ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.26, n.8, p.618-623, 2022
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v26n8p618-623

Marine calcium application on 'Palmer' mango production[1]

Aplicação de cálcio marinho na produção da mangueira 'Palmer'

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HIGHLIGHTS:

Application of calcium from Lithothamnium increases the yield of 'Palmer' mango.
Application of calcium until the first 30 days after flowering is crucial in increasing mango production.
Application of calcium increases fruit production up to a dose of 10 L plant^{-1}.

ABSTRACT: Considering the growing demand for mango to meet the national and international market and the competitiveness among the producing markets, the use of new products and management techniques that improve the potential production in the irrigated areas of the Brazilian northeast can be an important tool for the sustainability of its cultivation. In this context, the objective of the present study was to evaluate the effect of doses and periods of application of calcium from *Lithothamnium* seaweed via fertigation, in two production cycles of 'Palmer' mango in the Brazilian semiarid region. The experiment was conducted at the Saúde farm, located in the Projeto Senador Nilo Coelho N-09, in the city of Petrolina, PE, Brazil. The experimental design was randomized blocks, in a 5 × 4 × 2 factorial scheme, corresponding to five doses of *Lithothamnium* via fertigation (0, 5, 10, 15 and 20 L ha^{-1}), four periods of application (30, 60, 90 and 120 days after flowering) and two production cycles, with three blocks, totaling 120 plots. The variables evaluated were: number of marketable fruits and parthenocarpic fruits per plant, average weight of marketable fruits and parthenocarpic fruits, and marketable fruit production. Application of 12 L per plant of calcium from *Lithothamnium* promotes a 20% increase in 'Palmer' mango yield in the Sub-middle São Francisco Valley. Calcium from *Lithothamnium* should be applied from the beginning up to 30 days after flowering of 'Palmer' mango in the Sub-middle São Francisco Valley. The effect of the application of calcium from *Lithothamnium* seaweed on 'Palmer' mango production varies according to doses and production cycles.

Key words: *Mangifera indica* L., fertigation, *Lithothamnium*

RESUMO: Considerando a crescente demanda pela manga para atender ao mercado nacional e internacional e a competitividade entre os mercados produtores, o uso de novos produtos e técnicas de manejo que melhore o potencial produtivo nas áreas irrigadas do nordeste brasileiro pode ser uma importante ferramenta para sustentabilidade do cultivo da mesma. Neste contexto, o objetivo do presente estudo foi avaliar o efeito de doses e períodos de aplicação de cálcio proveniente das algas marinhas *Lithothamnium* via fertirrigação, em dois ciclos de produção da mangueira 'Palmer' no semiárido brasileiro. O experimento foi conduzido na fazenda Saúde, localizada no Projeto Senador Nilo Coelho N-09, na cidade de Petrolina, PE. O delineamento experimental foi em blocos casualizados, em esquema fatorial de 5 × 4 × 2, sendo cinco doses de *Lithothamnium* via fertirrigação (0; 5; 10; 15 e 20 L ha^{-1}), quatro períodos de aplicação (30; 60; 90 e 120 dias após a floração) em dois ciclos de produção, com três blocos, totalizando 120 parcelas. As variáveis avaliadas foram: número de frutos comerciais e de manguitos por planta, peso médio dos frutos comerciais e de manguitos, e produção comercial de frutos. A dose de 12 L por planta de cálcio proveniente do *Lithothamnium* proporciona um incremento de 20% na produtividade da mangueira 'Palmer' no Vale do Submédio do São Francisco. A aplicação do cálcio proveniente do *Lithothamnium* deve ser realizada do início até 30 dias após a floração da mangueira 'Palmer', no Vale do Submédio São Francisco. O efeito da aplicação do cálcio proveniente das algas marinhas *Lithothamnium* sobre a produção da mangueira 'Palmer' varia em função das doses e dos ciclos produtivos.

