Cultivos Tropicales, Vol. 43, No. 4, October-December 2022, e-ISSN: 1819-4087, p-ISSN: 0258-5936, https://ediciones.inca.edu.cu

Cu-ID: https://cu-id.com/2050/v43n4e14

Original article

Efficiency of nutrient utilization by coffee plant seedlings produced in tubes

Eficiencia de utilización de nutrientes por posturas de cafetos producidas en tubetes

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ABSTRACT: In order to evaluate application effect of doses of controlled release fertilizers on the efficiency of the use of nitrogen, phosphorus and potassium by coffee seedlings variety Isla 6-14 produced in tubes, the experiment was developed in the nursery of the Institute for Agro-Forestry Research UCTB Tercer Frente, from November 2018 to May 2019. In a completely randomized design, seven doses of the controlled release fertilizer Multicote (0; 1; 2; 3; 4; 5 and 6 g tube^{-1}) were studied. The fertilizer was applied at the time of preparing the Brown soil substrate-bovine manure in a 1:1 ratio. The absorption of nitrogen, phosphorus and potassium, the efficiency of use of these macronutrients and their relationship with the seedling's quality index were evaluated. The data were subjected to a simple classification analysis of variance and Duncan's test was applied at 5 % probability to compare the means. The nutrient utilization efficiency was higher for phosphorus followed by nitrogen and finally potassium, regardless of the applied fertilizer dose. When applying the dose of 2 g tube^{-1} of the fertilizer, the highest efficiency values were found. The seedling's quality index increased with the efficiency of nutrient utilization.

Key words: absorption, quality, fertilization, nutrition, nursery.

RESUMEN: Con el objetivo de evaluar el efecto de la aplicación de dosis de fertilizantes de liberación controlada sobre la eficiencia de utilización de nitrógeno, fósforo y potasio por posturas de cafetos de la variedad Isla 6-14 producidas en tubetes, se desarrolló el experimento en el vivero del Instituto de Investigaciones Agro-Forestales UCTB Tercer Frente, desde noviembre 2018 hasta mayo 2019. En un diseño completamente aleatorizado se estudiaron siete dosis (0; 1; 2; 3; 4; 5 y 6 g tubete^{-1}) del fertilizante de liberación controlada Multicote, que se aplicaron al momento de elaborar el sustrato suelo Pardo-estiércol vacuno en proporción 1:1. Se evaluó la absorción de nitrógeno, fósforo y potasio, la eficiencia de utilización de estos macronutrientes y su relación con el índice de calidad de las posturas. Los datos se sometieron a análisis de varianza de clasificación simple y para comparar las medias se aplicó el test de Duncan al 5 % de probabilidad. La eficiencia de utilización de los nutrientes fue superior para el fósforo, seguido del nitrógeno y, por último, el potasio, independientemente de la dosis de fertilizante aplicada. Al aplicar la dosis de 2 g tubete^{-1} del fertilizante Multicote se encontraron los mayores valores de eficiencia. El índice de calidad de las posturas se incrementó con la eficiencia de utilización de los nutrientes

Palabras clave: absorción, calidad, fertilización, nutrición, viveros.

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Received: 31/07/2021

Accepted: 31/10/2021

INTRODUCTION

In Cuba, more than 70 % of the coffee trees are between 30 and 40 years old (1), so it is necessary to renew the plantations in order to obtain high levels of production. For this reason, it is necessary to have healthy and vigorous seedlings, which will result in the rapid initial development of the plants, in the reduction of expenses in replanting and, finally, in the successful establishment of plantations (2).

Among the technological innovations in coffee growing is the production of seedlings in plastic containers, whose advantages include the reduction of incidence possibilities of pathogens, increased growth of vegetative organs and quality of seedlings (3), normal formation of the root system, lower volume of substrate, reduced incidence of weeds, less space in the nursery and reduced transportation costs (4,5). This technology includes the application of slow-release fertilizers, which ensure the availability of nutrients at different times during the growth of seedlings and plantations (6,7); however, these are characterized by their high prices.

