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Nutritional status and fruit production of *Carica papaya* as a function of coated and conventional urea

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Key words:

Carica papaya L.
controlled release fertilizer
plant nutrition
fruit yield

ABSTRACT

As a strategy to minimize N losses in the soil, mineral N sources, such as polymer-coated urea, have been studied as possibility to increase the synchronization of N release by the fertilizer and its absorption by plants. Thus, this study aimed to evaluate the contents of macronutrients and the production of Formosa papaya as a function of sources and doses of N fertilizer applied as top-dressing in the region of Bom Jesus-PI, Brazil. The treatments were arranged in a 2 x 4 factorial scheme corresponding to N sources (coated urea and conventional urea) and N doses (350, 440, 530 and 620 g plant⁻¹ of N), with four replicates and four plants per plot. The contents of macronutrients in the leaf dry matter and fruit production were evaluated. The sources and doses of top-dressing N fertilization incremented the leaf contents of macronutrients and the production of Formosa papaya hybrid Caliman 01. Under the experimental conditions and based on the macronutrient contents considered as adequate for crop nutrition, associated with maximum fruit production (8.08 kg plant⁻¹), the supply of 525 g of N plant⁻¹ is recommended in the form of coated urea.

Palavras-chave:

Carica papaya L.
fertilizante de liberação lenta
nutrição de plantas
produtividade

Estado nutricional e produção do mamoeiro Formosa em função da aplicação de ureia protegida e convencional

RESUMO

Como estratégia para minimizar as perdas de N no solo tem-se estudado fontes minerais de N-fertilizantes protegidas com polímeros a partir das quais é possível aumentar o sincronismo entre a liberação do nutriente pelo fertilizante e sua absorção pela planta. Neste sentido teve-se, como objetivo, avaliar os teores dos macronutrientes e a produção do mamoeiro Formosa em função de fontes e doses de N-fertilizante aplicadas em cobertura na região de Bom Jesus, PI. Os tratamentos foram dispostos em esquema fatorial 2 x 4 correspondentes a fontes de nitrogênio (ureia protegida e ureia convencional) e doses de nitrogênio (350, 440, 530 e 620 g planta⁻¹ de N) com quatro repetições e quatro plantas por parcela. Avaliaram-se os teores de macronutrientes na massa seca foliar e a produção de frutos. As fontes e doses de adubação nitrogenada em cobertura incrementam as concentrações foliares de macronutrientes e a produção do mamoeiro Formosa híbrido Caliman 01. Nas condições em que o experimento foi desenvolvido e considerando os teores de macronutrientes admitidos como adequados para a nutrição da cultura associada à produção máxima de frutos (8,08 kg planta⁻¹) recomenda-se o fornecimento de 525 g planta⁻¹ de N na forma de ureia protegida.



INTRODUCTION

Formosa papaya is a plant that absorbs large amounts of nutrients and has continuous requirements, especially during its first year, reaching the maximum point twelve months after transplantation (Fontes et al., 2010). The characteristics of intermittent harvest of papaya causes the plant to require water and nutrient supplies in frequent intervals, thus allowing the continuous flow of flower and fruit production (Brito Neto et al., 2011).

Despite the nutritional requirement of the crop, it is notorious the necessity to provide correct quantity of fertilizer in order to promote maximum plant yield (Santos et al., 2014). The recommendations of nitrogen (N) fertilization for the crop vary considerably from region to region, in both the applied amount of nutrients and fertilization installments, which is due to the different ecological systems that directly influence fertilization efficiency.

Incorrect fertilizer management with respect to the dose, source and application frequency, has direct impact on plant nutrition, an essential factor for the achievement of economically viable productions. Thus, a nutritional balance must be promoted, especially regarding N, since it has great importance in plant nutrition and participates as a constituent in proteins, nucleic acids and chlorophyll molecule, besides directly acting on the processes of cell division and expansion (Marchner, 2005). On the other hand, N fertilization management is complex, because of the multiplicity of soil biochemical reactions, dependence on edaphoclimatic conditions and vulnerability to losses in the soil (Hu et al., 2012).

Excessive application of N fertilizers can cause nutritional imbalance in the plants and pollute the environment through the contamination of the water table, which makes the practice of fertilization uneconomic, because there may be higher concentration of soluble forms of N in the soil solution, which are more susceptible to losses (Lorenzini et al., 2012). Therefore, as a strategy to minimize the availability of nitrate (N-NO_3^-) through leaching in the soil profile and ammonia (N-NH_3) through volatilization, mineral sources with controlled N release, such as polymer-coated urea, have been used, from which it is possible to increase the synchronization between N release from the fertilizer and its absorption by plants, compared with the use of conventional urea (Azevedo et al., 2009). According to Morgan et al. (2009), urea granules are coated with three layers of polymers and the outmost layer comprises a low-solubility additive, which requires a greater volume of water to dissolve (10 to 20 mm), while the other layers remain in the solution along with ammonium (NH_4^+), thus compromising their recognition by nitrifying bacteria and reducing losses through leaching.