Palavras-chave: *Mangifera indica* L., fertirrigação, *Lithothamnium*

• Ref. 258368 – Received 18 Nov, 2021
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• Accepted 22 Apr, 2022 • Published 03 May, 2022
Editors: Lauriane Almeida dos Anjos Soares & Carlos Alberto Vieira de Azevedo

Introduction

Mango cultivation under semi-arid conditions has socioeconomic importance. 'Palmer' mango is a variety grown in the Brazilian semi-arid region that has wide acceptance in the domestic market as fresh fruit and fruit for the industry and in the foreign market (Mouco, 2015). Brazil had a production of 1,319,296 tons of mango, with the Northeast region accounting for 76.3%. From this total, the participation of Pernambuco and Bahia states was 38 and 29%, respectively (IBGE, 2019). However, it has shown incidence of physiological disorders due to an imbalance in metabolism induced by one or more pre - or post-harvest environmental factors, leading to cellular collapse that results in the production of parthenocarpic fruits, whose development is compromised by the absence of the embryo and which have no commercial value (Mogollón et al., 2020).

Adequate nutritional management is one of the factors that contribute to avoiding physiological disorders and thus reduces fruit losses. Calcium is a nutrient that promotes the control of physiological disorders, by reducing respiration and ethylene production in the middle lamella of cell walls, in addition to promoting the maintenance of fruit quality and storage capacity after harvest (Taiz et al., 2017). Calcium is most commonly applied in the soil manually or mechanically, but it can be applied with the fertigation technique, as it enables a better distribution of the nutrient in the soil and allows a greater splitting of fertilization (Marouelli et al., 2015).

According to Battacharyya et al. (2015), water-soluble natural mineral products containing Ca from *Lithothamnium* can minimize abscission and increase fruit set, as well as changing the Ca/N ratio and reducing the incidence of internal collapse in mango fruits, thus inducing physiological responses of plant growth and improved flowering and fruiting.

Thus, knowledge on the ideal period for application of Ca from *Lithothamnium* seaweed via fertigation can become an efficient way of making Ca available to the plant in its period of greatest demand. In this context, the objective of this study was to evaluate the effect of doses and periods of application of calcium from *Lithothamnium* seaweed via fertigation on the production of 'Palmer' mango in the Brazilian semi-arid region.

Material and Methods

The experiment was conducted at the Saúde farm, located in the Projeto Senador Nilo Coelho N-09, in the city of Petrolina, PE, Brazil (latitude 09° 08" S, longitude 40° 18' W, and altitude of 370 m). According to Köppen's classification, the climate in the municipality of Petrolina is BSwh', with an average annual rainfall around 500 mm, concentrated from November to April. The average annual relative air humidity is 66% and the average annual air temperature is 26.5 °C (Lopes et al., 2017).

The mango plants were of the cultivar Palmer, with spacing of 6 m between rows and 4 m between plants. The irrigation system in the orchard uses two drip lines per row, with the plant in the center, at a spacing of 0.50 m between drippers. Cultural practices such as weeding, fertilization and spraying with pesticides followed the norms used in the farm and

Table 1. Chemical analysis of sandy clay soil of the experimental area with 'Palmer' mango at depths of 0-0.2 and 0.2-0.4 m

Depth (m)	Sorption complex ($cmol_c$ dm^{-3})							
	Ca	Mg	Na	K	SB	H + Al	T	Al^{+++}
0-0.2	1.4	0.8	0.02	0.10	2.30	0.43	3.12	0.00
0.2-0.4	1.8	0.8	0.03	0.13	2.75	1.72	4.00	0.00
	pH 1:2.5	V (%)	C ($g\ kg^{-1}$)	MO ($g\ kg^{-1}$)	P ($mg\ dm^{-3}$)			
0-0.2	6.6	74	5.0	8.6	26.7			
0.2-0.4	6.1	68	4.8	8.2	42.9			

Ca - Exchangeable calcium; Mg - Exchangeable magnesium; Na - Exchangeable sodium; - Exchangeable potassium; SB -Sum of Exchangeable Bases; H + Al -Potential acidity; T-Total Cation Exchange Capacity; Al^{+++}- Exchangeable Aluminum; pH - Hydrogen potential; V - Base saturation; C - Organic carbon; OM - Organic matter; P - Available phosphorus extracted with $Mehlich^{-1}$

recommended by Mouco (2015). Soil analysis was performed before the experiment was set up, at depths of 0-0.2 and 0.2-0.4 m (Table 1).