In Cuba, when adapting the technology of tubes, small containers in the form of tubes, defoliation and decrease of quality were observed, as the seedlings grew. Based on the results that referred to the greater development of seedlings produced in the larger tubes (7), investigations were carried out on the volume of the tubes for the soil-climatic conditions of the country (8), the selection of the substrate (9) and then on the action of the controlled release fertilizer (CRF) Multicote (18-6-12). The greatest growth of the postures was found, with doses that oscillated between 2 and 3 grams per tube (10); higher doses depressed some growth variables.

The technical instructions for cultivation (11) recommend mineral fertilization in the nursery phase of the crop, which, together with the high production plans for seedlings, considerably increase the costs of this activity. For Brazil, the cost of fertilizer represents 30 % of the total cost of production (12). The above situation, together with the increase in the price of fertilizers in the world market, makes it necessary to look for solutions that lead to an increase in the efficiency of the use of these carriers.

The term nutritional efficiency is used to characterize the capacity of plants to absorb and utilize nutrients (13) and is related to terms such as absorption, translocation and utilization efficiency (14). Utilization efficiency reflects the ability of a cultivar to produce well under conditions of low soil nutrient availability (13).

Absorption efficiency is related to the rate of nutrient uptake per unit root mass. Nutritional efficiency is also referred to as production per unit of fertilizer applied and other terms in the field of physiology and agronomy; however, few studies have been conducted on this subject in coffee cultivation (14). The optimization of nutritional efficiency is fundamental to improve productivity and reduce costs (15).

Due to the absence of works on this subject in Cuba, the research was carried out with the objective of establishing the effect of different doses of the controlled release fertilizer (CRF), Multicote (18-6-12), on the nutritional efficiency of coffee plants postures produced in tubes and its relation with their quality index.

MATERIALS AND METHODS

The experiment was developed in the period from November 2018 to May 2019, in the nursery of the Institute of Agroforestry Research in the Unit of Science and Technology Base Third Front, located at 20º 9' 15.8394" North latitude and -76º 16' 16.3554" West longitude, in the province Santiago de Cuba. The average temperature during the experimental period was 25.1 ºC, the relative humidity was 69 % and 654.7 mm of rain in 36 days.

In a completely randomized experimental design, the effect of seven doses of FLC was studied: 0; 1; 2; 3; 4; 5 and 6 grams, on the growth of seedlings of *Coffea arabica* L., variety "Isla 6-14". It grown in a Brown soil-cow manure substrate, in a 1:1 ratio with 8.2 % organic matter, pH in water of 7.38; high values of phosphorus and potassium-279.5 and 282.7 mg of P_2O_5 and K_2O in 100 g of soil, respectively.

The seeds were pregerminated in sand and sown in conical propylene tubes, with internal grooves and dimensions of 5 cm internal diameter at the top, 1 cm internal diameter at the bottom opening, 13 cm height and 180 cm^3 capacity. Sowing was done at 2 cm depth and one seed was placed per tube.

The fertilizer used was FLC Multicote (18-6-12), with a total nutrient release rate of 60 to 120 days at a temperature of 30 ºC. The fertilizer doses were applied at the time the substrate was prepared.

Each treatment consisted of 54 tubers placed in a tray. From these, the 24 central plants of each tray were considered as a useful plot.

A black shade net, with a light passage of 50 %, placed two meters above the tubes, as well as on the side of the nursery to avoid direct sunlight on the plants, was used as a cover to control insolation.

At the time of evaluation, the postures were divided into leaves, stems and roots, which were washed with distilled water and dried in an oven with forced air ventilation at 70 ºC, until a constant weight was reached. After weighing, three samples of each organ and each treatment were analyzed in the soil and fertilizer laboratory of the Sugarcane Territorial Station of Palma Soriano.

The plant material was subjected to wet digestion with sulfuric acid and selenium for the determination of total nitrogen, phosphorus and potassium contents. Nitrogen was determined by the Nessler technique, phosphorus by colorimetry with ammonium molybdate and potassium by flame photometry.

