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Nutrient partition and nutritional efficiency of mango cv. Palmer as a function of plant age in São Francisco Valley, Brazil

Partição de nutrientes e eficiência nutricional da mangueira cv. Palmer em função da idade das plantas no Vale do São Francisco, Brazil

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Highlights

Fertilizer recommendation in mango orchards is essential for commercial production.
Proper fertilization management in mango is empirical due to lack of nutritional data.
Mango fertilizer management in Brazilian Semiarid region needs calibration studies.
Nutrient accumulation and partitioning were determined in mango commercial orchards.
For mango biomass and fruit production, P, Mg, Cu, and B are more efficient.

Abstract

Knowing the accumulation of nutrients in mango plants is essential for calibrating fertilization programs aiming to increase yield in nutritionally unbalanced orchards. The work aimed to evaluate mango nutritional efficiency through nutrient accumulation and partitioning in plants of Palmer cultivar grown in sand soils at São Francisco Valley, Northwest Brazil. Commercial orchards located in Bahia and Pernambuco States, Brazil, under semi-arid climate (BShw; 400-800 mm annual rainfall) had the vegetable biomass and nutrient contents in the mango compartments determined in 1, 2, 4, 7, and 12 years old plants, by evaluating four plants of each age from 20 sample units. The separated samples of the harvested trees originated the compartments roots, stems, thick twigs, thin twigs, leaves and fruits. Nutrient contents and plant dry matter per compartment were determined and plant nutrient accumulation evaluated. Biomass and fruits coefficient of biological utilization were calculated. There was increment in the accumulated content of

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macronutrients in the mango plants over the years, with superiority for N and K, for which there was a sharp increase as compared to the other macronutrients. Manganese and Fe were the most accumulated micronutrients in the plants over the years. The canopy of the mango Palmer plants is the compartment that accumulates more macro and micronutrients, and the partition within the canopy occurs in the sequence: leaf> thin twig> thick twig. Phosphorus and Mg, and Cu and B are the nutrients more efficient to generate plant biomass and fruit production in the mango Palmer orchards.
Key words: Nutrient accumulation. Biological coefficient utilization. *Mangifera indica* L.

Resumo

Informações sobre o acúmulo de nutrientes em plantas de mangueira é requisito essencial para calibrar um programa de adubação visando aumento de produtividade em pomares com nutrição desbalanceada. Objetivou-se avaliar o acúmulo e partição de nutrientes e a eficiência nutricional em mangueira 'Palmer' com diferentes idades na região do Vale do São Francisco. As áreas de estudo estão localizadas nos municípios de Casa Nova, Bahia, e de Petrolina, Pernambuco, sob clima semiárido, com precipitação variando de 400 à 800 mm durante o ano. Foi quantificada a biomassa vegetal e calculados os conteúdos dos nutrientes nos compartimentos das plantas de mangueira com idades 1, 2, 4, 7 e 12 anos, sendo avaliadas quatro plantas por idade, totalizando 20 unidades amostrais. As árvores-amostra foram abatidas e separadas em raiz, caule, galho grosso, galho fino, folhas e frutos, para obtenção do conteúdo de nutrientes por compartimento. Em cada compartimento foi quantificada a massa de matéria seca e os teores de alguns nutrientes, calculando-se o conteúdo de cada nutriente e estimando-se o seu acúmulo. Houve incremento no conteúdo acumulado dos macronutrientes nas plantas de mangueira ao longo dos anos, com superioridade para o N e o K, que obtiveram aumento acentuado em relação aos demais macronutrientes. Manganês e Fe foram os micronutrientes mais acumulados nas plantas ao longo dos anos. A partição de macro e micronutrientes na mangueira 'Palmer' ocorreu, geralmente, nos compartimentos que compõem a copa das plantas, e nessa sequência: folha> galho fino > galho grosso. Fósforo, Mg, Cu, e B são os nutrientes com maior eficiência na produção de biomassa e frutos da manga Palmer.
Palavras-chave: Acúmulo de nutrientes. Coeficiente utilização biológico. *Mangifera indica* L.

Introduction

The mango tree (*Mangifera indica* L.) is a plant originated from Southwest Asia and disseminated into almost all world regions, being considered a typically tropical fruit tree species of high expressivity in the international agribusiness (Miguel et al., 2013). Besides the "Tommy Atkins", several other cultivars originated from Florida, such as the "Keitt" and "Kent", were introduced in Brazil around 1970, although the interest in the production of mango for export started only in 1980 (Pinto et al., 2009). The Northeast and Southeast regions possess the largest areas of mango production in Brazil. In the Northeast, the São Francisco Valley stands out as the area with highest mango production (Mitra, 2016). However, the average national production is still low if considered the potential of Brazilian production. Low yields are often associated with the deficient use of production resources, and a nutritional management that does not answer the plant demands (Carneiro et al., 2017).

The nutritional demand of the mango crop through the vegetative cycle and the knowledge of the nutrient content in the plant, especially in the harvested parts, is fundamental in order to evaluate the removal of these elements in the cultivation area and to aid in the recommendation of fertilization programs (Sinha et al., 2017). Studies on the analysis of growth, uptake and accumulation of nutrients in the plant growth stages provide indications of the times when the plant uptakes and accumulates nutrients at greater or lesser extent, and allows to follow up the plant development throughout its productive cycle (Natale et al., 2012).

The average nutrient contents and sodium in mango fruits obey the following descending order: K > N > P > Mg > Ca > Na and Fe > Mn > B > Zn > Cu (Sinha et al., 2017). In order to determine the nutritional requirements, it is necessary to know the growth curve and the nutrient extraction by fruits in the various stages of development within the productive cycle (Costa et al., 2011). In addition, it is necessary to quantify how much of the absorbed nutrients are immobilized in the plant compartments (roots, stem, twigs and leaves) (Verlindo et al., 2014).

In spite of the technological advances in mango culture, the available mineral fertilization is yet empirical, since the information about the proper nutritional management for the plant is scarce. Therefore, further studies on mango nutrition are needed to stablish more reliable mineral fertilization programs (Carneiro et al., 2017).

The aim of the present work was to evaluate the accumulation, partition and the efficiency of nutrient utilization in mango cv. Palmer plants of different ages in orchards in the São Francisco Valley region, Brazil.

Material and Methods

Location

The experiment was carried out in commercial mango orchards (Palmer cultivar) located in the cities of Petrolina, Pernambuco State, and Casa Nova, Bahia State, Brazil, with plants 1, 2, 4, 7 and 12 years old.