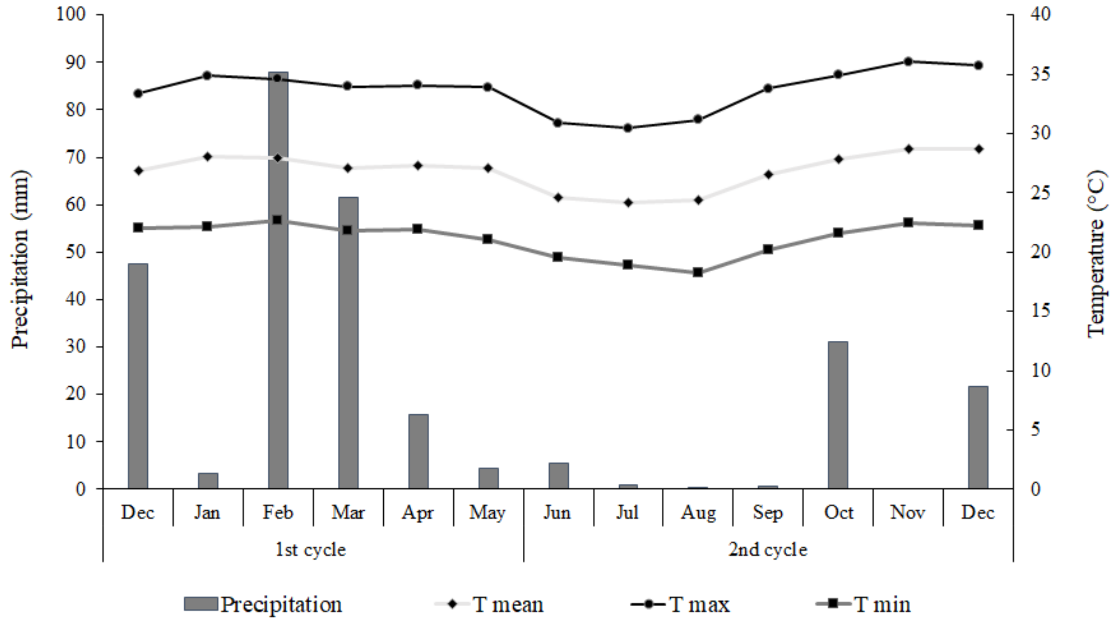
The experimental design was randomized blocks, arranged in a 5 × 4 × 2 factorial scheme, and the treatments consisted of five doses of *Lithothamnium* seaweed extract (0, 5, 10, 15 and 20 L ha^{-1}), four application periods (up to 30, 60, 90 and 120 days after flowering), in two production cycles (first and second half of the year), with three blocks, totaling 120 plots. Each plot consisted of four plants, two usable plants and two borders.

The product applied via fertigation was a mineral fertilizer based on seaweed *Lithothamnium* (70%), which has in its composition 24% of Ca, 1.5% of Mg, 10% of humic substances, 5% of surfactant of 15% of water, with density of 1.7 and a salt index of 0.83%, which was applied weekly from the beginning of flowering. The injection of the product was carried out by means of fertilizer injectors of the derivation tank type, called the "lung" region, in which the diluted solution enters the system by pressure difference and dosages were carried out through syringes. In the first cycle, flowering occurred in December 2018 and harvest was performed in May 2019, while in the second cycle flowering occurred in July 2019 and harvest was performed in December 2019. The data of rainfall and values of maximum, mean and minimum air temperature during the experiments are presented in Figure 1.

