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Nutrient export by cupuassu fruits grown in the Brazilian Amazon

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Abstract: In *Theobroma grandiflorum* (cupuassu) orchards, efficient nutrient management is essential to achieve high yields and fruit quality. Thus, fertilization programs should be guided by the concentration of nutrients exported by fruits, as observed with other fruit species. The aim of this study was to quantify the export of macro and micronutrients by fruits of cupuassu genotypes, in order to guide nutrient replacement recommendations replacement. Six cupuassu genotypes ('BRS Careca', 'BRS Fartura', 'BRS Duquesa', 'BRS Curinga', 'BRS Golias' and 'genotype 63') were used, and 40 fruits per genotype were sampled, totaling 240 fruits, in the municipality of Tomé-Açu (Pará/Brazil). Fruits were broken and manually pulped and then separated into peel, seed and pulp. In each fruit part, the contents of macro and micronutrients were analyzed, and later extrapolated to ton of fresh fruits. Potassium was the macronutrient most exported by cupuassu fruits, and 'genotype 63' accounted for the largest exports per ton of fresh fruits of this nutrient. The export of nutrients per ton of fresh fruits followed this order for macronutrients (kg ton^{-1}): K (4.34), N (2.73), P (0.54), Mg (0.40), S (0.29), Ca (0.26) and for micronutrients (g ton^{-1}): Zn (6.24), Fe (4.97), Mn (3.49), Cu (2.45), Ni (0.18) and Mo (0.11). The average replacement per plant and per year, during the productive phase, for the five Cupuassu genotypes is 471 g of K_2O, 326 g of N, 245 g of P_2O_5, 27 g of CaO, 56 g of MgO, 63 g of SO_4^{-2} and 15 g of Fritted Trace Elements (FTE).

Index terms: *Theobroma grandiflorum*, Brazilian fruticulture, plant nutrition, fertilizer recommendation.

Exportação de nutrientes pelos frutos de cupuaçuzeiro cultivados na Amazônia Brasileira

Resumo: Em pomares de *Theobroma grandiflorum*, o manejo eficiente dos nutrientes é fundamental para alcançar altas produtividades e qualidade dos frutos. Nesse

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sentido, um programa de adubação deve ser norteado pela quantidade de nutrientes exportados pelos frutos, como vem sendo utilizado em outras frutíferas. O objetivo deste estudo foi quantificar a exportação de macro e de micronutrientes nos frutos de genótipos de cupuaçuzeiro, a fim de nortear a recomendação da adubação de reposição. Foram empregados seis genótipos de cupuaçuzeiro (BRS Careca, BRS Fartura, BRS Duquesa, BRS Curinga, BRS Golias e o genótipo 63), sendo 40 frutos por genótipo, totalizando 240 frutos, no município Tomé-Açu (Pará/Brasil). Os frutos foram quebrados e despolpados manualmente e, em seguida, separados em casca, semente e polpa. Em cada parte do fruto, foram analisados os teores de macro e de micronutrientes; posteriormente, extrapolados para tonelada de frutos frescos. O potássio foi o macronutriente mais exportado pelos frutos de cupuaçuzeiro, sendo o genótipo 63 responsável pelas maiores exportações por toneladas de frutos frescos desse nutriente. A exportação dos nutrientes por tonelada de frutos frescos obedeceu à seguinte ordem para os macronutrientes (kg t^{-1}): K (4,34), N (2,73), P (0,54), Mg (0,40), S (0,29) e Ca (0,26); e para os micronutrientes (g t^{-1}): Zn (6,24), Fe (4,97), Mn (3,49), Cu (2,45), Ni (0,18) e Mo (0,11). A reposição média por planta e por ano, durante a fase produtiva, para os cinco genótipos de Cupuaçu é de 471 g de K_2O, 326 g de N, 245 g de P_2O_5, 27 g de CaO, 56 g de MgO, 63 g de SO_4^{-2} e 15 g de FTE (Fritted Trace Elements).

Termos para indexação: *Theobroma grandiflorum*, fruticultura brasileira, nutrição de plantas, recomendação de adubação.

Introduction

The Amazon rainforest is considered as the center of origin and diversity of several plant species, among them, cupuassu [*Theobroma grandiflorum* (Willd. ex Spreng.) K. Schum]. This species has gained prominence in the national and international markets, mainly for its use in food and cosmetics production, using pulp and seeds (SANTOS et al., 2016; COSTA et al., 2020). Commercial crops have been expanding since the 1970s (ALVES et al., 2010) with commercial cultivation in the Northern, Northeastern and Southeastern regions of Brazil.

In this sense, the knowledge on the nutritional requirements of this crop is scientifically and commercially valuable for the successful development of the activity. In addition to affecting the production fruit productivity and quality, adequate nutrition interferes with vegetative growth, tolerance to pests and diseases, as well as in the post-harvest period of fruits (NATALE et al., 2012).