Characterization of study areas

Area 1

Property of 14 ha, located in the Senador Nilo Coelho Irrigation Perimeter - Nucleus 10, Petrolina - PE, under the geographical coordinates: 9°18'12.27" S, 40°25'12.46" W, and average elevation of 379 m. The climate of the region is semi-arid (BSwh') (Alvares et al., 2013), with annual precipitation not exceeding 500 mm, concentrated in three to four months of the year. The native vegetation is the hyperxerophyle Caatinga. The mango tree samples were withdrawn from an area of approximately 3 hectares within the orchard, which was planted in succession to a coconut orchard that remained in the area for a period of 20 years (1996 - 2016). The mango orchard was planted in a 6 × 3 m plant spacing in 2014; later, in 2015, the tree density was increased up to the plant spacing of 6 × 1.5 m, which is a tendency of mango growers in order to reach higher fruit yields, as also verified by Cavalcante et al. (2018). At planting, each planting hole received a base-dressing fertilization with 120 g of phosphorus (single super phosphate), and in the second month after transplanting it received 150 g $hole^{-1}$ of nitrogen in the form of ammonium sulfate. Topdressing fertilizations were performed

with nitrogen and potassium, applying 210 and 40-80 g per plant in the second and third years, respectively, following the instructions of Genú and Pinto (2002). In the first year, the plants were pruned in order to break the apical dominance and to allow the launching of new branches for the plant canopy formation. In the second year, the plants were pruned two more times for the plant canopy formation, staying with three defined branches. The plants were cut down in 2016, at ages of 1 and 2 years. Before harvesting, soil and leaf samples were collected in order to evaluate the soil fertility and nutritional status of the orchard. The irrigation system was set with the micro sprinkler method, with the water being piped and distributed to the plants through sprinklers, supplying for each plant the equivalent to 150 liters per day. Irrigation management was performed based on crop evapotranspiration (ETc, mm), determined through the multiplication of the reference evapotranspiration (ETo, mm) and the crop coefficient (Kc), as defined by Soares et al. (2006).

Area 2

Property of approximately 30 hectares, located at the Herculano Agrícola farm in Casa Nova - BA, under the geographic coordinates: 09º11'43.5" S, 41º01'59.2" W, and average elevation of 400 m. The climate of the region is BSwh' (semiarid) (Alvares et al., 2013), with annual precipitation below 500 mm, concentrated in three to four months of the year. The native vegetation is hyperxerophyle Caatinga. The planting of the mango orchard (2005) succeeded a coconut orchard that had been cultivated in the area for a period of 10 years (1995-2005). The plant spacing for the mango plants was set as 7 × 7 m, and later modified to 7 × 3.5 m, after eight years (2013), in order to increase the plant density. In order to break the apical dominance and to allow the launching of new branches, the plants were pruned in the first and second years. In the third year, the first production pruning was performed, followed by the floral induction process. All management practices such as pruning, weed control, pests and disease control, and addition of plant growth regulators were performed based on the instructions of Genú and Pinto (2002). In the 2016/2017 harvest, the fertilization of the orchard consisted of 1 kg plant^{-1} of NPK (06-24-12), divided into two applications. 20 g plant^{-1} of boric acid and 1 kg plant^{-1} of NKálcio® (09-00-24) were also added, divided into two applications during the fruiting period. Leaf fertilization was supplied with Nitrabor (181.5 kg ha^{-1}), boric acid (5 kg ha^{-1}) and ferrous sulphate (2.55 kg ha^{-1}). From an area of approximately 2.58 hectares, intercalated plants located in the planting lines, with ages 4 and 12 years, were sampled by cutting the plants near to the soil surface and separating them into compartments with the aid of a chainsaw. The irrigation system was set with the micro sprinkler method, with the water being daily piped and distributed to the plants through sprinklers, for two hours, providing for each plant the equivalent to 300 liters of water per day. Irrigation management was performed based on crop evapotranspiration (ETc, mm), determined through the multiplication of the reference evapotranspiration (ETo, mm) and the crop coefficient (Kc), as defined by Soares et al. (2006).

Area 3

Property of 300 ha in the Timbaúba Farm, belonging to the Queiroz Galvão Group, located in the city of Petrolina, PE. The area is in the Senador Nilo Coelho Irrigation Perimeter - Nucleus 11, under the geographical coordinates: 7°30'19 " S, 35°19'05" W, and average elevation of 136 m. The climate of the region is BSwh' (semiarid) (Alvares et al., 2013), with low rainfall throughout the year (460 to 600 mm) (J. Silva et al., 2015). The native vegetation is hyperxerophyle Caatinga. In 2011, just after the removal of the caatinga vegetation, the mango orchard (Palmer cultivar) was planted in a 4 ×2.5 m plant spacing. In order to increase the formation of a large number of branches, and to get a denser plant canopy, the plants were pruned in the first and second years. In the third year, the first pruning for production improvement was performed, followed by the floral induction process. Pruning management, weed control, pests and disease control, and the addition of growth regulators for inhibiting gibberellin synthesis (Cultar®) and dormancy breakers (calcium nitrate) were performed following the instructions of Genú and Pinto (2002). The fertilizer application for the maintenance of the 2016/2017 harvest was performed with 2 kg plant^{-1} of NPK (06-24-12), divided into two applications. Leaf sprays with potassium nitrate and calcium nitrate were weekly applied right after the emergence of the branches, in the floral induction process, with 50 kg ha^{-1} per application. The sample trees were cut from an area of approximately 3.12 ha. When the trees reached 7 years of age, right after the fruit harvest in 2017, the sample trees were cut near the soil surface, using a circular saw. The method of drip irrigation, with the water being delivered near the mango root system, drop by drop, supplied the water. Irrigation management was performed based on crop evapotranspiration (ETc, mm), determined through the multiplication of the reference evapotranspiration (ETo, mm) and the crop coefficient (Kc), as defined by Soares et al. (2006).

Soil sampling and analysis

From each soil layer, at 0-20, 20-40, 40-60 and 60-100 cm of depth, 15 single soil samples were randomly collected in the areas delimited by the tree canopy projections, forming a composite sample collected for soil analysis. For each soil depth, the single soil samples withdrawn from the planting lines formed one composite sample. After air-drying, grinding, homogenization and sieving through a 2.0 mm mesh, the soil samples were chemically analyzed (Table 1). Soil pH was determined in water (1:2.5 v/v). The potential acidity (H + Al) (extraction in 0.5 mol L^{-1} calcium acetate at pH 7.0) and determined by titration with NaOH 1 mol L^{-1} and soil organic matter content (OM), according to the methodology proposed by A. P. Silva et al. (2009). Ca, Mg and Al were extraction with KCl 1 mol L^{-1} and determined through atomic absorption photometry (Ca and Mg) and through titration with NaOH 0.125 mol L $^{-1}$ (Al). P, K and Na were extraction with Mehlich-1 and determined by colorimetry, for P (Braga & Defelipo, 1974), and flame photometry for K and Na. Additionally, the contents of Fe, Mn, and Zn were extraction with Mehlich-1 and determined through atomic absorption spectrophotometry. Physical characterization consisted in granulometric analysis of the soil through the pipette method (Ruiz, 2005), at the 0-20, 20-40, 40-60 and 60-100 cm depth layers (Table 1).