Irrigation management was performed using data from a weather station installed at 1200 m from the experimental area, in order to estimate evapotranspiration by the FAO standard method (Penman-Monteith equation). Irrigations were carried out daily by applying 100% of crop evapotranspiration and crop coefficients (Kc), as suggested by Teixeira et al. (2008) for the 'Tommy Atkins' mango, as there is no recommendation in the literature of Kc's for the 'Palmer' mango, replacing the water volume between the irrigations, in order to keep the soil moisture close to field capacity.

The fruits were harvested with light green skin color at the maturity stage E2, adopted as the standard for export, and the harvests were performed manually in the morning. At harvest, the fruits of the two evaluated plants of each plot were collected to determine the number of total fruits per plant (NTF) and total yield (TY).

The fruits were separated to determine the number of parthenocarpic fruits per plant (NPF), average weight of parthenocarpic fruits per plant (AWPF), parthenocarpic fruit yield (PFY), number of marketable fruits per plant (NMF),



Source: Weather station at 1200 m from the experimental area

Figure 1. Data of precipitation and maximum (T max), mean (T mean) and minimum (T min) air temperatures during the experiment (December 2018 to December 2019), in the two cultivation cycles

average weight of marketable fruits (AWMF) and marketable yield (MY).

The results were subjected to analysis of variance by F test ($p \leq 0.05$) using SISVAR software, version 5.6. The means of application periods and production cycles were compared by Tukey test at $p \leq 0.05$. When the effects of the doses were significant, polynomial regression analysis was performed at $p \leq 0.05$.

Results and Discussion

The analysis of variance indicated a triple interaction between the factors evaluated for the average weight of parthenocarpic fruits per plant (AWPF). In addition, significant effects were observed in the interaction between cycles and doses of *Lithothamnium* seaweed extract for the number of total fruits per plant (NTF), number of parthenocarpic fruits per plant (NPF) and parthenocarpic fruit yield (PFY).

The analysis also indicated a significant effect of the causes of variation related to the cycle for the variables average weight of marketable fruits (AWMF), number of marketable fruits per plant (NMF), marketable yield (MY) and total yield (TY), as well as significant simple effects of *Lithothamnium* seaweed extract doses and application periods for NMF, MY and TY.

For the average weight of parthenocarpic fruits per plant (AWPF) variable, in the first cycle, an appropriate model was found to represent the data, except for *Lithothamnium* doses applied 60 days after flowering. In the second cycle, an appropriate model was found only in the application period of 30 days, considering that in the other periods the fit of any model should be accepted with caution, because the regression lacking fit was significant ($p \leq 0.05$). In all cases, the quadratic model was chosen among the significant regressions based on the F test (Table 2).

The average weight of parthenocarpic fruits in the first cycle was significantly higher than those of the second cycle, regardless of the periods of application of *Lithothamnium*. In this context, when correlating the data with the climatic characteristics of the region, as previously commented, high temperatures recorded during the flowering of the first cycle favored the formation of parthenocarpic fruits. It should also be noted that the high rainfall levels, recorded during fruiting

Table 2. Average weight of parthenocarpic fruits per plant (AWPF) as a function of doses of *Lithothamnium* for different cultivation cycles and periods of application