The nutritional status of agricultural crops has been studied for several species, taking into account the interpretation of soil and leaf tissue analyses, aiming to improve productivity by fertilization (ROZANE; NATALE, 2014; MARROCOS et al., 2020). However, in perennial plants, especially fruit-bearing ones, where fruits are removed from the orchard for later commercialization, the export of nutrients by the fruit should also be taken into account (SÃO JOSÉ et al., 2014). The determination of nutrient exports by fruits is important for calculations and effective nutrient replacement for crops, ensuring the increase or maintenance of fruit productivity and quality (AULAR; NATALE, 2013).

The cupuassu genetic improvement program of Embrapa Eastern Amazon registered by the Ministry of Agriculture, Livestock and Food Supply (MAPA), includes cultivars under codes 28732, 28733, 28735, 28741 and 28744, in 2020, whose denominations are: ‘BRS Careca’, ‘BRS Fartura’, ‘BRS Duquesa’, ‘BRS Curinga’ and ‘BRS Golias’, respectively. Considering the growing demand of the fruit sector for the development of new cupuassu cultivars, these cultivars were used in this study for several reasons: they provide high fruit productivity, are resistant to the fungus *Moniliophthora perniciosa* (witches' broom) and are mainly intended for use in the replacement of canopies in old low-productivity orchards. Furthermore, they are used in the production of grafted seedlings to form new orchards (ALVES; CHAVES, 2020) and are indicated for agroforestry systems (ALVES; CHAVES, 2022). Nutrition studies with cupuassu cultivars are scarce and, therefore, studies on the export of nutrients by fruits are necessary to propose nutrient replacement recommendations acement program for the crop.

In this context, this study aimed to quantify the macro and micronutrient exportations by fruits of different cupuassu genotypes and to recommend a nutrient replacement program.

Material and Methods

Location, climate and soil

The study was developed in the experimental area of the Embrapa Eastern Amazon, in the municipality of Tomé-Açu (02˚26'08'' S; 48˚09'08'' W), state of Pará, Brazil. The work was carried out in a cupuassu orchard, whose plants underwent a grafting process 13 years ago by the crown grafting technique with 16 improved genotypes (ALVES et al., 2020). Of this total, six genotypes were used in this study, and 'BRS Careca', 'BRS Fartura', 'BRS Duquesa', 'BRS Curinga', 'BRS Golias' cultivars were made available to producers at the beginning of 2022. 'Genotype 63' (in the final genetic improvement phase), which was also used in this study, was selected due to its large fruits and desirable physicochemical characteristics of the pulp (VIEIRA et al., 2022).

The average monthly rainfall and temperature in the experimental area are shown in Figure 1. These data were obtained during the 2017/2018 harvest, through the meteorological station located at Embrapa Eastern Amazon. The observation period started in May 2017, when plants underwent leaf renewal, starting the crop cycle, and lasted until April 2018, with the end of the fruit collection period. The total rainfall was 2.331 mm, enough for the crop development. The region presented relative humidity of around 84.80%, characterizing a mesothermal and humid climate, classified as Ami type, according to the Köppen classification (BOLFE; BATISTELLA, 2011).

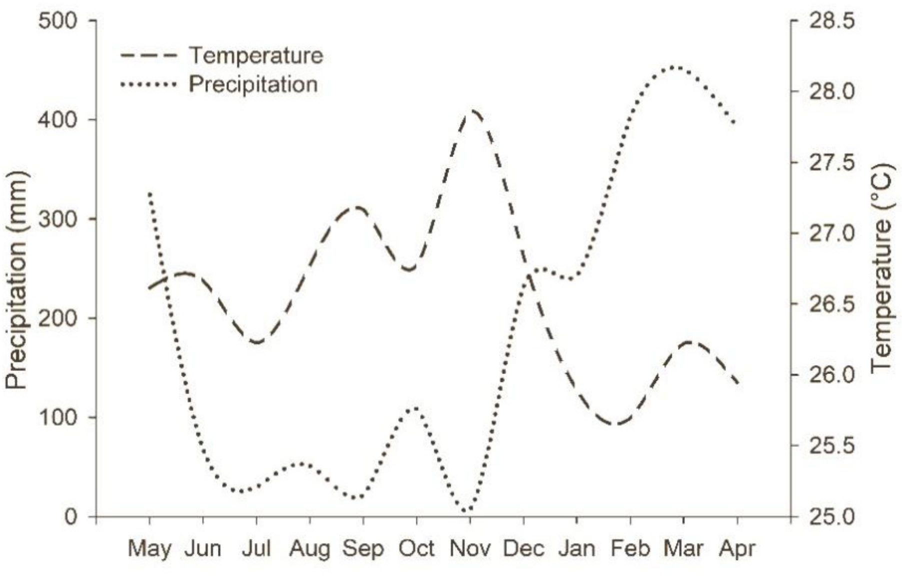

Figure 1. Average monthly rainfall and temperature during the 2017/2018 cupuassu harvest in Tomé-Açu, Pará, Brazil.