Table 1
Soil characterization in mango orchards at areas of São Francisco Valley, Brazil

Area (1)	Depth	OM (2)	Sand	Silt	Clay	pH	P	K	Ca	Mg	Al	H+Al	Zn	Fe	Mn
	cm	g kg^{-1}	_____ g kg^{-1} _____			H_2O	mg dm^{-3}	_____ cmol$_c$/dm^3 _____					_____ mg/dm³ _____		
1	0-20	18.32	913.82	46.51	39.67	6.88	101.44	0.50	2.43	0.25	0.04	1.38	9.40	74.98	37.16
	20-40	16.81	865.74	58.26	76.00	6.40	20.11	0.52	2.05	0.28	0.05	1.79	3.99	117.18	24.11
	40-60	11.53	819.07	54.93	126.00	5.80	14.13	0.61	1.97	0.37	0.10	3.22	1.24	173.82	9.98
	60-100	12.58	743.83	115.17	141.00	5.24	9.56	0.47	1.51	0.29	0.18	4.45	1.17	173.70	5.66
2	0-20	30.76	826.83	63.17	110.00	5.96	102.56	1.69	2.32	0.71	0.05	4.78	59.21	126.79	66.96
	20-40	20.54	549.23	184.44	266.33	5.80	35.65	2.65	4.29	0.93	0.05	4.45	32.07	170.91	14.30
	40-60	19.04	517.28	151.68	331.04	5.61	11.48	2.79	4.17	1.41	0.08	3.62	11.41	117.28	13.43
	60-100	18.44	488.81	197.52	313.67	5.58	10.21	2.43	3.33	1.85	0.07	3.23	7.51	108.04	16.74
3	0-20	8.26	860.39	76.28	63.33	7.55	97.95	1.09	2.81	0.51	0.00	0.64	153.6	31.05	38.84
	20-40	4.59	845.59	80.74	73.67	7.00	67.05	1.05	1.76	0.51	0.00	1.11	35.49	59.60	14.11
	40-60	3.63	768.22	86.11	145.67	6.35	63.32	1.03	1.74	0.56	0.06	1.24	19.28	76.50	4.07
	60-100	3.36	642.37	212.30	145.33	5.89	55.04	1.01	2.17	0.85	0.08	1.55	15.57	80.02	2.52

(1) Area 1 = mango one and two years old; Area 2 = mango four and twelve years old; Area 3 = mango seven years old; (2) OM = Organic Matter.

Plant sampling and plant tissue analysis

The determination of the produced biomass and the nutrient accumulation in the mango plants was performed. Experimental plots were delimited, with 20 plants each, randomly distributed in a field of approximately 3 ha. Within each plot, a representative plant (sample-plant) was selected, using as reference the homogeneity of the plant canopy and the diameter of the stem (Table 2).

Leaves were collected before harvesting the fruits and before the sample plants were felled. The leaf samples were collected in the median portion of the plant canopy, in the penultimate branch launching, in the four cardinal directions, (Quaggio, 1996). The leaves, after washing in distilled water, were oven-dried at 65 ºC until reaching constant weight, grinded in a Wiley mill and passed through a 1 mm mesh sieve.

Table 2
General characteristics of the mango orchards located at the São Francisco Valley, Brazil

Ages	Spacing(1)	PD(2)	Material from Pruning	Pruning	Irrigation system	Pre-mango use	Period of use	Farm	County	State
(year)	(m)	(ha)	(kg plant^{-1})	(t ha^{-1})	-	-	(year)	-	-	FU (3)
1	6 × 3	555	0.69	0.38	Micro sprinkler	Coco	20	Francisco Pinto	Petrolina	Pernambuco
2			3.75	2.08						
4	7 × 7	204	8.47	1.72	Micro sprinkler	Coco	10	Herculano Agrícola	Casa Nova	Bahia
7	4 ×2,5	1000	5.70	5.70	Drip	Caatinga	-	Timbaúba	Petrolina	Pernambuco
12	7 × 7	204	45.41	9.26	Micro sprinkler	Coco	10	Herculano Agrícola	Casa Nova	Bahia

(1) Spacing between mango plants of the same age, considering that plants of different ages are intercalated in the planting line, this spacing between plants is divided by 2, thus doubling the number of plants per hectare; (2) PD = Population density; (3) FU = Federation unity.

The fruits from the sample plants were randomly collected at the time of harvest, after reaching their physiological maturity, and then sent to the laboratory. In the laboratory, the fruits were washed in running water, dried and weighed. Afterwards, they were cut and taken to a forced air-drying oven (65 ºC), until reaching constant mass, being weighed again in order to obtain the dry matter. The already dried material was grinded in a Wiley mill and passed through a 1 mm sieve, composing the samples for analysis of macro and micronutrient concentrations.

Sample plants with different ages (1, 2, 4, 7 and 12 years) were harvested in three distinct areas, due to the difficulty of finding five distinct plant ages within the same area. From each area (1, 2, and 3), sample plants were cut down and the plant components

(roots, stem, thick twigs (Ø > 10 cm), thin twigs (Ø < 10 cm), leaf and fruits) were weighed separately for fresh matter determination. Then, from each component, a representative sample was chosen and sent to the laboratory for dry matter determination. In the laboratory, the samples were separately weighed and placed to dry in a forced-air drying oven at 65 °C, until reaching constant weight. The samples were then once more weighed, in order to determine the sample dry matter for each plant compartment, and the sum of these compartments was calculated as the plant dry matter.

The plants with ages of 1 and 2 years (vegetative phase) were at the stage of formation, and therefore did not have fruits. Conversely, the plants with ages of 4, 7 and 12 years (reproductive phase) were sampled immediately after fruit harvest. Mango plants in the Sub-Middle region of the São Francisco Valley are usually induced to produce in the third year after transplanting.

In order to estimate the root volume of each sample plant, a part of the root system of these plants was manually extracted with diggers, opening trenches from the stem, 1.25 m in the line and 2.00 m in the line of planting, equivalent to 2.5 m^2 of the area occupied by the mango plants. Subsequently, the roots were separated from the soil, and the roots were weighed in the field in order to avoid water loss and underestimation of the fresh matter. Afterwards, a representative sample of the root system was removed and sent to the Soil Fertility Laboratory of the Federal University of São Francisco Valley for dry matter determination and chemical nutrient analysis. In the laboratory, the root system was washed in running water in order to remove the rest of the soil adhered to the sample, then reweighed and packed in dry in paper bag at the temperature of 65 ºC into a forced air-drying oven. Assuming that the distribution of the root system in the mango plant is homogeneous, the root system collected in the portion relative to ¼ of the space, multiplied by four, is the estimated total root volume of the sample-tree (Santos et al., 2014).

Stem samples were taken in form of wood discs at a distance from 0.30 to 0.40 m from the soil surface. The sawdust obtained from the wood discs with an electric drill was passed through a Wiley mill and a 1 mm mesh sieve.

Thick branch samples, in form of wooden discs, were taken at three branch positions from each sample-tree. Based on the total length of the branch, the basal discs were removed from 10 to 15% of the length, the medium discs from 50 to 60% of the length, and the top discs from 75 to 80% of the length. Thin branches, or twigs, were sampled by cutting off the twigs in pieces, approximately 15 cm long, which were put for oven-drying at 65 °C and scraped, in order to obtain the sawdust.

Samples of the plant compartments were passed through a 1 mm sieve, and a 0.5 g portion of each sample was taken into an electric muffle for dry ashing digestion. The ash produced in the digestion received 25 mL of HNO3 1 mol L^{-1}. The extract was filtered and analyzed for plant nutrient determination (A. P. Silva et al., 2009). Phosphorus was determined by colorimetry (Braga & Defelipo, 1974), Ca, Mg, Fe, Zn, Cu and Mn by atomic absorption spectrophotometry, and K by flame emission photometry (Tedesco et al., 1995). Nitrogen

was determined by the Kjeldahl method, in extracts of sulfuric mineralization (Bremner, 1996). Incluída a referencia em "References" Boron was determined by colorimetry after calcination of the plant material (Tedesco et al., 1995).

With the plant nutrient concentrations and the plant dry weight, nutrient contents in the different parts of the plant were calculated.

