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CROP PRODUCTION AND MANAGEMENT - Article

Planting spacing and NK fertilizing on physiological indexes and fruit production of papaya under semiarid climate

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ABSTRACT: The nutritional requirements of papaya (*Carica papaya* L.) increase continuously throughout the crop cycle, especially for potassium and nitrogen, which are the most required nutrients and act on plant vital functions such as photosynthetic activity, respiration, transpiration and stomatal regulation. An experiment was conducted from November 2010 to December 2012 to evaluate physiological indexes and fruit production of papaya cv. Caliman-01 as a function of planting spacing and NK fertilizing. The experimental design consisted of randomized blocks, with treatments distributed in a factorial arrangement (2 × 4 × 4), using 2 planting spacing [simple rows (3.8 × 2.0 m) and double rows (3.8 × 2.0 × 1.8 m)], 4 nitrogen doses (320, 400, 480 and 560 g of N per plant^{-1}) and 4 potassium doses (380, 475, 570 and 665 g of K_2O per plant^{-1}) with 4 replications of 3 plants each. The following variables were evaluated: leaf area index (LAI), leaf chlorophyll index (*a*, *b* and total index), intercepted photosynthetically active radiation (*Int.*PAR, in μmol·m^{-2}·s^{-1}), efficiency use of photosynthetically active radiation (*Ef.*PAR) and fruit yield. The fruit production and physiological characteristics of papaya cv. Caliman-01 depend on planting spacing. Under the soil, climate and plant conditions of this study, 665 g of K_2O and 320 g of N per plant under double spacing could be recommended for the production of papaya cv. Caliman-01.

Key words: *Carica papaya* L., plant physiology, fruit yield.

INTRODUCTION

Papaya (*Carica papaya* L.) is a popular fruit species native to tropical America widely grown in Brazil, the second main world producer country with 1.582.638 t in 2013, harvested in 31.310 ha (FAO 2015)

Fertilizing management is one of the most important agronomic practices for papaya because it is a continuously growing plant, which produces fruits all the year, thus a high regular nutrient supply is necessary to sustain plant growth and fruit production (Fontes et al. 2010; Santos et al. 2014).

The most important nutrients for papaya crop are nitrogen (N) and potassium (K), since Fontes et al. (2010) reported that papaya physiology is strongly affected by NK fertilizer, and N presents an especial function because almost 23% of all N absorbed by papaya roots is exported to flowers and fruits (Lyra et al. 2010). In addition, N is a component of amino acids, proteins and nucleic acids and it directly or indirectly acts on several biochemical plant processes (Pessarakli 2014).

In relation to K, papaya also presents a higher demand maybe due to the sweetness of its fruit, since K is recognized as a quality nutrient which improves the major parameters of papaya fruits such as pulp thickness and sweetness (Pessarakli 2014). Accordingly, K has no structural function in plants, but it is crucial for photosynthesis, plant respiration and solute translocations (Marschner 2012).

The effect of both N and K fertilizing on physiological characteristics of papaya has been poorly studied in the scientific literature, beyond the close relation between the fertilizing practice and the plant physiology. This way, Ning et al. (2009) reported that biological growth and development of cultivated plants can be closely evaluated through physiological variables such as photosynthetically active radiation (PAR), leaf area index (LAI) and leaf chlorophyll. The intercepted solar radiation depends on leaf area, leaf angle, plant architecture →

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and plant distribution in the field, and the efficient radiation use is directly related to the canopy potential for PAR (radiation between 390 and 770 nm) interception since it is a measure of incident radiation photons with wavelengths useful for photosynthesis. Indeed, Pessarakli (2014) reported that the amount of PAR absorbed by a canopy is linearly related to its photosynthetic capacity with significant correlations between PAR, light levels and N plant supply.

In this sense, the objective of this research was to study the effect of NK fertilizing and planting spacing on physiological indexes and fruit production of papaya.

MATERIAL AND METHODS

Plant material and growth conditions

Papaya (*Carica papaya* L.) plants cv. Caliman-01 propagated by seeds were used in this study.

The research was conducted from November 2010 to December 2011 (first trial) and from November 2011 to December 2012 (second trial) at Federal University of Piauí, Campus Prof. Cinobelina Elvas, Piauí State, Brazil (Northeastern Brazil).