For chemical and physical soil analyses, soil samples were collected at depths of 0-20 and 20-40 cm in the canopy projection of cupuassu plants, determining their fertility and granulometry. The results for 0-20 and 20-40 layers were respectively: pH (H_2O) = 5.20 and 5.15; P (Mehlich-1) = 134.20 and 96.80 mg dm^{-3}; K (Mehlich-1) = 38.80 and 31.00 mg dm^{-3}; Ca = 1.96 and 1.46 cmolc dm^{-3}; Ca+Mg = 2.60 and 1.96 cmol$_c$ dm^{-3}; Al $^{3+}$ = 0.40 and 0.38 cmol$_c$ dm^{-3}; H+Al = 5.64 and 4.31 cmol$_c$ dm^{-3}; Cation Exchange Capacity (CEC pH 7.0) = 8.37 and 6.37cmol$_c$ dm^{-3}; Ca-Mg-K-Na saturation (V)=32.70 and 32.30%; Sand = 615 and 551 g kg^{-1}; Silt = 61 and 69 g kg^{-1}; Clay = 324 and 380 g kg^{-1}. The soil in the region is classified as Ferralsols (IUSS Working Group WRB, 2015).

Experimental design and treatments

The experiment was designed in completely randomized blocks with six genotypes ('BRS Careca', 'BRS Fartura', 'BRS Duquesa', 'BRS Curinga', 'BRS Golias' and 'Genotype 63'), the experimental unit was composed of 40 fruits collected from the eight plants of each genotype. Fruits were collected and selected during peak production from January to March 2018, totaling 240 fruits from of the six genotypes evaluated.

Plants from of the six genotypes were arranged in the field with spacing of 6 x 5 m, cultivated without irrigation during the rainy season and in the months with low rainfall and high temperatures (Figure 1), the irrigation system used 60 liters of water per plant per day to satisfy the crop needs. Annually, the area received 300 g plant^{-1} of agricultural limestone to meet Ca and Mg demands, being also fertilized with 1500 g plant^{-1} of N, P, K with 10-28-20 formulation, and 50 g plant^{-1} of fritted trace elements (FTE) BR12 (mixed granulated mixture of micronutrients containing 9% of Zn, of 1.80% of B, 0.80% of Cu, 2% of Mn and 0.10% of Mo) and another 200 g of KCl plant^{-1}.

Biometric and nutritional analyses

During data collection of cupuassu production, the number of fruits per plant and the average weight of five fruits per plant were recorded. Thus, it was possible to estimate the fruit yield per plant in ton per hectare [Yield (ton ha^{-1})= number of fruits x average weight of fruits (kg) x 333 plants per hectare/1000]. Fruits were broken and manually pulped using stainless steel scissors. After pulping, fruits were separated into peel, seed and pulp. A digital scale was used to measure fresh and dry fruit masses.

Peels and seeds were dried in a forced ventilation oven at 65ºC until constant mass. Then, samples were reduced to powder in Willey mills. Pulps were freeze-dried through the following procedures: first frozen in conventional freezer for 24 h (-18ºC) and then placed in lyophilizer for 96 hours.

In dried samples (peel, pulp and seed), macro and micronutrient contents were analyzed. The nitrogen (N) content was determined by digestion with H_2SO_4 by the colorimetric assay, with Nessler reagent (JACKSON, 1965) and reading was performed in spectrophotometer (Specord 210, Analytik Jena, Jena, Germany).

Phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), molybdenum (Mo) and nickel (Ni) contents were obtained after the digestion of concentrated nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) in an open digestion system, being quantified using induction-coupled plasma source emission spectrometry (ICPE-9000, Shimadzu®) (PETERS, 2005).

The export of macro and micronutrients in peel, seed and pulp were calculated by the relationship between the dry mass and the nutrient concentration in each fruit part. From these values, the export of nutrients per ton of fresh fruits was estimated. With the average values of nutrients exported by each genotype, the nutrient replacement recommendation per plant was based on an area of one hectare of cupuassu. The exported K, P, Ca, Mg, and S values were transformed into K_2O, P_2O_5, CaO, MgO, and SO_4^{-2} by multiplying factors 1.20; 2.29; 1.39, 1.69 and 3.03, respectively. Subsequently, the use of nutrients by plants was calculated using the absorption efficincy indices, i.e.: N = 50%, P = 30%, K = 60%, Ca and S = 80% and Mg = 70% (BALIGAR; BENNETT, 1986; VITTI; VIEIRA, 2016).

Statistical analysis

Analysis of variance (ANOVA) was performed and when significant difference was identified by the F test, the Tukey's test was performed at 5% probability, using the ExpDesp.pt package (FERREIRA et al., 2014) in R (R CORE TEAM, 2014).

Results and Discussion

Cupuassu yield

The number of fruits per plant and the fresh and dry masses of the six cupuassu genotypes are described in Figure 2. 'BRS Curinga', 'BRS Fartura', 'BRS Duquesa' and 'Genotype 63' genotypes had the highest fruit yields, with average values above 35 fruits per plant (Figure 2A). These four genotypes showed fruit yields above 20 ton ha^{-1} (Figure 2C). However, 'BRS Duquesa' fruits were heavier than those of the other genotypes, with average fresh mass value of 1984.13 g per fruit, and consequently higher dry mass (657.20 g), and fruits of this genotype presented 51.70% of its mass composed of pulp mass and seed mass (VIEIRA et al., 2022).