The distribution of the nutrients in the plant compartments (roots, stem, thick twig, thin twig, leaves and fruits) was calculated as the relation of the content of each nutrient in the compartment, expressed as percentage, in relation to the total nutrient content in the plant.

Nutritional efficiency of the mango tree

The coefficient of biological utilization of each nutrient (CBU_Nuti) (expressed in kg / kg) was determined for the vegetative and reproductive shoot parts of the mango plants, using the plant nutrient concentrations and plant dry matter weight, through the equation:

$$\mathrm{CBU\_Nut_i} = \frac{\text{Mass of dry matter}}{\text{Nutrient content (i)}} :$$

Statistical analysis

Regression analysis was utilized for the adjustment of the nutrient contents in the plants as a function of the ages of the mango plants. The equation models were adjusted based on the significance of the coefficients of the equations, the mean square of the ANOVA residue, and the coefficient of determination (R2).

Results and Discussion

Nutrient foliar concentrations in the plants

The mean of leaf nutrient concentrations of mango Palmer in the studied orchards, at the ages 1, 2, 4, 7 and 12 years, were: N = 15.45, P = 1.80, K = 16.75, Ca = 14.61, and Mg = 2.75 g kg^{-1}; Cu = 3.39, Zn = 35.16, Fe = 37.94, Mn = 181.18, and B = 21.89 mg kg^{-1}. Almeida et al. (2014) found in mature leaves of the mango Palmer 11.9 for N, 0.8 for P, 9.3 for K, 16.5 for Ca, and 1.7 g kg^{-1} for Mg. Mature leaves of mango Sensation (mean from leaves 2, 6 and 18 years old) presented N = 13.7; P = 1.1; K = 8.5; Ca = 16.4; Mg = 1.5 g kg^{-1} (Stassen et al., 2000). Root system structure, root zone, pH and root exudate characteristics may explain the differences among nutrient concentrations of different mango cultivars (Sinha et al., 2017). According to Quaggio (1996), the range of adequate concentrations in leaves of mango are N = 12-14; P = 0.8-1,6; K = 5-10; Ca = 20-35; Mg = 2.5-5.0 g kg^{-1}; Cu = 10-50; Zn = 20-40; Fe = 50-200; Mn = 50-100; B = 50-100 mg kg^{-1}. Based on that, the concentrations of N, P, K, Mg, Mn, and Zn we found in the mango Palmer orchards at São Francisco Valley were at sufficient foliar levels. For Fe and Ca, the nutrients reached 76 % and 73%, respectively, which are near the adequacy, requiring adjustment in their supply. Copper with 40 % and B with 44 % of the lower range limits showed insufficiency. Although the 21.89 mg kg^{-1} B found in the leaves of mango Palmer in the present work are in the range 20.83 to 23.19 mg kg^{-1} found in dry matter of leaves at different positions of mango plant by Konsaeng et al. (2005), it seems that the supply of B and Cu needs adjustment to assure nutrient adequacy for improving productivity.

Macronutrient foliar contents in the plants

Macronutrient contents in the mango Palmer increased with plant age and adjusted to exponential and quadratic regression models (Table 3), expressing the progressive accumulation of plant nutrients as the plant gets older. Sinha et al. (2017), for the accumulation of nutrients in mango plants as a function of the maturity stage and cultivar, found expressive variation in foliar macro- and micronutrient contents of different cultivars. The knowledge of plant nutrient composition is important for evaluation of nutritional efficiency. Ali (2018) studying nutritional composition diagnose in mango plants states that interactions of nutrients in mango may be positive or negative, affecting nutrient absorption and accumulation. Accordingly, the soil nutrient availability and the soil type are important for an efficient fertilizing management for the mango crop. The studied orchards in São Francisco Valley have soils predominantly sandy, in which, according to Faria et al. (2016), it is expected low nutrient availability, and high lixiviation and volatilization (for nitrogen), demanding a different fertilizing management, using fertigation and several fertilizing supplies.

One-year-old plants accumulated 16.50 g plant^{-1} of N in the vegetative biomass, and this value increased with plant age, reaching 901.18 g plant^{-1} at age 12, an annual increase of 73.72 g plant^{-1} of N in the vegetative biomass (Figure 1). Accumulation of N in mango biomass, which increased with plant age and growth (Figure 1), reflects the role of N as the main nutrient for the development of plant branches, leaves and fruits. Yet, N is an essential constituent of enzymes, proteins and chlorophyll, being indispensable for the mango canopy formation (Ramírez & Davenport, 2010).

Table 3
Regression equations and determination coefficients for the relationship between the plant macro and micronutrients contents (CNutrientPlant) and the age of the mango plants, in the region of the SãoFrancisco Valley, Brazil

Nutrient	Equations	*p* value	R^2
N	$\hat{y} = 10307.2256/1+\exp(-(x - 21.1916)/3.9177))$	<0.0122	0.98*
P	$\hat{y} = -7.3674 + 9.2854x + 0.1644x^2$	<0.0114	0.98*
K	$\hat{y} = 31.8447 + 2.4464x + 6.7366x^2$	<0.0060	0.99**
Ca	$\hat{y} = -49.0328 + 59.2912x - 1.9439x^2$	<0.0078	0.99**
Mg	$\hat{y} = 172.2716 / (1+\exp(-(x - 6.5425) / 1.6225))$	<0.0007	0.99**
Cu	$\hat{y} = 24.6442 - 1.1521x + 2.6776x^2$	<0.0059	0.99**
Zn	$\hat{y} = -99.0596 + 125.7077x + 5.1559x^2$	<0.0128	0.98*
Fe	$\hat{y} = -864.1363 + 1235.5062x - 49.8703x^2$	<0.0051	0.99**
Mn	$\hat{y} = 153.6504 + 35.9876x + 34.3990x^2$	<0.0025	0.99**
B	$\hat{y} = 8818.9619 / (1+ \exp(-(x - 18.4233) / 3.4029))$	<0.0096	0.99**