The physical and chemical characteristics of the soil used for the experiment are shown in Table 1. During the execution of the experiments, the precipitation was 1,100 mm, the temperature range was between 25 °C and 34 °C, and the air humidity was between 37 and 73%.

The plants were daily drip-irrigated with one self-regulating emitter per plant, for a flow of 2.8 $L \cdot h^{-1}$, following the Kc defined by Costa and Costa (2003) for papaya. Each hole (40 × 40 × 40 cm) at 60 days before planting received 15 L of goat manure (C:N, 17:1) and 169 g of simple superphosphate (18% P_2O_5). All experiment area was limed with 1.22 $t \cdot ha^{-1}$ at 60 days before the beginning of the experiment following soil analysis contained in Table 1. Plants were established as 7 week old transplants.

During the execution of the experiment, all plants were fertilized with 167 g of simple superphosphate (18% P_2O_5) at each 90 days. N and K fertilizing, following the treatments, were performed monthly following recommendations of Costa and Costa (2003) using urea (45% of N) and potassium chloride (60% of K_2O) as N and K sources, respectively. The fertilizers were applied in a circular track of 20 cm far from plant stem within the canopy.

The cultural practices performed in the experiment followed the instructions of Paull and Duarte (2011).

Treatments and experimental design

The experimental design consisted of randomized blocks, with treatments distributed in a factorial arrangement (2 × 4 × 4), using 2 planting spacing [simple rows (3.8 × 2.0 m) and double rows (3.8 × 2.0 × 1.8 m)], 4 N doses (320, 400, 480 and 560 g of N per plant) and 4 K doses (380, 475, 570 and 665 g of K_2O per plant) with 4 replications of 3 plants each. For single rows, a plant density of nearly 1,315 $plants \cdot ha^{-1}$ was registered, while double spacing rows promoted almost 893 $plants \cdot ha^{-1}$.The total amount of N applied in each trial reached 499.700 $kg \cdot ha^{-1}$, 526.000 $kg \cdot ha^{-1}$, 631.200 $kg \cdot ha^{-1}$ and 736.400 $kg \cdot ha^{-1}$ for single rows and 339.340 $kg \cdot ha^{-1}$, 357.200 $kg \cdot ha^{-1}$, 428.640 $kg \cdot ha^{-1}$ and 500.080 $kg \cdot ha^{-1}$ for double rows. The total amount of K applied in each trial reached 499.700 $kg \cdot ha^{-1}$, 624.625 $kg \cdot ha^{-1}$, 749.550 $kg \cdot ha^{-1}$ and 874.475 $kg \cdot ha^{-1}$ for single rows and 339.340 $kg \cdot ha^{-1}$, 424.175 $kg \cdot ha^{-1}$, 509.010 $kg \cdot ha^{-1}$ and 593.845 $kg \cdot ha^{-1}$ for double rows.

Data gathered and statistical analysis

The following variables were recorded: i) leaf chlorophyll (*a*, *b* and total index): measured using a chlorophyll meter (Falker®, Brazil) in three leaves of each plant following the methodology of El-Hendawy et al. (2005); ii) leaf area index (LAI) and intercepted PAR (*Int.*PAR, in $\mu mol \cdot m^{-2} \cdot s^{-1}$) were measured twice during each trial in triplicate using a multi-sensor (80 sensors) PAR "Ceptometer" (AccuPAR, Decagon Devices Inc., USA) in each of the four cardinal points of crop canopy between 9 – 10 a.m. of a sunny day; iii) efficiency use of PAR (*Ef.*PAR), calculated through the equation: *Ef.*PAR = *Int.*PAR – *Inc.*PAR (incident PAR); and iv) the fruit yield was measured as $t \cdot ha^{-1}$. When LAI and PAR readings were performed, papaya plants were on reproductive stage. During the fruit harvest time, all fruits were manually harvested when they were one-quarter to one-half ripe, weighted and considered for yield calculation.

Statistical analyses included analysis of variance (ANOVA), using combined data of two consecutive harvests, and regression analysis for N and K doses. All calculations were performed using the Sigmaplot software, and the terms were considered significant at $p < 0.01$.

RESULTS AND DISCUSSION

As can be seen in Table 2, plant spacing affected all variables studied ($p < 0.01$), while the interaction between planting spacing and K was significant for yield, and N *versus* P interaction was significant for LAI.