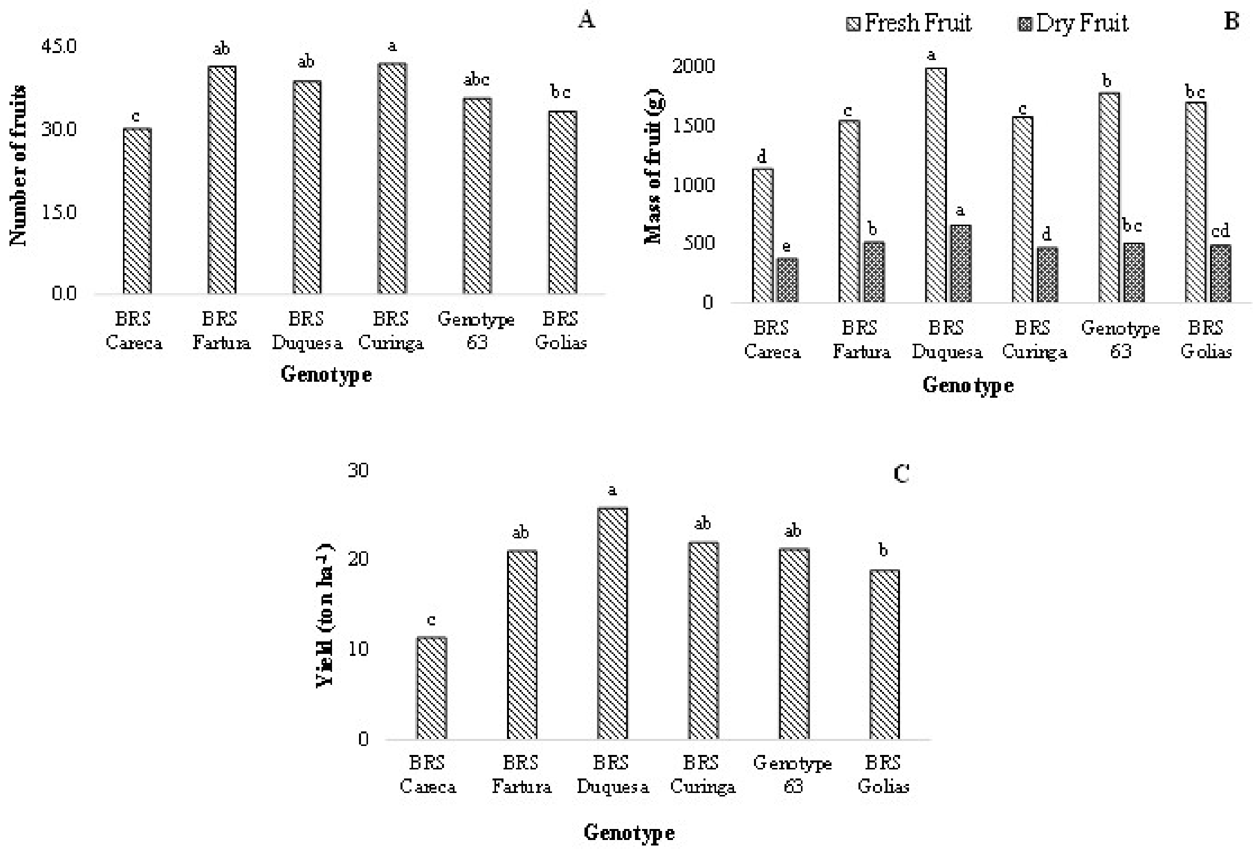

Figure 2. Number of fruits per plant (A), fruit fresh and dry mass (B) and yield (C) of cupuassu genotypes. Averages followed by different letters differ significantly between genotypes based on the Tukey's test at 5% probability.

The 'BRS Careca' genotype presented the lowest values for these variables, with the lowest fruit yield (11.33 ton ha^{-1}) (Figure 2 C), produced few fruits per plant (30.10), and fruits were small, with lower fresh and dry masses (Figure 2B). However, for variable number of fruits, this genotype did not differ from 'Genotypes 63' and 'BRS

Golias' genotypes. Similar result was observed by Alves et al., (2020), studying the 'BRS Careca' genotype, which presented lower production. Nevertheless, these authors recommended this genotype because it is highly resistant to witches' broom (*Moniliophthora perniciosa*) and has high pulp and seed index, when compared to the other genotypes (ALVES et al., 2020). Therefore, studies on the export of nutrients by fruits are important, as they can determine the best option for producers depending on the local conditions.

Nutrient exportation

Table 1 presents the average values of macronutrients exported by fruit parts of the six cupuassu genotypes. Based on the average values, the export of nutrients followed the descending order: peel: K > N > P > Mg > Ca = S; seed: N > K > P > Mg > S >Ca; and pulp: K > N > P = S > Ca > Mg, respectively.