**, * 1 % and 5 % significance, respectively.

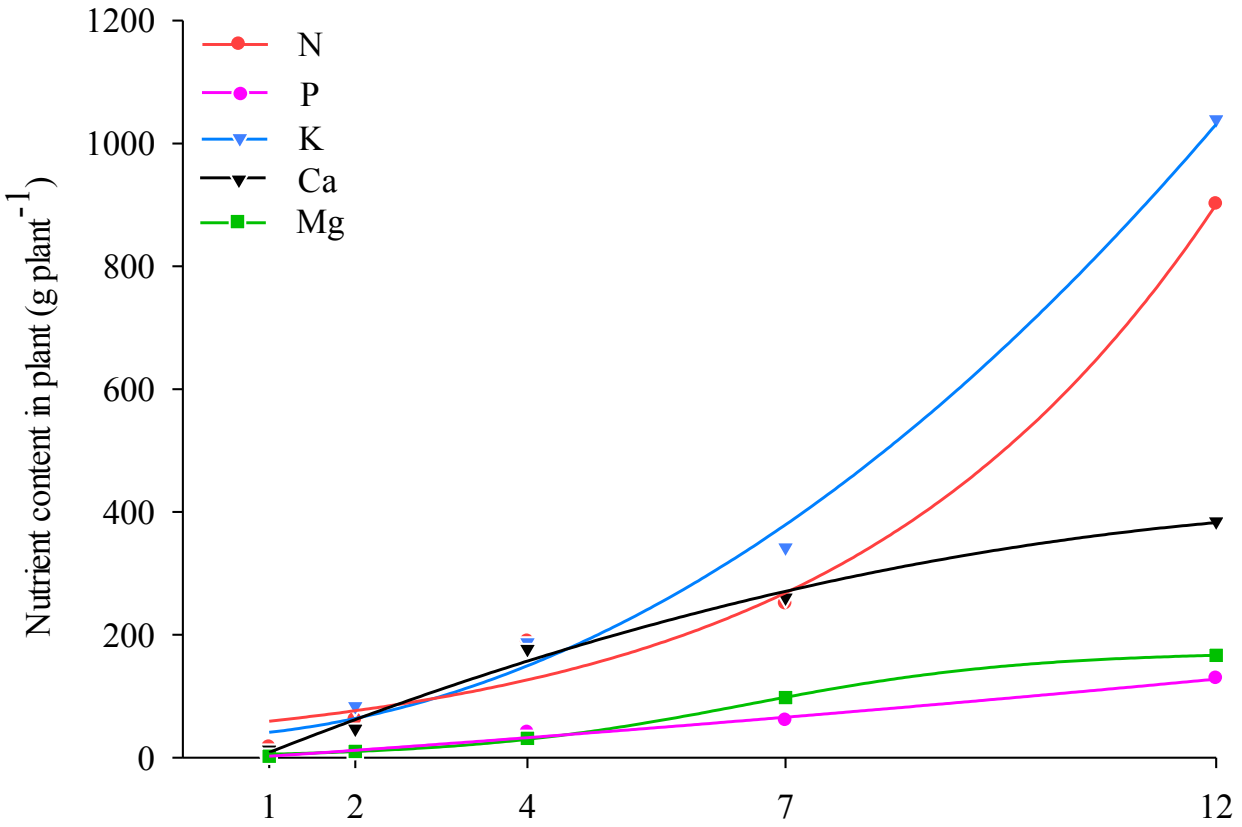

Figure 1. Content of accumulated macronutrients in the whole plant, as a function on the age of the mango plants (cv. Palmer) in the region of the São Francisco Valley, Brazil.

Plant contents of P increased exponentially with plant age, as shown by the evolution of P contents (1.92, 7.99, 40.93, 60.15 and 128.77 g plant-1) with the correspondent ages (1, 2, 4, 7 and 12 years) (Figure 1). This increase is crucial for plant growth since P is associated with energy storage and transport, being a source of energy for plant metabolic processes, having participation in the constitution of DNA and RNA, responsible for plant genetic information and protein synthesis (Taiz et al., 2017). In mango fruits, the P accumulation is variable among plants of different cultivars and at different maturation stages (Sinha et al., 2017).

Potassium was similar to N in the accumulation on plant tissues, with the quadratic regression model best fitting the data. Potassium content increased (12.25; 83.40; 187.47; 342.05 and 1039.28 g plant-1) proportionally to the increase of plant age (1, 2, 4, 7 and 12 years, respectively) (Figure 1). Acting in plant respiration, chlorophyll formation, photosynthesis and water regulation (Aular & Natale, 2013), it seems that K completed the effects of the three primary nutrients, N and P on the Palmer plants, actuating also as enzymatic activator, since more than 80 enzymes are known to be activated by K (Taiz et al., 2017). Furthermore, studies emphasize the importance of K in stomatal opening and

CO_2 entry for photosynthesis, as well as in the transport of carbohydrates to the plant drains, especially in the fruits (Aular & Natale, 2013).

Calcium accumulated exponentially in the plants at all ages, except for the 12-year-old ones, which presented a tendency to have a decrease in accumulation (Figure 1). Calculation for estimating the accumulated Ca in two years old, and older, mango plants (R^2 = 0.99) (Figure 1) found the value 359.23 g plant^{-1}, slightly lower than the observed in 12 years old plants (384.36 g plant^{-1}). Calcium accumulation in the plants was similar to the observed for the primary macronutrients. The Ca supply assured to the mango plants the holding of the plant cell walls together, which is the main function of Ca in plants. Calcium is a constituent of the middle lamella of the cell wall (Taiz et al., 2017) that has calcium pectate as a constituent of its structural layer. Calcium is required in large amounts by most cultivated plants, and its accumulation in plant tissues naturally occurs due to its relative immobility in the phloem of most plant species (Inanaga et al., 1988; Turan et al., 2018). It also acts as a co-factor by some enzymes involved in the hydrolysis of ATP and phospholipids (Taiz et al., 2017).

Exponential increase of Mg contents took place when plants got older, evolving to a tendency for stabilization (Figure 1). Values calculated through the regression equation (R^2 = 0.99) showed Mg contents (g plant^{-1}) equals to 172.00, 172.12, 172.19 and 172.23 at the corresponded plant ages of 17, 18, 19 and 20 years (Figure 1). Those values are very similar to each other, demonstrating a stabilization in the Mg accumulation in plants older than 17 years (Figure 1). Sinha et al. (2017) evaluated the variation of accumulated nutrients in mango plants, concerning the cultivar and the fruit maturation stage, and found maximum accumulation of Mg (0.23 dag kg^{-1}) in the Mahmood Bahar cultivar (for the other varieties, statistic differences were not significant).

Micronutrient foliar contents in the plants

Micronutrient contents in the mango Palmer increased with age, and the relationship adjusted to the exponential and quadratic models (Table 3). Manganese and Fe presented the highest contents (Figure 2).

Plant Cu contents increased exponentially as the plants got older, and contents ranged from 14.36 mg plant^{-1} in 1-year-old plants, to 399.29 mg plant^{-1} in 12-year-old plants (Figure 2). This represents an annual relative accumulation of 32.08 mg plant^{-1} Cu when the age of the mango plants increased from 1 to 12 years. Kirkby and Römheld (2007) point out that Cu is a constituent of several proteins, acting on photosynthesis, respiration, superoxide radical detoxification and lignification. They mention that in a Cu deficiency condition, the activity of these proteins is drastically reduced, affecting the development of the plant.