From the dry mass values and nutrient contents, nutrient uptake was calculated and, from these data, nutrient utilization efficiency (EU) indices were calculated (16).

$$EU = (g\ total\ dry\ matter)^2 / mg\ nutrient\ in\ plant$$

The analysis of variance simple classification was carried out using a completely randomized design, according to the linear fixed effects model. Data were processed using Statistica for Windows. The normality of the data was tested by the Kolmogorov-Smirnov test and the homogeneity of variance by the Levene test. For the determination of differences between treatments, Duncan's multiple range comparison dyme for p≤0.05 was used.

Leaf N/P ratio data, as well as nutrient utilization efficiency and stand quality index were fitted to several models and the one with the highest coefficient of determination (r^2) was selected.

RESULTS AND DISCUSSION

Fertilizer doses (FLC) significantly influenced (p≤0.05) the nitrogen, phosphorus and potassium contents in all organs of the coffee plants (Table 1). Nitrogen and phosphorus values differed between organs and generally followed the following behavior: leaves>root>stem, while for potassium it was root>leaves>stem.

The leaf values of macronutrients obtained in this work were higher than those ones reported for Isla variety when applying FitoMas E at 1 %, monthly (17). In the case of phosphorus contents in leaves, they were also higher than the values between 0.21-0.26 reported for greenhouse conditions in Colombia, when studying the effect of phosphate solubilizing bacteria (18).

With the exception of the nitrogen content in the leaves of the control treatment, the rest of the values of this element and those of phosphorus and potassium were higher than the critical values found in these studies for seedlings produced in tubers in Brazil (19), which could be related to the type of substrate used. The concentrations of phosphorus and potassium were higher than the sufficiency ranges reported when correlating foliar and soil analyses for coffee plants with high productive levels in Brazil (20).

In the tubes, seedlings find greater availability of water and nutrients, which, together with the development of the root system, minimizes hydric stress and limits metabolism (21).

The application of the FLC doses made possible the gradual increase of nutrient concentrations. In leaves and roots, the maximum values of nitrogen and phosphorus, significantly higher than the rest of the contents, were reached when 5 grams of Multicote were applied (Table 1). In leaves, the highest potassium content was reached with the highest dose of FLC.

The N:P ratio in plant tissues was proposed as a limiting indicator of growth. It was found that this ratio ranged between 5.36 and 10.25, and in the specific case of leaves, between 7.41 and 10.25, which is a reflection that nitrogen was the limiting factor in the substrate, since ratios higher than 16 indicate that growth is limited by phosphorus (22), while ratios lower than 16 indicate nitrogen. High and significant coefficients of determination (R^2) were found between the doses of FLC and the N/P ratio, these being of greater value in the root of the coffee plants (Figure 1).

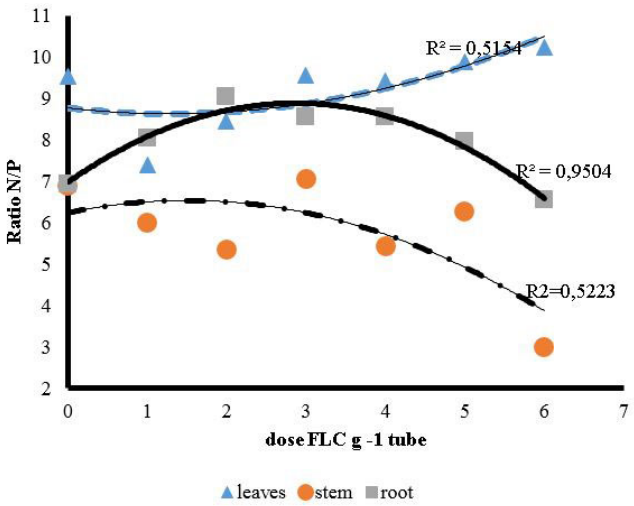


Figure 1. Effect of controlled release fertilizer doses on the N/P ratio in coffee plant seedlings

Nutrient uptake was increased in all organs by the effect of the FLC doses, and it differed according to the nutrient analyzed. Thus, the 3 g FLC tube^{-1} dose guaranteed nitrogen values statistically similar to the highest value reached with the 5 g FLC tube^{-1} dose (Table 2).