Table 1. Macronutrient exportations by peel, seed and pulp in fruits of six cupuassu genotypes cultivated in the Brazilian Amazon.

	Genotype	N	P	K	Ca	Mg	S
g peel^{-1} (dry peel)	BRS Careca	0.75d	0.20d	2.05e	0.12e	0.18e	0.12d
	BRS Fartura	1.25c	0.31c	3.09d	0.16d	0.25bc	0.21b
	BRS Duquesa	1.55b	0.53a	4.25b	0.37a	0.40a	0.24a
	BRS Curinga	1.36c	0.41b	4.14b	0.23b	0.27b	0.19c
	Genotype 63	1.79a	0.38b	6.72a	0.19c	0.22d	0.24a
	BRS Golias	1.77a	0.30c	3.64c	0.18c	0.24cd	0.24a
	Average	1.41	0.36	3.98	0.21	0.26	0.21
	CV%	16.28	11.94	11.62	18.44	16.35	15.55
g seed^{-1} (dry seed)	BRS Careca	1.53d	0.32c	0.84d	0.13a	0.35c	0.13c
	BRS Fartura	2.03b	0.48a	0.97b	0.09b	0.43a	0.17a
	BRS Duquesa	2.43a	0.29c	0.37e	0.05d	0.18d	0.09d
	BRS Curinga	1.66cd	0.28c	0.41e	0.08c	0.17d	0.06e
	Genotype 63	1.79c	0.42b	1.05b	0.09b	0.40b	0.15b
	BRS Golias	1.66cd	0.44ab	1.21a	0.09b	0.42ab	0.14bc
	Average	1.85	0.37	0.81	0.09	0.33	0.12
	CV%	15.37	18.20	11.66	11.18	13.76	15.83
g pulp^{-1} (lyophilized pulp)	BRS Careca	0.75d	0.08d	1.17e	0.07d	0.03d	0.09e
	BRS Fartura	1.09c	0.11c	1.67d	0.10c	0.04c	0.12cd
	BRS Duquesa	1.47a	0.17a	3.03a	0.16a	0.07a	0.18a
	BRS Curinga	1.08c	0.14b	2.07c	0.09c	0.04c	0.13bc
	Genotype 63	1.11bc	0.14b	2.27b	0.10c	0.05b	0.14b
	BRS Golias	1.18b	0.15b	2.13bc	0.12b	0.05b	0.11d
	Average	1.11	0.13	2.22	0.11	0.05	0.13
	CV%	11.53	16.92	14.15	17.93	16.90	18.44
General average		**4.37**	**0.86**	**6.99**	**0.41**	**0.58**	**0.46**

Means followed by different letters within each fruit share differ significantly between genotypes based on the Tukey test at 5% significance. General average and coefficient of variation (CV) estimated in fruits of six cupuassu genotypes.

Potassium was the nutrient most exported by cupuassu pulp and peel. Thus, studies on this nutrient are important to address nutrient replacement recommendations for the cupuassu crop. Potassium plays an important role in fruit formation, acting in the transport of photoassimilates in the phloem (MARSCHNER, 2012). The peel accounted for 56.90% of K exports, and 'Genotype 63' genotype exported higher percentage of this nutrient in relation to the whole fruit, i.e. more than half of K exports by cupuassu fruits are through fruit peel, confirming that the peel should return to the crop after its processing. Silva (2009) and Souza Júnior et al. (2012) observed similar effect in cocoa (*Theobroma cacao* L.), where K was the nutrient most exported by cocoa peels. In this culture, fruit peels are returned to the crop in a concentrated way through the 'casqueiro', a pile of decomposing peel.

Nitrogen was the second nutrient most exported by the peel of genotypes under study, with total of 32.30% when compared to the total fruit exports. 'BRS Golias' and 'Genotype 63' genotypes presented the highest export values through peel, while 'BRS Careca' had the lowest average export values. 'BRS Duquesa' exported more N through pulps and seeds compared to the other genotypes. These results highlight the importance of studying genotypes separately and at the end, make an average nutrient replacement recommendation to meet the needs of all genotypes. Nitrogen was the nutrient most exported by cupuassu seeds. Likewise, it was the nutrient most exported by cocoa almonds (SILVA, 2009; SANTOS, 2018). This can be explained by the composition of seeds of species of the genus *Theobroma*, which are rich in lipids, proteins and carbohydrates (MARTINNI; TAVARES, 2005), and N is a constituent of chlorophyll, amino acids, proteins, alkaloids and protoplasm (MOHIDIN et al., 2015). In cupuassu almonds (defatted powder), the average protein content is around 28.14% (LOPES et al., 2008); therefore, there is high N accumulation in this fruit part.