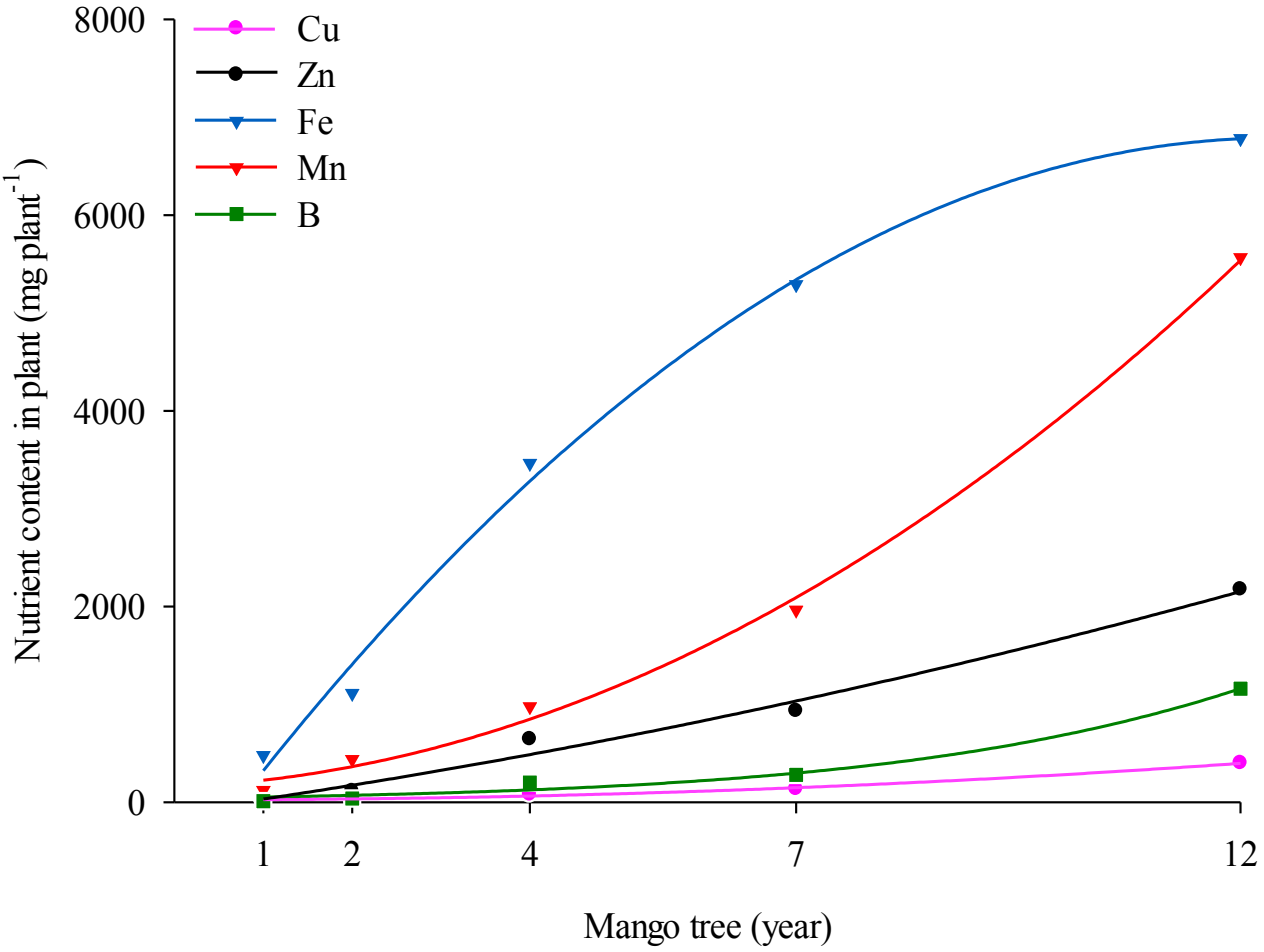

Figure 2. Content of accumulated micronutrients in the whole plant, as a function on the age of the mango plants (cv. Palmer) in the region of the São Francisco Valley, Brazil.

Zinc contents showed exponential increase with the mango plant development, similarly to the behavior observed for P and Mg. The contents were 23.60; 109.96; 640.11; 931.46 and 2,171.33 mg plant^{-1} Zn for the respective plant ages of 1, 2, 4, 7 and 12 years (Figure 2). The accumulated Zn, especially in 12-year-old plants, was expressive, which could be due to the ready Zn availability, consequence of its low retention in sandy soils particles.

Plant Fe content increased with age, with a tendency to decrease when the plants reached ages greater than 12 years. The regression equation for Fe contents as a function of plant ages (between 1 and 12 years) gave an estimation of the Fe accumulation in the plants, showing 6,137.16; 5,216.99 and 3,897.87 mg plant^{-1} of Fe in the respective ages of 16, 18 and 20 years (Figure 2).

The Mn accumulation in the mango plants increased with plant age, showing contents of 121.66 mg plant^{-1} in 1-year-old plants and 5,566.61 mg plant^{-1} in 12-year-old plants, representing an annual increase of 453.74 mg plant^{-1}, considering the Mn content and the evolving time from one to twelve years in the plant age (Figure 2). Manganese and iron presented the higher contents in the mango plants, among the micronutrients (Figure 2). Taiz et al. (2017) reported that some plant tissues, such as mesophyll, contain almost as much Mn or Fe as Mg and S.

Similar to the cationic micronutrients, B contents in the plants increased exponentially with plant age, showing 9.40; 37.88; 198.89; 279.09 and 1,160.38 mg plant^{-1} B in plants at the corresponding ages 1, 2, 4, 7 and 12 years (Figure 2). After B uptake, it moves in the xylem and tends to accumulate in the leaves since it has restricted mobility in the phloem of most species of cultivated plants. Konsaeng et al. (2005) reported B phloem immobility in various tropical woody species, one of which is mango. Therefore, the B accumulated in leaves of Palmer plants is not remobilized in the phloem. The predominance of sandy soils in the orchard areas (Table 1) favors the B mobility in the soil, and the B uptake by roots through the soil solution reaching the roots by mass flow. However, after the upward movement in the xylem B is accumulated in the leaves of the mango. The deeper layers reached by the mango roots enables the absorption of B that moved down in the soil profile, mainly in sandy soils.

Partition of nutrients in the plants

Macronutrients

Nutrient accumulation predominated more within the compartments of the plant canopy of the mango trees (leaf thin twig and thick twig) than in the remaining compartments (Table 4).

The accumulated N in the mango compartments showed the following distribution: leaf> thin twigs> thick twigs> root> stem> fruit, except for the 12-year-old plants that accumulated more N in the thick twig than in the thin twig (Table 4). The immobilization of nutrients in permanent parts of fruit tree plants is necessary in order to keep them as reserves for the new growth cycle of the perennial crop (Verlindo et al., 2014). The adequate concentration of N in mango is 1.0 to 1.4 dag kg^{-1} for satisfactory vegetative growth after the production pruning (Davenport, 2006; Maloba et al., 2017). Evaluating the management for floral induction of mango trees, Davenport (2006) reported the incidence of 100% of vegetative sprouts with the spraying of 4% KNO_3 solution on 2 months old stems, while this application in 4.5-month-old branches resulted in 100% reproductive sprouts.

The P allocation was larger in the compartments that constitute the mango plants plant canopy, with 26.0, 25.4 and 24.4% of accumulated P in the thick twig, leaf and thin twig, respectively (Table 4). The low accumulation of P in the roots of mango plants, with more P in the canopy may be associated with its mobility within the plant (Verlindo et al., 2014; Faria et al., 2016).

The average values of accumulated K in the mango plant compartments were 36, 27, 15.8, 11.6 and 9.6% (decreasing order) for leaf, thin twig, thick twig, roots, and stem, respectively (Table 4). Stassen et al. (2000), evaluating the absorption, distribution and requirement of macronutrients by mango plants, stated that the leaves and fruits hold about 20% of the total K accumulated by the plants. These authors stat that, at K-deficiency conditions, an annual application of a single dose of K during the spring should be sufficient to attend the mango crop requirement. Information on the nutritional status of K in plants is essential for the management of fertilization programs, and since the correct application of K is not yet well clarified, unnecessary K fertilizations often inhibit Ca absorption, with physiological disturbance in mango fruits (Stassen et al., 2000).