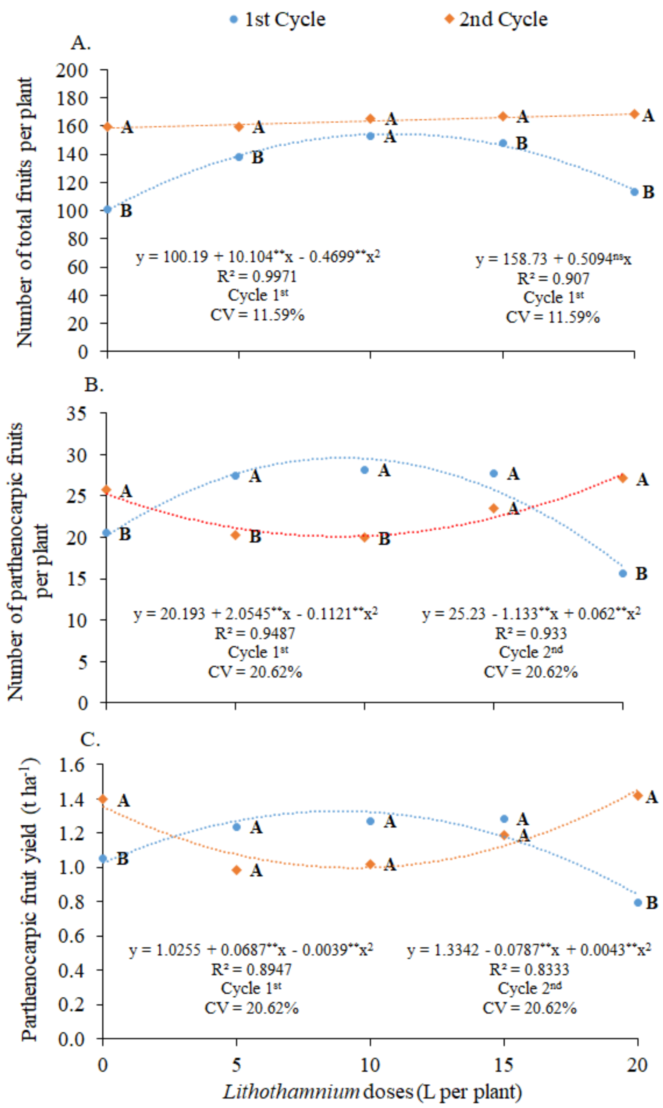
Period of application (days)	Dose ($L\ ha^{-1}$)					Regression equation	R^2	CV (%)
	0	5	10	15	20			
1st Cycle								
1-30	0.24 aA	0.23 aA	0.21 aA	0.21 aA	0.24 aA	$y = 0.2383 - 0.0026^{*}x + 7E - 05^{*}x^2$	78.7	5.11
1-60	0.24 aA	0.24 aA	0.24 aA	0.22 aA	0.24 aA	$\hat{Y} = \bar{y}$	--	4.32
1-90	0.24 aA	0.21 aA	0.23 aA	0.22 aA	0.24 aA	$y = 0.2383 - 0.0029^{*}x + 0.0001^{*}x^2$	61.1	4.85
1-120	0.24 aA	0.19 aA	0.21 aA	0.24 aA	0.24 aA	$y = 0.2384 - 0.008^{*}x + 0.0004^{*}x^2$	99.8	8.42
2nd Cycle								
1-30	0.13 bA	0.12 bA	0.12 bA	0.11 bA	0.08 bA	$y = 0.1295 - 0.0024^{*}x + 9E - 05^{*}x^2$	93.3	5.41
1-60	0.13 bA	0.11 bA	0.13 bA	0.13 bA	0.12 bA	$\hat{Y} = \bar{y}$	--	7.47
1-90	0.13 bA	0.12 bA	0.11 bA	0.12 bA	0.13 bA	$\hat{Y} = \bar{y}$	--	7.03
1-120	0.13 bA	0.12 bA	0.14 bA	0.13 bA	0.13 bA	$\hat{Y} = \bar{y}$	--	4.47

Means followed by equal uppercase letters, in the row between periods, do not differ from each other and means followed by equal lowercase letters, in the row between cycles, do not differ from each other by Tukey test ($p \leq 0.05$). * and ** - Significant at $p \leq 0.05$ and $p \leq 0.01$ by F test, respectively of this cycle, may have favored the increase in the average weight of the fruits.

According to Bitange et al. (2019), calcium reduces the fall and increases the weight of fruits, thus increasing yield. The increase in the weight of parthenocarpic fruits in the cycles resulted probably from the reduction of fruit fall and increase in growth caused by the calcium sources. However, although the average weight of parthenocarpic fruits in the first cycle was significantly higher than in the second, they did not reach an adequate standard for marketing.