Phosphorus was the third macronutrient most exported by the different fruit parts (Table 1). Similar results were observed in soursop fruits (GOMES JUNIOR et al., 2018) and watermelon fruits (AGUIAR NETO et al., 2016), in which P export was only lower than K and N exports. In this study, the average P export by fruits of the different genotypes, was 0.90 g fruit^{-1}. Peel and seed together accounted for 84.90% of the total P exports among analyzed genotypes. Regarding the P export by the peel and pulp, 'BRS Duquesa' presented the highest values. On the other hand, when seeds were analyzed, 'BRS Fartura' and 'BRS Golias' genotypes exported more P in this fruit part than the other genotypes, and 'BRS Golias' did not differ from 'Genotype 63'.

Macronutrients Ca, Mg and S had lower values exported by the different parts of cupuassu fruits (Table 1). 'BRS Duquesa' exported more Ca and Mg in the peel and pulp, and higher amount of S in the pulp compared to the other genotypes. Both Ca and Mg exports were lower than those observed by Costa (2006). This author studied the nutrient exports by cupuassu fruits grown in three soils of the state of Amazonas, Brazil, and observed values ranging from 0.67 to 1.07 g fruit^{-1} (Ca) and 0.70 to 1.05 g fruit^{-1} (Mg). The lower values for these two nutrients may be related to their nutritional demand variation, which is possibly due to different management practices, soil type, nutrient availability, climatic conditions and cultivar. In the soil of this study, Ca and Mg contents added together were around 2.60 $cmol_c$ dm^{-3}, lower than those analyzed by Costa (2006), in which contents reached 12.40 $cmol_c$ dm^{-3} at the same depth (0-20cm).

Micronutrient exports (Table 2) in the different fruit parts followed the order: Zn > Fe >Mn> Cu > Mo > Ni (peel), Zn > Fe > Cu >Mn> Ni > Mo (seed), and Fe > Zn > Cu = Mn> Mo > Ni (pulp). Zinc was the nutrient most exported by the different fruit parts of the analyzed genotypes, except for pulp, which was Fe (Table 2). Seeds accounted for 49.10% of Zn exports compared to the whole fruit. Zinc exports were lower than those observed by Costa (2006), and this difference may be related to the high P concentration in the soil of this study, since excessive P applications in the soil can induce low Zn concentrations in plant tissues (ZHANG et al., 2017). Moreover, these genotypes were different from those used in the study by Costa (2006), which could present different nutrient allocation.

Table 2. Micronutrient exportations by peels, seeds and pulps in fruits of six cupuassu genotypes cultivated in the Brazilian Amazon.

	Genotype	Zn	Fe	Cu	Mn	Ni	Mo
mg peel^{-1} (dry peel)	BRS Careca	2.84d	2.23d	0.85d	1.91e	0.08b	0.05c
	BRS Fartura	3.70bc	2.63b	1.03bc	3.02c	0.07b	0.09b
	BRS Duquesa	5.49a	4.08a	1.09ab	6.13a	0.11a	0.12a
	BRS Curinga	3.77bc	2.97c	0.91cd	3.99b	0.05c	0.09b
	Genotype 63	3.38c	3.83cd	1.21a	2.70cd	0.06c	0.13a
	BRS Golias	3.92b	5.40 a	0.78d	2.36d	0.06c	0.13a
	Average	3.85	3.52	0.98	3.35	0.07	0.10
	CV%	16.64	28.43	23.43	17.43	24.45	20.38
mg seed^{-1} (dry seed)	BRS Careca	5.30b	2.67b	2.01b	1.53ab	0.21a	0.05b
	BRS Fartura	6.87a	3.06a	1.86b	1.76a	0.19a	0.06a
	BRS Duquesa	3.96c	1.03d	1.79b	0.97d	0.07d	0.04b
	BRS Curinga	2.41d	0.94d	1.69b	1.21cd	0.06d	0.05b
	Genotype 63	5.44b	2.44c	2.78a	1.55ab	0.14c	0.05b
	BRS Golias	4.64b	2.68b	1.98b	1.42bc	0.17b	0.06a
	Average	4.77	2.14	2.02	1.41	0.14	0.05
	CV%	17.33	16.14	25.67	27.68	22.47	27.12
mg pulp^{-1} (lyophilized pulp)	BRS Careca	0.79d	1.87cd	0.71c	0.59d	0.06b	0.021c
	BRS Fartura	0.92cd	2.54b	0.75bc	0.79bc	0.06b	0.034b
	BRS Duquesa	1.79a	3.19a	1.32a	1.54a	0.08a	0.06 a
	BRS Curinga	1.01bc	2.06c	0.92b	0.65cd	0.07b	0.033b
	Genotype 63	1.11b	1.69cd	0.92b	0.85b	0.06b	0.030b
	BRS Golias	0.93cd	1.49d	0.41d	0.56d	0.05b	0.029b
	Average	1.09	1.97	0.83	0.83	0.06	0.034
	CV%	9.71	7.63	3.84	5.59	0.27	0.18
General average		**22.64**	**28.43**	**37.33**	**27.49**	**25.61**	**38.37**

Means followed by different letters within each fruit share differ significantly between genotypes based on the Tukey test at 5% significance. General average and coefficient of variation (CV) estimated in fruits of six cupuassu genotypes.