On average, 53.8% of accumulated Ca in the mango plants allocated in the leaves, with insignificant redistribution to the fruits (Table 4). This low redistribution is associated with the low mobility of Ca in the plant (Marschner, 2011). The Ca transport within the plant is unidirectional, from the roots into the shoot part, through the transpiration stream (via xylem), being preferentially transported to places with greater transpiration rates (Aular & Natale, 2013).

Table 4
Partition of nutrients in the compartments of mango Palmer plants in orchard from the region of São Francisco Valley, Brazil

Nutrient	% of nutrient in Shoots [1] (St) and Roots (Rt) at ages 1, 2, 4, 7, 12 years													
	1 year		2 years		4 years		7 years		12 years		Mean		SD[2]	
	St	Rt	St	Rt	St	Rt	St	Rt	St	Rt	St	Rt	St	Rt
	----------%----------													
N	90.1	9.9	94.1	5.9	88.2	11.8	90.1	9.9	94.0	6.0	**91.4**	**8.6**	**2.5**	**2.6**
P	85.9	14.1	88.1	11.9	75.2	24.8	88.3	11.7	81.4	18.6	**83.5**	**16.5**	**5.7**	**5.7**
K	73.8	26.2	91.0	9.0	86.8	13.2	83.1	16.9	97.0	3.0	**86.3**	**13.7**	**8.7**	**8.6**
Ca	91.2	8.8	92.9	7.1	91.4	8.6	91.8	8.2	90.1	9.9	**91.5**	**8.5**	**1.0**	**1.0**
Mg	85.4	14.6	91.2	8.8	75.3	24.7	89.0	11.0	92.0	8.0	**87.0**	**13.0**	**6.8**	**8.8**
Cu	79.2	20.8	75.5	24.5	87.0	13.0	80.7	19.3	93.8	6.2	**83.2**	**16.8**	**7.2**	**7.2**
Zn	55.2	44.8	67.0	33.0	75.6	24.4	69.8	30.2	88.6	11.4	**71.2**	**28.8**	**12.2**	**12.2**
Fe	20.6	79.4	34.2	65.8	34.5	65.5	8.3	91.7	47.8	52.2	**29.1**	**70.9**	**15.1**	**15.1**
Mn	94.4	5.6	97.0	3.0	89.0	11.0	95.7	4.3	94.3	5.7	**94.0**	**6.0**	**3.0**	**3.0**
B	67.2	32.8	90.3	9.7	90.1	9.9	78.2	21.8	76.5	23.5	**80.4**	**19.6**	**9.8**	**9.8**

continue...

continuation...

Nutrient	% of nutrient in Leaves (Lf) and Fruits [3] (Fr) at ages 1, 2, 4, 7, 12 years													
	1 year		2 years		4 years		7 years		12 years		Mean		SD	
	Lf	Fr	Lf	Fr	Lf	Fr	Lf	Fr	Lf	Fr	Lf	Fr	Lf	Fr
	----------%----------													
N	68.5	-	53.8	-	20.5	13.3	50.1	21.9	28.9	11.0	**44.5**	**9.2**	**19.5**	**9.3**
P	54.7	-	41.9	-	14.6	12.1	26.0	12.0	16.1	10.0	**30.7**	**11.3**	**17.3**	**1.2**
K	28.0	-	43.3	-	16.0	36.1	19.9	25.7	30.6	25.4	**27.5**	**29.1**	**10.6**	**6.1**
Ca	86.0	-	60.6	-	23.3	6.3	68.6	1.6	24.7	7.4	**52.7**	**5.1**	**27.7**	**3.1**
Mg	58.5	-	56.7	-	24.1	14.0	22.8	13.9	25.1	9.0	**37.5**	**12.3**	**18.4**	**2.9**
Cu	4.7	-	25.9	-	7.9	11.6	17.9	25.1	12.1	9.0	**22.5**	**15.2**	**16.1**	**8.8**
Zn	27.7	-	29.5	-	10.8	6.6	44.3	9.3	16.8	8.4	**26.0**	**8.1**	**12.9**	**1.4**
Fe	10.7	-	11.6	-	2.7	3.9	5.8	0.8	11.1	8.5	**8.4**	**4.4**	**4.0**	**3.9**
Mn	88.2	-	87.5	-	46.7	8.7	77.1	6.8	53.5	4.2	**70.6**	**6.6**	**19.4**	**2.3**
B	15.0	-	16.7	-	30.1	16.4	8.5	33.7	39.7	5.0	**22.0**	**18.4**	**12.6**	**14.4**
Nutrient	% of nutrient in Thin twigs (Tin) and Thick twigs (Thi) at ages 1, 2, 4, 7, 12 years													
	1 year		2 years		4 years		7 years		12 years		Mean		SD	
	Tin	Thi	Tin	Thi	Tin	Thi	Tin	Thi	Tin	Thi	Tin	Thi	Tin	Thi
	----------%----------													
N	7.5	-	27.0	-	21.3	27.2	5.3	10.3	18.0	34.6	**15.8**	**14.4**	**9.2**	**15.8**
P	21.0	-	32.6	-	22.6	20.5	10.3	31.1	37.4	14.6	**24.8**	**22.0**	**10.6**	**8.4**
K	21.3	-	35.3	-	19.1	12.5	22.4	10.4	30.4	9.2	**25.7**	**10.7**	**6.8**	**1.7**
Ca	1.4	-	24.8	-	26.6	28.2	10.3	7.2	49.3	7.4	**22.5**	**14.3**	**18.3**	**12.1**
Mg	7.2	-	18.6	-	14.9	16.4	11.5	26.4	30.8	22.7	**16.6**	**21.8**	**9.0**	**5.1**
Cu	1.1	-	8.2	-	4.1	4.1	21.7	23.0	65.2	23.9	**20.1**	**17.0**	**26.4**	**11.2**
Zn	10.1	-	21.6	-	16.0	20.4	4.1	6.9	35.5	15.6	**17.5**	**14.3**	**12.0**	**6.8**
Fe	2.4	-	10.7	-	2.4	1.7	0.2	0.4	7.6	10.3	**4.7**	**4.1**	**4.3**	**5.4**
Mn	2.2	-	5.4	-	9.7	9.7	4.4	4.5	17.0	10.6	**7.8**	**8.3**	**5.9**	**3.3**
B	19.9	-	42.6	-	10.2	12.4	10.8	16.2	10.6	8.5	**18.8**	**12.4**	**13.9**	**3.9**

[1] Shoots = Canopy + Stem (Canopy = thin twigs + thick twigs + leaves + fruits)
[2] Standard Deviation
[3] Nutrient in the fruits expressed in relation to the total nutrient in the canopy.

Magnesium accumulation in the mango plant compartments was variable and dependent on the plant age (Table 4), and this may be associated with the Mg mobility in the phloem. Marschner (2011) reported that Mg is easily remobilized from source organs, as leaves, to drain organs, as fruits, mainly. This remobilization leads the plant to a biochemical cycling of the nutrient inside the plant, which is very beneficial in situations

where nutrient supply via soil is deficient or temporarily interrupted, due to, for example, a water deficit in the soil (Whitehead, 2000; Marschner, 2011).

Micronutrients

The accumulation of Cu in the Palmer plants was larger in leaves, thin twig and root (leaves>thin twig>roots), and smaller in stem (stalk), thick twig and fruit (stalk, thick twig and fruits) (Table 4). Copper is a constituent of several proteins that act on photosynthesis, respiration, toxic radical detoxification and lignification (Kirkby & Römheld, 2007), therefore, Cu deficiency reduces the activity of these proteins, directly affecting the plant growth and development (Deus et al., 2020).