Significant interaction ($p \leq 0.05$) was observed between doses of *Lithothamnium* seaweed extract and cycles for the variables NTF, NPF and PFY, which indicates the need for decomposition of the interaction to evaluate the integrated effect of the treatments on these variables (Figure 2).

It was observed that, in the first cycle, the doses applied were described by a positive quadratic model, and treatment with the dose of 10.75 L per plant, with an average NTF value of 154.50 per plant, surpassed both the treatment without application and those with the highest applications of the product (Figure 2A).



Regression coefficients significant with $p \leq 0.01$ (**) and $p \leq 0.05$ (*) by F test

Figure 2. (A) Number of total fruits per plant (NTF), (B) number of parthenocarpic fruits per plant (NPF) and (C) parthenocarpic fruit yield (PFY) as a function of doses of *Lithothamnium* seaweed extract for different cycles

In the decomposition of the interaction between the cultivation cycles and doses of *Lithothamnium* for number of parthenocarpic fruits per plant (NPF) (Figure 2B) and parthenocarpic fruit yield (PFY) (Figure 2C), it was observed that in the first cycle the applied doses were also described by a positive quadratic regression model with the maximum point with mean values of NPF of 29.60 and PFY of 1.32 t ha^{-1}, achieved respectively at doses of 9.16 and 8.8 L per plant, thus surpassing both the treatment without application and those with greater applications of the product.

In the second cycle, a negative quadratic polynomial model fitted the data, with the minimum point with mean values of NPF of 20.05 (Figure 2B) and PFY of 0.97 t ha^{-1} (Figure 2C), achieved respectively at doses of 9.13 and 9.15 L per plant. Thus, the application of *Lithothamnium* dose of 10 L per plant can reduce the number of parthenocarpic fruits by 23.95%.

On the other hand, the increase in NTF with the increase in doses in the second cycle (Figure 2A) may be associated with the role of calcium in cell formation and its function in preventing cell wall degradation (Uluisik & Seymour, 2020), associated with the adaptability of the crop to the climatic characteristics of this cycle. The application of Ca increases fruit production up to a dose of 10 L per plant. Therefore, the application of higher concentrations of calcium, which performs different functions in plant tissues, must favor the increase in the number of fruits per panicle, when applied under climatic conditions favorable to mango cultivation.

The reductions of NTF (Figure 2A) and NPF (Figure 2B) for the highest doses in the first cycle may be related to the physiological and metabolic processes of plants. According to Moura et al. (2015), in the period of flowering, setting and fruiting, inadequate climatic conditions, especially high temperatures, can reduce fruit production and induce parthenocarpy in mango cultivation.

As high temperatures tend to compromise embryo development, affecting adequate fruit growth, the increase in the production of parthenocarpic fruits in the first cycle (Figure 2C) may result from the cumulative effect of the increase in the number of parthenocarpic fruits per plant (Figure 2B), which may be associated with the occurrence of high temperatures during flowering and onset of fruiting.

Yadav et al. (2020) report that the appearance of mango fruits with partially formed seeds occurs due to embryonic abortion and not to failure in fertilization. Abortion occurs due to climatic conditions (Lora & Hormaza, 2018).

Significant effects were also recorded ($p \leq 0.05$), in both cycles, for the average weight of marketable fruits (AWMF), number of marketable fruits per plant (NMF), marketable yield (MY) and total yield (TY) (Table 3).

Considering that climatic characteristics (evapotranspiration, precipitation and temperature) are fundamental for crop production, it is observed that during the first cultivation cycle of 'Palmer' mango, the rainfall level was higher (220.28 mm), while in the second cycle it rained only 60.45 mm (Figure 1), which may have influenced abortion or fruit growth (Zuazo et al., 2019); the increase in the soil water content during fruit growth,

Table 3. Average weight of marketable fruits (AWMF), number of marketable fruits per plant (NMF), marketable yield (MY) and total yield (TY), in different cultivation cycles of mango cv. Palmer

Cycle	AWMF (kg)	NMF	MY (t ha^{-1})	TY (t ha^{-1})
1st	0.589 a	53.41 b	13.06 b	14.14 b
2nd	0.433 b	140.50 a	25.30 a	26.49 a

Means followed by equal lowercase letters in columns do not differ from each other by Tukey test ($p \leq 0.05$)

especially in the stages of cell elongation and maturation, tends to increase the weight of the fruits. The source/sink ratio had a great influence on fruit weight. It is common to observe in fruit growing a reduction in the average weight with the increase in the number of fruits.