Double spacing promoted higher *Int.*PAR and *Ef.*PAR (Table 2) in relation to single spacing ($p < 0.01$), which happened due to the better light use and the probable better root development (Hammer et al. 2009). Paull and Duarte (2011) argued that, after papaya seedlings transplanting, there is an intense root growth exceeding plant canopy →

Table 1. Chemical and physical characteristics of the soil (0 – 20 cm and 20 – 40 soil depth) where the experiment was carried out.

Soil characteristics	Value	
	0 – 20 cm	20 – 40 cm
pH (in water)	5.0	4.8
	$cmol_c \cdot dm^{-3}$	
Ca^{2+}	1.6	0.9
Mg^{2+}	0.4	0.2
$Ca^{2+} + Mg^{2+}$	2.0	1.1
Al^{3+}	0.0	0.0
$H^{+} + Al^{3+}$	1.7	1.3
K^{+}	0.23	0.11
CEC	3.9	2.5
	$mg \cdot dm^{-3}$	
P	18.0	14.0
	%	
Organic matter	1.0	0.4
Al^{3+} saturation	0.0	0.0
Basis saturation	57.0	48.0
	$g \cdot kg^{-1}$	
Clay	60	60
Silt	20	20
Sand	920	920

P, K: Melich 1; H + Al: calcium acetate (extractor) 0.5 M, pH 7; Al, Ca, and Mg: KCl 1 M extractor. CEC = cationic exchangeable capacity.

Table 2. Intercepted photosynthetically active radiation (*Int.*PAR), efficiency use of PAR (*Ef.*PAR), yield, leaf area index (LAI) and index of leaf chlorophyll (*a*, *b*, and total) of papaya (cv. Caliman-01) as a function of NK fertilizing and plating spacing.

	*Int.*PAR	*Ef.*PAR	Yield	LAI	Chlorophyll *a*	Chlorophyll *b*	Total chlorophyll
	($\mu mol \cdot m^{-2} \cdot s^{-1}$)		($t \cdot ha^{-1}$)			Index	
Spacing	6.18*	0.22*	48.73*	531.69*	8.82*	16.92*	13.36*
Simple	780.93b	0.56b	2.7b	0.21b	35.30b	10.97b	46.27b
Double	1,002.52a	0.58a	7.3a	0.23a	36.37a	11.95a	48.32a
LSD	**330.12**	**0.01**	**1.31**	**0.004**	**1.33**	**0.87**	**2.07**
Doses (N)	0.33ns	0.43ns	0.25ns	1.10ns	3.61*	3.25*	3.91*
Doses (K)	0.17*	2.83**	1.11ns	0.87ns	1.37ns	1.02ns	1.25ns
S × N	0.57ns	0.58ns	1.36ns	0.17ns	2.09ns	0.48ns	1.49ns
S × K	0.34ns	0.68ns	2.76*	0.09ns	0.20ns	0.40ns	0.21ns
N × K	1.60ns	1.06ns	2.21ns	0.24**	1.81ns	1.70ns	1.94ns
S × N × K	0.45ns	0.69ns	2.11ns	0.29ns	0.85ns	0.90ns	0.94ns
CV%	**49.99**	**43.79**	**64.75**	**3.36**	**5.69**	**11.70**	**6.69**

*Significant at $p < 0.01$ probability error; **significant at $p < 0.05$ probability error. Average data followed by different letters in columns are significantly different according to Tukey test ($p < 0.01$). S = spacing; LSD = least significant difference; ns = non-significant; CV = coefficient of variation.

that makes possible a larger area exploration for water and nutrient absorption. Similar results were reported by Rosati and Dejong (2003) and Rendón et al. (2012).

Increasing potassium doses promoted a significant average enhancement of nearly 25% (*Int.*PAR) and 26% (*Ef.*PAR) from the lower to the higher K dose (Figures 1a, b). This result occurred due to the high K demand of papaya (Bisht et al. 2010) associated to the low soil K before the execution of the experiment (Table 1). Indeed, it is relevant the high light saturation level of papaya [1,000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ according to Paull and Duarte (2011)], showing that probably there was no light saturation, since the highest PAR registered above the plant canopy was 1,900 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

The average *Ef.*PAR values recorded in the present experiment for the plants fertilized with 665 g of K_2O are compatible with the averages presented by Atkinson et al. (2006) for strawberry and Carretero et al. (2010) for wheat; but, independently of the treatment, all averages presented in Figure 1 are lower than those quoted by Salvagiotti and Miralles (2008) for wheat and Cavalcante et al. (2014) for custard apple.