The 2 g FLC tube^{-1} dose allowed obtaining phosphorus uptake values statistically similar to the highest values of this element reached with the 5 g FLC dose (Table 2). With the application of this same dose, higher potassium uptake

Table 1. Effect of FLC Multicote doses on nutrient concentrations (%) in seedlings of *Coffea arabica* L

Multicote	Leaves			Stem			Root		
(g tube^{-1})	N	P	K	N	P	K	N	P	K
0	2.00 g	0.239 f	3.74 d	1.31 e	0.19 e	2.56 c	1.38 e	0.19 c	4.03 g
1	2.28 e	0.27 d	3.92 c	1.14 f	0.19 e	2.30 e	1.44 d	0.17 d	4.27 f
2	2.11 f	0.25 e	3.69 d	1.12 g	0.20 d	2.34 d	1.62 b	0.17 d	4.90 c
3	2.68 d	0.28 c	3.90 c	1.34 d	0.19 e	2.69 b	1.54 c	0.18 d	4.54 e
4	2.73 c	0.29b	3.77 d	1.41 c	0.26 a	2.71 b	1.96 a	0.23 b	5.15 b
5	3.16 a	0.32 a	4.13 b	1.57 b	0.25 b	3.08 a	1.99 a	0.25 a	5.33 a
6	2.86 b	0.28 c	4.63 a	1.83 a	0.23 c	2.71 b	1.64 b	0.25 a	4.74 d
S.E. $\bar{x}$	0.07*	0.0007*	0.03*	0.002*	0.0002*	0.01*	0.01*	0.001*	0.01*

*Means with different letters in the same column differ from each other for p<0.05 according to Duncan's decimal point

values were achieved, which differed statistically from those achieved with the rest of the treatments (Table 2).

The relative distribution of macronutrient uptake in the plant organs was different according to the nutrient analyzed. As an average of all the doses, 64.2 % of the nitrogen was located in the leaves of the seedlings, followed by 26.2 % in the roots. The rest of this element was located in the stem, with the characteristic of a marked decreasing effect, from 11.3 % for the control, to 4.5 % in the treatment with the dose of 6 g FLC tube^{-1}.

The 58.6 % of phosphorus was located in the leaves, 27.4 % in the roots and 14 % in the stem.

The distribution of potassium among the organs was also different and it was found, as an average of all doses, 61.8 % in roots, 31.8 % in the leaves and only 6.4 % in stems.

The efficiency of utilization results from the interactions between absorption, transport, redistribution and metabolism of nutrients in a plant and reflects not only the content of the nutrient in the different organs, but also the amount of dry matter produced per unit of nutrient acquired (23).

For coffee plants grown in tubers, it was found that the efficiency of nutrient utilization, regardless of FLC dose applied, was higher for phosphorus, followed by nitrogen and, finally, potassium (Table 3). It should be noted that the highest values of utilization efficiency of the three nutrients were found when applying the dose of 2 g tube^{-1} of fertilizer, which is in agreement with the morphological evaluations previously carried out in this experiment (10).

Similar behavior of higher efficiency of phosphorus utilization over nitrogen and potassium, was found when studying this indicator in three grafted varieties of coffee (24). These authors cite Gerloff and Gabelman (25), who state three possible reasons to explain this situation, of which the one that relates it to the greater redistribution of the nutrient to the growing points is considered more in line with the results of this research.

The highest nitrogen utilization efficiency was found with the dose of 2 g Multicote tube^{-1}, which implies 0.36 g N per tube^{-1}, which coincides with research where it was concluded that doses higher than 0, 4 g N plant^{-1} depress the growth of coffee seedlings (26). Nitrogen overdoses can increase nitrate content, reduce essential amino acids, cause ammonium toxicity or damage the root system, among other negative effects and, in summary, damage plant growth, yield and quality.