Thus, the increase in water availability with rainfall may have been an essential factor for increasing the average weight of marketable fruits in the first cycle. This result corroborates those found by Figueirêdo et al. (2020), who obtained higher average weight of 'Keitt' mango fruits in the cycle with higher total water depth applied (irrigation + rainfall).

On the other hand, the differences in the number of fruits per plant and in the yield from one cycle to the other can be explained by the biennial bearing of mango. Considering that this species has an alternated production, with increase and reduction in the number of fruits from one cycle to the other, mainly due to the age of the plants, edaphoclimatic conditions and crop management adopted (Modesto et al., 2016).

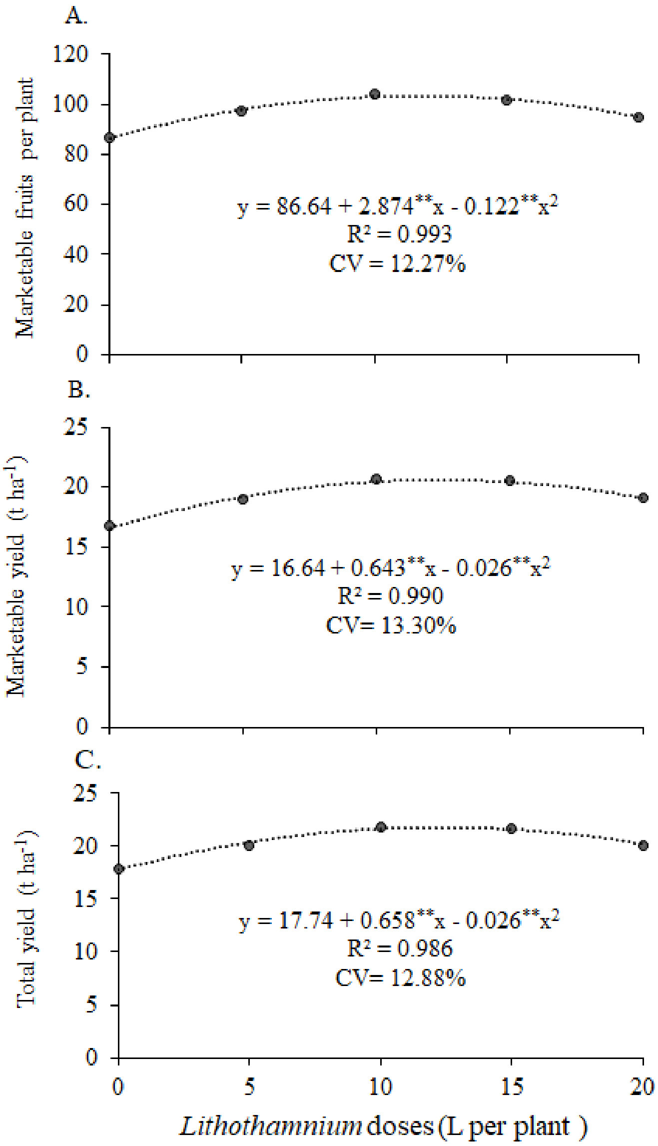
For the tested doses of *Lithothamnium* seaweed extract, the data were described by a quadratic regression, with the maximum points of 103.57 for number of marketable fruits per plant (NMF) (Figure 3A), 20.62 t ha^{-1} for marketable yield (MY) (Figure 3B) and 21.90 t ha^{-1} for total yield (TY) (Figure 3C), respectively obtained with doses of 11.78, 12.36 and 12.65 L per plant of the product.