In this sequence, Fe, Mn and Cu were the micronutrients with relevant export values. Exports were on average 7.63, 5.59, and 3.84 mg fruit^{-1} for Fe, Mn and Cu, respectively (Table 2). In the order of micronutrient export, Ni and Mo were the least exported by fruits, with averages of 0.27 and 0.18 mg fruit^{-1} (Table 2). Although absorbed in small amounts by plants, micronutrients are critical as they play specific roles in plant growth, development, and metabolism (TRIPATHI et al., 2015). Thus, studies on micronutrient export by different plant parts are essential for a balanced management of fertilization of the cupuassu crop.

Nutrient exports per ton of fresh fruit are presented in Table 3 in the following decreasing order: K > N > P > Mg > S > Ca (macronutrients), and Zn > Fe >Mn> Cu > Ni > Mo (micronutrients). Potassium was the macronutrient most exported by cupuassu fruits, and ‘Genotype 63’ accounted for the largest exports per ton of fresh fruits of this nutrient. Similar results were observed by Cravo and Souza (1996), with 4.96 kg ton^{-1} and close to those observed by Cunha (2012), analyzing two genotypes (186 and 215) in which the K export value was 6.62 kg ton^{-1} in fresh cupuassu fruits.

Table 3. Export of macro and micronutrients per ton of fresh fruits of six cupuassu genotypes.

Genotype	Macronutrients (kg ton^{-1} of fresh fruits)						Micronutrients (g ton^{-1} of fresh fruits)					
	N	P	K	Ca	Mg	S	Mn	Fe	Mo	Ni	Cu	Zn
BRS Careca	2.67b	0.54b	3.61d	0.28ab	0.50a	0.30b	3.59b	6.03a	0.10c	0.31a	3.17a	7.94a
BRS Fartura	2.88a	0.59a	3.79d	0.24c	0.47a	0.32a	3.67b	5.44b	0.12ab	0.21b	2.40c	7.58a
BRS Duquesa	2.78ab	0.51b	3.91cd	0.29a	0.33d	0.26c	4.40a	4.28cd	0.11bc	0.14d	2.16cd	5.73b
BRS Curinga	2.61b	0.54b	4.26b	0.27b	0.31d	0.24c	3.77b	3.84d	0.10c	0.11e	2.26c	4.64c
Genotype63	2.68b	0.54b	5.72a	0.23c	0.38c	0.30b	2.90c	4.51c	0.12ab	0.15d	2.80b	5.65b
BRS Golias	2.76ab	0.53b	4.19bc	0.24c	0.43b	0.30b	2.59c	5.72ab	0.13a	0.17c	1.89d	5.88b
Average	**2.73**	**0.54**	**4.34**	**0.26**	**0.40**	**0.29**	**3.49**	**4.97**	**0.11**	**0.18**	**2.45**	**6.24**
CV (%)	**11.16**	**13.32**	**11.72**	**14.22**	**12.39**	**12.31**	**14.55**	**15.04**	**16.60**	**16.43**	**18.62**	**12.91**

Means followed by different letters differ significantly from each other based on the Tukey test at 5% significance. CV: coefficient of variation.

Regarding fruit formation, K plays an important role in the transport of photoassimilates in the phloem (MARSCHNER, 2012). Given its importance in other crops, it is the nutrient most exported by *Malpighia emarginata* (LIMA et al., 2008), *Musa* spp. (HOFFMANN et al., 2010), *Annona muricata* (GOMES JÚNIOR et al., 2018) and *Passiflora alata* fruits (DUTRA et al., 2015).

Nitrogen was the second nutrient most exported among macronutrients, with values ranging from 2.61 to 2.88 kg ton^{-1} of fresh fruits, 'BRS Fartura' genotype exported more P by fruits and the other genotypes did not differ statistically from each other.

Phosphorus was the third macronutrient most exported among cupuassu genotypes, with values ranging from 0.51 to 0.59 g ton^{-1} of fresh fruit.

Calcium, Magnesium and Sulfur were the least exported by fresh fruits among analyzed genotypes. According to Souza Júnior et al. (2012), the deficiency frequency of these nutrients is low in Brazilian cocoa crops.

Calcium was the least exported macronutrient. Fruits face challenges in terms of nutrition and Ca physiology as this nutrient is immobile in the plant, thus limiting its distribution to fruits (HOCKING et al., 2016). Among genotypes under study, 'BRS Duquesa' (0.29 kg ton^{-1}) was the one that most exported Ca, followed by 'BRS Careca' and 'BRS Curinga' (0.28 and 0.27 kg ton^{-1}, respectively). These values are similar to those observed by Cravo and Souza (1996), which exported 0.22 kg ton^{-1} of Ca in fresh fruits.

Magnesium export varied among genotypes, and the highest exports were observed for 'BRS Careca' and 'BRS Fartura' genotypes (0.50 and 0.47 kg ton^{-1} of fresh fruits, respectively), and it was observed that these genotypes exported more S (Table 1).