These dry mass values obtained per mg of phosphorus reaffirm the role of the nutrient in this phase of the crop, which, in addition to promoting premature root growth, improves water use efficiency (27). On the other hand, the lower biomass production per unit of potassium may be

Table 2. Nutrient uptake by postures produced in tubes (mg posture^{-1}).

Organ	Nutrient	Fertilizer dose							SE $\bar{x}$
		0	1	2	3	4	5	6	
Leaves	N	25.60 c	12.26 d	26.22 bc	36.33 a	30.09 b	40.11 a	25.06 c	1.39 *
	P_2O_5	3.24 c	1.99d	3.74 b	4.56 a	3.84 b	4.90 a	2.95 c	0.17 *
	K_2O	96.26 b	55.01 c	105.32 b	120.62 a	94.87 b	120.18 a	93.05 b	4.91 *
Stem	N	4.53 abc	3.69 c	5.03 a	4.78 ab	4.37 abc	4.13 bc	4.08 bc	0.26 *
	P_2O_5	0.79 c	0.74 cd	1.13 a	0.82 bc	0.97 b	0.79 c	0.62 e	0.05*
	K_2O	20.29 bc	17.07 cd	24.09 a	21.98 ab	19.25 bc	18.58 bc	13.86 d	1.21*
Root	N	10.05 bc	10.29 bc	16.18 a	10.70 bc	11.42 b	9.34 c	7.65 d	0.56*
	P_2O_5	1.75 b	1.54 bc	2.16 a	1.5 c	1.6 bc	1.41 c	1.42 d	0.08*
	K_2O	67.24 bc	69.87 b	112.07 a	72.27 b	68.72 b	57.09 cd	50.94 d	3.64*
Total	N	40.19 d	26.24 e	47.44 bc	51.81 ab	45.88 c	53.59 a	36.80 d	1.70 *
	P_2O_5	5.78 b	4.28 d	7.03 a	6.88 a	6.42 ab	7.10 a	4.98 c	0.24*
	K_2O	183.80 c	141.96 d	241.48 a	214.88 b	182.83 c	195.85 bc	157.86 d	7.35*

*Means with different letters in the same column differ from each other for p<0.05 according to Duncan's decimal point

Table 3. Nutrient utilization efficiency by seedlings (g^2 of dry matter mg nutrient^{-1})

Multicote Dose (g tube^{-1})	Efficiency of use		
	N	P_2O_5	K_2O
0	0.122 b	0.845 b	0.027 a
1	0.124 b	0.764 c	0.024 b
2	0.143 a	0.963 a	0.028 a
3	0.111 c	0.839 b	0.027 a
4	0.093 d	0.671 d	0.024 b
5	0.074 e	0.561 e	0.020 c
6	0.072 e	0.494 f	0.016 d
SE $\bar{x}$	0.003*	0.022*	0.0007*

*Means with different letters in the same column differ from each other for p<0.05 according to Duncan's decimal point

related to its low requirement at this phenological stage of the crop and, consequently, low uptake efficiency (Table 3).