Currently, studies on the use of controlled-release fertilizers in the cultivation of fruit crops have been expanded in order to reduce the number of fertilizations per cycle and the final production cost (Kandil et al., 2010).

Therefore, this study aimed to evaluate the contents of macronutrients and the production of Formosa papaya as a function of sources and doses of N fertilizer applied as top-dressing in the region of Bom Jesus-PI, Brazil.

MATERIAL AND METHODS

The experiment was carried out from November 2011 to February 2013, at the Fruticulture Experimental Area of the Campus Professora Cinobelina Elvas (CPCE), at the Federal University of Piauí (UFPI), in Bom Jesus-PI, Brazil (09° 04' 28" S; 44° 21' 31" W; 277 m). The municipality of Bom Jesus belongs to the semiarid region of Piauí and has hot and humid climate, Cwa, according to Köppen's classification.

The seedlings were produced using certified seeds of Formosa papaya, hybrid Caliman 01, provided by the Capixaba Institute of Research, Technical Assistance and Rural Extension (INCAPER). The substrates consisted of sandy soil and cattle manure at the proportion of 3:1, respectively, mixed with 1.4 kg of single superphosphate (18% of P_2O_5) and 1.0 kg potassium chloride (60% of K_2O) per m^3 of substrate, following the recommendations of Marin (2004). The seedlings were transplanted when they were approximately 20 cm high, 60 days after sowing (Marin, 2004).

The treatments were arranged in a 2 x 4 factorial, corresponding to two N sources [coated urea (Kimcoat N[®]), covered with polymer layers and conventional urea, 45% of N] and four N doses (350, 440, 530 and 620 g plant⁻¹ of N). The treatments were distributed in randomized blocks with 4 replicates and 6 hermaphrodite plants of Formosa papaya per plot, 4 evaluated plants and 2 border plants, cultivated at double spacing (3.8 m between double rows x 1.8 m between rows x 2.0 m between plants), totaling 192 plants with a density of 1,785 plants ha⁻¹.

N doses corresponded to 80, 100, 120 and 140% of N fertilization, monthly divided, in a total of twelve applications, following the recommendations of Costa & Costa (2007).

Potassium chloride (60% of K_2O) was used as K source, whereas single superphosphate (18% of P_2O_5) was used as P source. All the fertilizers (urea, single superphosphate and potassium chloride) were applied in a circle under the canopy projection, 20 cm distant from the stem and gradually incorporated to the soil.

The soil of the experimental area is classified as Quartzarenic Neosol (EMBRAPA, 2013) with sandy texture and showed the following physical and chemical characteristics before the experiment (Table 1).

The data referring to the climatic variables (temperature, relative air humidity and rainfall), collected at the weather

Table 1. Physical and chemical characteristics of the soil in the experimental area in the layers of 0-20 and 20-40 cm

| Soil characteristics | Unit | Layer (cm) | |
|-------------------------------|------------------------------------|------------|-------|
| | | 0-20 | 20-40 |
| pH - H ₂ O (1:2.5) | - | 5.0 | 4.8 |
| Potassium | cmol _c dm ⁻³ | 0.23 | 0.11 |
| Calcium | cmol _c dm ⁻³ | 1.6 | 0.9 |
| Magnesium | cmol _c dm ⁻³ | 0.4 | 0.2 |
| Sodium | cmol _c dm ⁻³ | 0.02 | 0.02 |
| Aluminum | cmol _c dm ⁻³ | 0.0 | 0.0 |
| Hydrogen | cmol _c dm ⁻³ | 1.7 | 1.3 |
| CEC [*] | cmol _c dm ⁻³ | 3.9 | 2.5 |
| P (Mehlich-1) | mg dm ⁻³ | 18.0 | 14.0 |
| Organic matter | g kg ⁻¹ | 10.0 | 4.0 |
| Base saturation | % | 57.0 | 48.0 |
| Clay | g kg ⁻¹ | 60 | 60 |
| Silt | g kg ⁻¹ | 20 | 20 |
| Sand | g kg ⁻¹ | 920 | 920 |

*CEC – Cation exchange capacity

station of the UFPI/CPCE during the experimental period, are shown in Figure 1.