'BRS Careca' genotype presented higher export of micronutrients Fe, Ni, Cu and Zn. Cupuassu fruits exported more Zn and Fe, followed by Mn and Cu. Similarly, the most exported micronutrients of 15 mango tree cultivars were Fe, Zn, Mn and Cu (AQUINO et al., 2014). In this study, Zn export ranged from 4.64 to 7.94 g ton^{-1} of fresh fruits for 'BRS Curinga' and 'BRS Careca', respectively. 'BRS Careca' exported more Fe, Ni, Cu and Zn. Overall, Mn was the third micronutrient most exported among genotypes, and 'BRS Duquesa' presented the highest Mn export by fresh fruits.

The micronutrients exported in smaller amounts were Mo and Ni, ranging from 0.10 to 0.13 g ton^{-1} and 0.11 to 0.31 g ton^{-1} of fresh fruits, respectively. Although required in small amounts by plants, micronutrients deserve special attention because they are vital for the growth and reproduction of fruit trees (FACHINELLO et al., 2012).

Nutrient replacement

Maintenance fertilization basically aims at the replacement of nutrients that were exported through the harvest. In this sense, taking into account that the genotypes used in this study have different productions, and diverge in terms of nutrient exports, fertilizations were individually calculated for each genotypes (Table 4), thus avoiding unnecessary fertilizer applications, preventing nutritional imbalances to plants and negative impacts on the environment, and also avoiding unnecessary economic expenses to the producer.

Table 4. Nutrient replacement recommendation for cupuassu genotypes in the 6 x 5 m spacing.

Genotype	N	P_2O_5	K_2O	CaO	MgO	SO_4^{-2}	FTE*
				g plant^{-1}			
BRS Careca	182.28	140.56	245.46	16.61	40.96	38.78	10.29
BRS Fartura	366.37	286.18	480.21	26.52	71.74	77.09	17.30
BRS Duquesa	427.48	299.01	598.84	38.74	60.89	75.71	16.45
BRS Curinga	343.35	270.86	558.18	30.86	48.93	59.79	12.63
Genotype 63	338.76	260.26	720.13	25.26	57.64	71.81	14.25
BRS Golias	310.90	227.63	470.09	23.49	58.12	61.86	16.11

*FTE: Fritted Trace Elements

The amount of fertilizer per plant recommended for ‘BRS Careca’ was the lowest compared to the other genotypes (Table 4) because this genotype presents low fruit production (Figure 2). Moreover, ‘Genotype 63’ requires higher amount of K_2O since the amounts of nutrients exported per ton of fresh fruits were higher for this genotype (Table 3). In addition, K exports by peel (Table 1) contribute to the high values of recommended nutrient replacement for this genotype. Therefore, these values can be subtracted if producers choose to return the fruit peel to the production orchard and to enrich soil fertility via nutrient cycling in the ecosystem, reported by Mohammed et al., (2020) for cocoa crop residues.

Since the five clones (BRS Careca, BRS Fartura, BRS Duquesa, BRS Curinga and BRS Golias) launched in 2022, also called Cupuassu 5.0 clonal kit, present high productivity of both pulp and seed and resistance to witches’ broom, they have the potential to become an important bioeconomy and development strategy for producers. To cultivate the plants, as they are clones, which complement each other, they must be planted simultaneously and arranged in the field in an interspersed manner.

In this sense, fertilization of clones in an individualized way is not possible. Thus, the average nutrient replacement value for the five cultivars that make up the clonal kit was calculated; taking into account the spacing of 6 x 5 m (333 plants ha^{-1}) and the nutrients exported per ton of fruits. For this, a recommendation is suggested for K, the most exported nutrient, replacement fertilization of 471 g plant^{-1} of K_2O. For N, replacement of 326 g plant^{-1} of N per harvest. Phosphorus was the third macronutrient most exported, and the recommendation of 245 g plant^{-1} of P_2O5 is suggested. For Ca, Mg and S replacement, 27 g of CaO, 56 g of MgO and 63 g of SO_4^{-2} per plant^{-1}, respectively, is suggested. In addition as a source of micronutrient, the use of 15 g plant^{-1} of FTE is recommended.

Conclusions

The export of nutrients followed this order for macronutrients (kg ton^{-1} of fresh fruits): K (4.34), N (2.73), P (0.54), Mg (0.40), S (0.29), Ca (0.26), and for micronutrients (g ton^{-1} of fresh fruits): Zn (6.24), Fe (4.97), Mn (3.49), Cu (2.45), Ni (0.18), and Mo (0.11). Since fruit peel presents high K export, this fruit part should be returned to crops, i.e., it should be used as a substrate in seedling preparation.

For greater precision in the maintenance fertilization (nutrient replacement) of cupuassu orchards, recommendations should also be based on the exports of nutrients by fruits.

The average replacement per plant and per year, during the productive phase, for the five genotypes that compose the Cupuassu 5.0 clonal kit is 471 g of K_2O, 326 g of N, 245 g of P_2O_5, 27 g of CaO, 56 g of MgO, 63 g of SO_4^{-2} and 15 g of plant^{-1} of FTE.

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