It can be observed that, without application of the product, the plant produced 86.85 marketable fruits (Figure 3A), which resulted in MY of 16.74 t ha^{-1} (Figure 3B) and TY of 17.87 t ha^{-1} (Figure 3C).

According to Taiz et al. (2017), Ca contributes to the growth and development of plants, both through the increase of fruit weight, by improving cell wall structure, and through the stimulation of root growth, which can contribute to greater absorption of nutrients.

The results corroborate those obtained by Bitange et al. (2019), who report that the application of Ca sources increases mango yield, which is justified by the increase in fruiting per panicle, due to the reduction of their abscission. According to Uluisik & Seymour (2020), this response comes from the covalent binding of Ca in the plant cell wall to pectins, originating calcium pectate, restricting the action of pectinmetylesterase and polygalacturonase.

Thus, the reduction of abscission may have occurred because the calcium-pectin complex acted as a cementing agent, strengthening the cell wall in the abscission zone. Thus, the application of *Lithothamnium* doses may have caused reduction in the abscission rate and increase in the number of fruits, with consequent increase in crop yield variables.



Regression coefficients significant with $p \leq 0.01$ (**) and $p \leq 0.05$ (*) by F test

Figure 3. (A) Marketable fruits per plant (NMF), (B) Marketable yield (MY) and (C) Total yield (TY) as a function of *Lithothamnium* seaweed extract doses. Petrolina, 2018-2019

Ca application until the first 30 days after flowering was determinant for increasing the number of marketable fruits, marketable yield and total yield of the orchard, probably due to the effect of calcium in reducing the premature fall that occurs in the first days of fruiting (Table 4).

The application of Ca through liming or agricultural gypsum is recommended in the rest period of the mango crop or in basal fertilization (Maria et al., 1993). Thus, highlighting the importance of supplying this element in periods of greater

Table 4. Number of marketable fruits per plant (NMF), marketable yield (MY) and total yield (TY) in different periods of application of *Lithothamnium* seaweed extract

Period of application (days after flowering)	NMF	MY (t ha^{-1})	TY (t ha^{-1})
1-30	106.1 a	21.4 a	22.5 a
1-60	89.2 c	17.6 b	18.7 b
1-90	97.5 b	18.9 b	20.1 b
1-120	95.1 bc	18.7 b	20.0 b

Means followed by equal lowercase letters in columns do not differ from each other by Tukey test ($p \leq 0.05$)

demand by plants, it should be considered that translocation occurs exclusively by convective flow in the xylem, that is, along with the water absorbed by the plant, with no redistribution of Ca in the phloem (Taiz et al., 2017).

Ca is absorbed more efficiently by the root system, and its best absorption occurs during the postharvest vegetative flush and the initial development of the fruits. At this stage, the demand for Ca is high and the nutrient must have high availability in the soil to be absorbed by the root system, since the transport of Ca applied on the leaves to the terminal points of the tree, where the fruits are, is insignificant, as it is practically immobile in the phloem, with no redistribution in the plant.

According to the results obtained, fertigation performed in the earliest stage must promote better distribution of calcium and other nutrients with low mobility in the plant, considering the high demand of mango trees for calcium (Taiz et al., 2017).

Similar results were reported by Bitange et al. (2019), when investigating the effect of various sources of calcium, applied at different times and doses, on the yield and calcium concentration in the fruit of 'Van Dyke' mango, in plants with low Ca levels. These authors found that the maximum yield was obtained with calcium application during the early stages of fruit development, while late application resulted in the worst yields.

Conclusions

1. Application of 12 L per plant of the product with calcium from *Lithothamnium* promotes a 20% increase in 'Palmer' mango yield in the Sub-middle São Francisco Valley.

2. Calcium from *Lithothamnium* should be applied from the beginning up to 30 days after flowering of 'Palmer' mango in the Sub-middle São Francisco Valley.

3. The effect of the application of calcium from *Lithothamnium* seaweed on 'Palmer' mango production varies according to doses and climatic conditions.

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