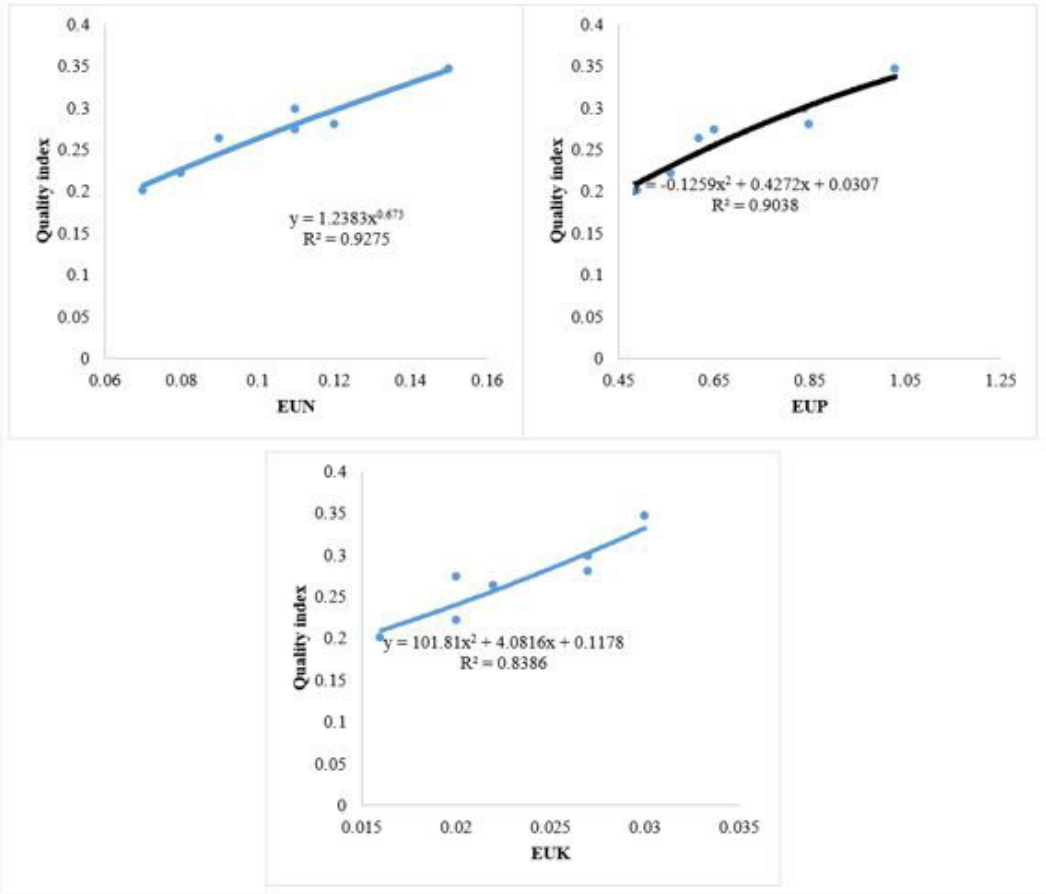
Regression data between FLC doses and utilization efficiency of the three nutrients showed better fits to different functions. For nitrogen, exponential with R^2=0.58; while, for phosphorus and potassium, quadratic with R^2 of 0.59 for both. In all cases, there was a tendency for efficiency to decrease with increasing doses of fertilizer. A similar situation of decreasing efficiency of utilization with increasing doses of Osmocote was found in the production of *Pinus halepensis* mil seedlings (28) and in coffee plants, when studying the relationship between nitrogen doses, photosynthesis and yield in coffee plants 2.5 years old planted in Ethiopia (29). A similar decrease in nitrogen uptake with increasing urea dosage was demonstrated in studies on coffee with nitrogen isotopes (30).

It should be noted that the quality index of the coffee roasts in the experiment was close to the value of 0.42, considered ideal for them (31). The correlation values between the quality index of coffee seedlings and the nutrient utilization index reached values of 0.93, 0.90 and 0.84 for nitrogen, phosphorus and potassium, respectively. The gradual increase of this index was found with the increase in the efficiency of nutrient utilization (Figure 2). When studying phosphorus absorption and efficiency indexes in coffee genotypes (27), positive correlations were found with height, stem diameter, number of leaves and branches, all of which are related to the dry mass of the plant, a significant component in the calculation of the phosphorus utilization coefficient.

Thus, it was established that for the fertilization of coffee plants produced in tubes, the 2 g dose of Multicote provided the highest efficiency of nutrient utilization and that higher doses could increase the absorption of nutrients. It could also cause negative impacts, such as a greater environmental risk, due to the increase of leachates, in addition to the economic impact of using a higher dose of the costly fertilizer.

CONCLUSIONS

- The utilization efficiency of the nutrients, independently of the dose of fertilizer applied, was higher for phosphorus, followed by nitrogen and finally potassium.
- The highest values of utilization efficiency of the three nutrients were found when 2 g tube^{-1} of fertilizer was applied.
- The quality index of the seedlings increased with the efficiency of utilization of the nutrients.



EU - efficiency of use

Figure 2. Ratio between nutrient utilization efficiency and quality index of seedlings

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