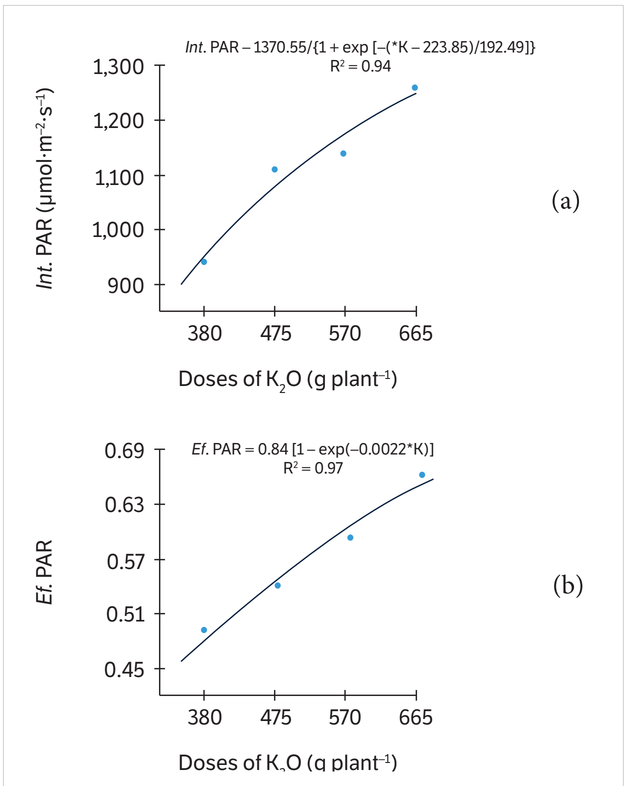

Figure 1. (a) Intercepted photosynthetically active radiation (*Int.*PAR) and (b) efficiency use of photosynthetically active radiation (*Ef.*PAR) of papaya (cv. Caliman-01) as a function of potassium fertilizing.

Plants in double spacing presented significantly higher fruit yield, *i.e.* almost 63% more than single spacing plants (Table 2). The average fruit yield recorded for double-spaced plants is compatible with that referred by Garcia et al. (2007), but lower than those reported by Posse et al. (2009) and Marinho et al. (2010), all of them in studies on papaya (pawpaw). The lower fruit yield values gathered in the present study could be caused by the high air temperatures (25 °C – 34 °C range) and low air humidity (37% – 73% range) registered during the experimental time, because if air humidity be lower than 60% during papaya flowering phase, most of flowers fall (Paull and Duarte 2011).

Papaya fruit yield was significantly enhanced by K rates applied on double-spaced plants (Figure 2), which could be caused by the higher K demand during the initial and reproductive phases, as reported by Santos et al. (2014). At the same time, fruit yield presented the same tendency observed for *Int.*PAR and *Ef.*PAR, showing that, under the higher K doses and double spacing, papaya plants intercepted more PAR with higher efficiency. For single-spaced plants, no significant model was registered.

The LAI followed the same tendency of the *Int.*PAR (Table 2), as previously expected, because the absorption of incident radiation by crops depends on their leaf area (Radin et al. 2003). Double spacing presented LAI nearly 10% higher than single spacing. In addition, Fontes et al. (2010), in a study about different planting spacing for papaya (pawpaw) cv. Caliman-01, reported a higher activity for nitrate reductase enzyme (the most important enzyme for plant N assimilation) for plants under double spacing, which could increase N use and LAI, since N enhances plant photosynthetic rate and biomass production (Cavalcante et al. 2012).