Zinc accumulated in the mango plants was distributed in leafs (45.2%), thin twigs (18.2%) and roots (17.2%) (Table 4), reflecting a regular distribution in the crop. Since it is required for biosynthesis of chlorophyll, carbohydrates and proteins, the regular and adequate supply of Zn is essential for plant growth and development, (Taiz et al., 2017), with a demand of a regular supplying of Zn for the mango crop.

The Fe accumulation was higher in the roots, at all evaluated ages. Counting on all plant compartments, the higher Fe contents appeared in roots and leaves (Table 4). This behavior might be associated with Fe being a structural component of the ferruginous enzyme, which is present in the plastids of the roots and chloroplasts, participating in the process of assimilation of the N and in the photosynthetic electron transport chain (Taiz et al., 2017).

Manganese accumulated predominantly in the mango leaves (70.8% on average), whereas in the other compartments it was evenly distributed (Table 4). In banana grown under fertigation, the leaf was the compartment with largest accumulation of Mn (Deus et al., 2020), which plays a fundamental role as enzyme activator, besides being a constituent of enzymes that act in the breakdown of water molecules in the photosystem II and in the enzyme superoxide dismutase (Kirkby & Römheld, 2007; Taiz et al., 2017).

Boron accumulated mainly in the leaves, thin twig and roots, and had unsatisfactory redistribution to the fruits (Table 4). The accumulation in leaves corroborates the low B mobility in the plant phloem (Malavolta, 2006). Like Ca, B is also transported by the upward movement of water in the xylem, driven by the loss of water throughout the transpiration flow from the roots to the leaf, where they accumulate (Brown & Hu, 1998). Sankar et al. (2013) found higher concentration of B in the leaves at flowering and harvesting stage when mango plants were sprayed with boric acid followed by boric acid + sorbitol. The authors suggest this might be due to the B binding compounds present in the cell, favoring the B uptake, in a non-metabolic process, consequence from the formation of cytoplasm and cell wall non-exchangeable B complexes.

Nutritional efficiency

Macronutrients

The plant coefficient of biological utilization (CBU_Nuti) for a nutrient evaluates its

efficiency in converting the absorbed nutrient into dry matter (Rosim et al., 2016), therefore a plant with a higher CBU_Nuti is expected to be more efficient in biomass production than a plant with a smaller CBU_Nuti. Phosphorous and Mg, reached the highest values of biological utilization coefficient (CBU_Nuti) for biomass production in the Palmer plants, the largest for P (1194.40, in 12-years old plants) followed by Mg (1185.66, in 4-years old plants) (Table 5). These data may help the decision making for fertilization management of the studied mango orchards in the São Francisco Valley. For pineapple, A. P. Silva et al. (2009) calculated the CUBs for plant compartments and the nutrient distribution in the compartments that feed a flowchart for estimation of crop nutrient requirement, which may be a more versatile alternative to the tables traditionally used in the manuals for fertilizer recommendation. Oliveira et al. (2005) developed a similar fertilization system for the banana crop. The same approach could be applied to the nutrient CBU's for mango fruit production in the studied orchards, where the nutrient CUB for plants older than 4 years (Table 5) for example may help to manage fertilization with the nutrients, targeting the improvement of crop production. The macronutrients with higher CBU_Nuti for fruit production were Mg and P (Table 5). In the banana crop, Deus et al. (2020) found significant differences in CBU_Nuti for Mg and Ca in plant compartments for different fruit yields. They found less sensitivity for N and P CBUs while for Ca and Mg there was more sensitivity, based on productivity variations, and suggest there is an "ideal compartmentalization" of nutrients to promote higher productivity, pointing out the need of further studies to confirm that.

Micronutrients

Copper and B showed the highest CBU for biomass production, Cu reached the highest CUB (458.38, in 4-years old plants), followed by B (275.17, in 1-year old plants) (Table 5), indicating great efficiency of Cu and Mn. Deus et al. (2020) found that Mn presented significant differences in the CBUs for all plant organs of the banana tree.

For fruit production, the highest CBU for Cu, Zn, and Mn took place in 4-year-old plants, while for Fe it was in 7-years-old and for B in 12-year-old plants (Table 5). According to Raja et al. (2005), B plays a major role in the quality of mango fruits and its deficiency is a major factor for restricting the production of a mango cultivar in sandy-loam acidic soils in India western coast.

As for macronutrients, knowing the micronutrients CBU's for mango fruit production could help managing the fertilization recommendation for the orchards at São Francisco Valley at different plant ages, in order to improve crop production. About 85% of Brazilian exports of fresh mango originates from the São Francisco Valley region, accounts for (VALEXPORT, 2016), Sankar et al. (2013) pointed out that several limiting factors, nutrient deficiency among them, affect the quality production, the market value and the exports of mango.

The flowcharts for estimation of crop nutrient requirement for pineapple (A. P. Silva et al., 2009) and for banana (Oliveira et al., 2005) have input information with data about micronutrient distribution in the plant parts and their CUBs for plant compartments. Likewise, for mango Palmer, the micronutrient distribution in plant compartments, along with their CUBs, may complement the information to be used for crop fertilizer recommendation.

Table 5
Coefficient of biological utilization (CBU) for the production of biomass and fruits by mango (Palmer cultivar) in orchard from the region of the São Francisco Valley, Brazil

Nutrient	Plant ages (year)				
	1	2	4	7	12
	CUB - Biomass [1]				
N	113.24	135.72	136.47	175.47	151.16
P	1042.47	1097.09	931.22	617.14	1194.40
K	207.12	105.02	181.13	110.82	131.27
Ca	163.85	182.61	170.87	126.25	445.11
Mg	934.18	858.99	1185.66	343.48	850.48
Cu	156.92	248.11	458.38	335.37	358.47
Zn	138.85	104.90	61.71	48.54	75.05
Fe	18.47	22.28	51.18	81.16	60.18
Mn	15.14	18.56	35.99	16.81	25.19
B	275.17	230.28	112.42	219.49	172.34
	CUB - Fruits [2]				
N	-	-	27	2	9
P	-	-	167	16	62
K	-	-	8	1	3
Ca	-	-	77	38	24
Mg	-	-	177	8	58
Cu	-	-	65	3	17
Zn	-	-	16	1	4
Fe	-	-	6	9	2
Mn	-	-	9	1	4
B	-	-	14	1	25

[1] Dry matter-shoots (kg) / Nutrient content-shoots (kg for macronutrients, g for micronutrients).
[2] Dried fruit-at maturity (kg) / Nutrient content-fruit at maturity (kg for macronutrients, g for micronutrients).

Conclusions

The canopy of the mango Palmer plants accumulates majorly the macro and micronutrients and the compartmental partition within the canopy occurs in the sequence: leaf> thin twig> thick twig.

With plant aging, macronutrients N and K and micronutrients Mn and Fe have the higher accumulation in the Palmer plants.

Phosphorus and Mg, and Cu and B are the nutrients more efficient to generate plant biomass and fruit production in the Palmer orchards.

Nutrient distribution in plant compartments, along with their CUBs, as plant age evolves, may complement information to be used for mango Palmer fertilizer recommendation.

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