies decrease.

The potential of the biostimulant as a sustainable agricultural alternative for conventional and organic management in coffee nurseries is demonstrated.

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DOI: https://doi.org/10.29312/remexca.v17i6.4223

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Effects of Enerplant® concentrations on the nutritional efficiency of coffee seedlings

Journal Information
Journal ID (publisher-id): remexca
Title: Revista mexicana de ciencias agrícolas
Abbreviated Title: Rev. Mex. Cienc. Agríc
ISSN (print): 2007-0934
ISSN (electronic): 2007-9230
Publisher: Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (México)

Article/Issue Information
Date received: 01 March 2026
Date accepted: 01 June 2026
Publication date: 01 September 2026
Volume: 17
Issue: 6
Electronic Location Identifier: e4223
DOI: 10.29312/remexca.v17i6.4223

Categories

Subject: Article

Keywords:

Keywords:

Coffea arabica L.

absorption

biostimulant

Counts

Figures: 0

Tables: 5

Equations: 0

References: 27