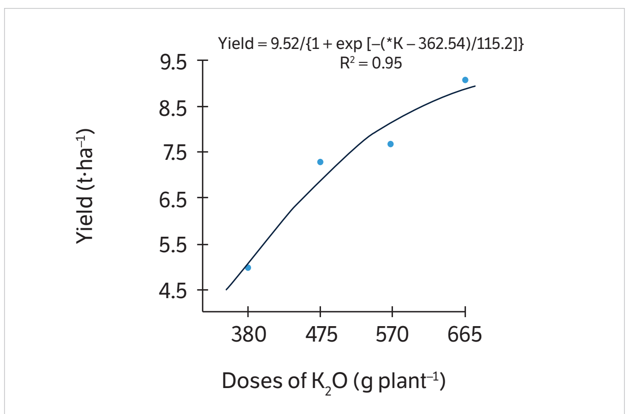

Figure 2. Yield of papaya (cv. Caliman-01) as a function of potassium fertilizing on double-spaced plants.

Leaf chlorophyll *a*, *b* and total indexes were significantly higher on double-spaced plants (Table 2), following the same tendencies of the other variables. According to Resende and Costa (2003), on conventional farms, there is a greater pressure by plant population on plant growth and development due to the competition for essential growth factors (sun light, nutrient and water) and essential photosynthesis factors, with consequent leaf chlorophyll production (Pessarakli 2014).

As observed in Figures 3a, b, c, the increase in N levels promoted an exponential enhancement of leaf chlorophyll index (*a*, *b* and total) of papaya. This enhancement can be explained by N, which, after its metabolism, is present in plants on organic form (almost 90%) with the main function of structure and composing organic composts, such as chlorophyll (Wani et al. 2011). Additionally, Pessarakli (2014) argue that N is the core component of chlorophyll molecule as the structural component in porphyrin ring, and thus its content in the leaf is directly proportional to chlorophyll content. Similar results were also reported by Ziadi et al. (2008) and Cavalcante et al. (2012).

In a general form, it is important to detach the non-significant effect of N doses applied on PAR variables and fruit yield (Table 2). This result possibly could be explained by the high amount of organic matter (goat manure) used for hole formation at 60 days before planting, although the known papaya exigency on soil organic matter, as reported by Paull and Duarte (2011).

CONCLUSION

Thus, the results of this study indicate that the fruit production and physiological characteristics of papaya cv. Caliman-01 depend on planting spacing. Under semiarid climate, 665 g of K_2O and 320 g of N per plant under double spacing could be recommended for the production of papaya cv. Caliman-01.

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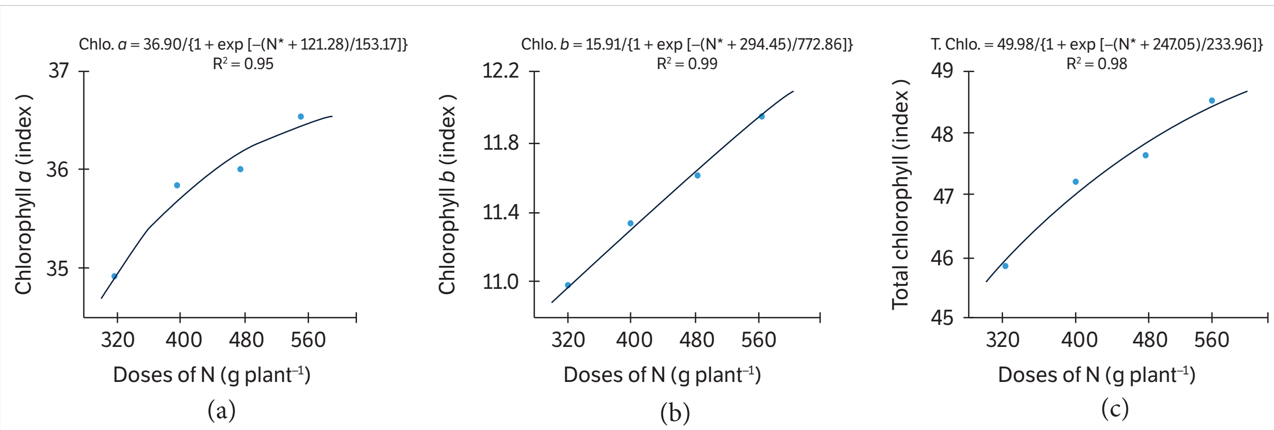

Figure 3. Leaf chlorophyll indexes. (a) Chlorophyll a index, (b) chlorophyll b index, and (c) total chlorophyll index as a function of nitrogen fertilizing.

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