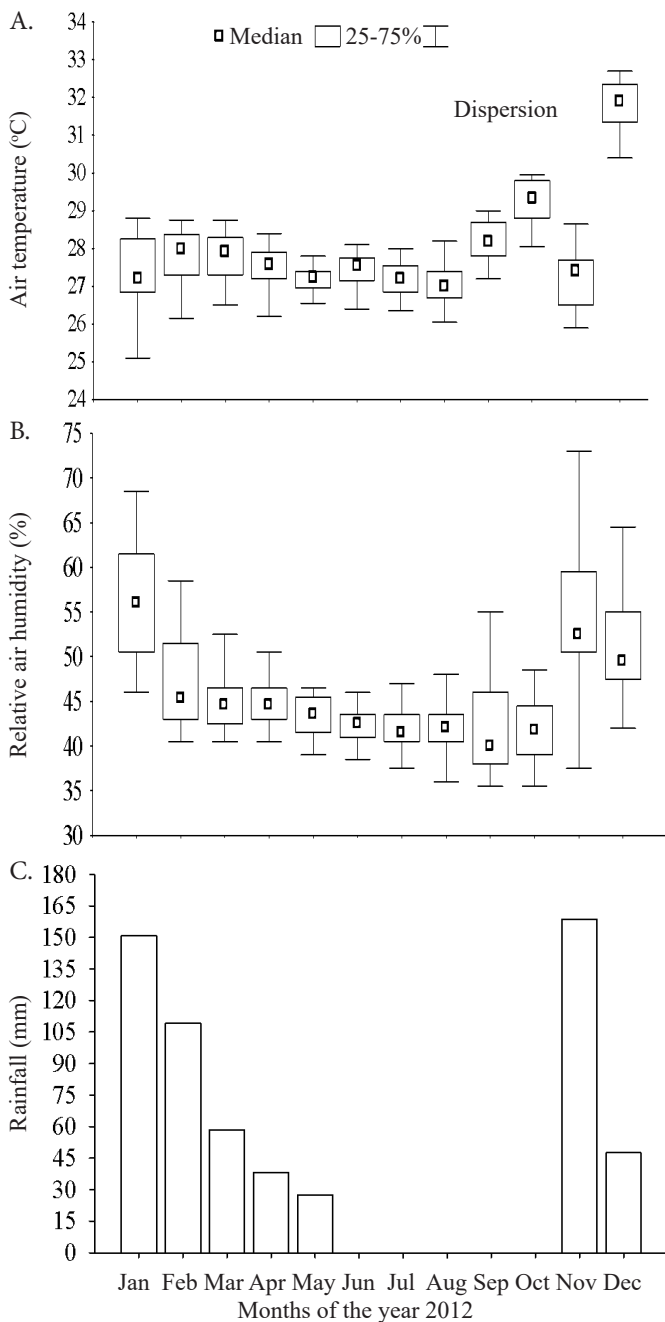


Figure 1. Air temperature (A), relative humidity (B) and rainfall (C) during the experimental period

Table 2. Summary of analysis of variance and mean leaf contents of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) and production of Formosa papaya cultivated under different doses of coated and conventional urea

| Source of variation | N | P | K | Ca | Mg | S | Production |
|---------------------|--------------------|--------------------|----------|--------------------|--------------------|--------------------|------------------------|
| | Mean square | | | | | | |
| Source of N (S) | 4.26** | 1.50 ^{ns} | 172.78** | 0.06 ^{ns} | 0.01 ^{ns} | 0.10 ^{ns} | 16.68** |
| Doses of N (D) | 13.80** | 4.86* | 113.84** | 11.11** | 4.69* | 3.23* | 25.51** |
| Interaction (S x D) | 25.99** | 0.95 ^{ns} | 47.73** | 14.60** | 1.30 ^{ns} | 2.72 ^{ns} | 1.52** |
| CV (%) | 1.91 | 12.21 | 3.07 | 6.45 | 12.23 | 11.48 | 17.96 |
| | Mean | | | | | | |
| | g kg ⁻¹ | | | | | | kg plant ⁻¹ |
| Coated urea | 43.67 a | 6.80 a | 35.07 a | 19.87 a | 5.85 a | 4.00 a | 6.19 a |
| Conventional urea | 42.57 b | 6.45 a | 30.40 b | 19.98 a | 5.85 a | 3.95 a | 4.77 b |
| LSD | 0.60 | 0.59 | 0.74 | 0.94 | 0.52 | 0.34 | 0.72 |

CV – Coefficient of variation; LSD – Least significant difference; ^{ns}Not significant; **Significant at 0.01 probability level
Means followed by different letters in the columns differ statistically by Tukey test

Liming was performed 60 days before transplantation, based on the result of the soil chemical analysis for the experimental area, through the application of 1.22 t ha⁻¹ of dolomitic limestone (RNV = 75%) in the total area. The pits were opened with dimensions of 40 x 40 x 40 cm, where 170 g of single superphosphate (18% of P₂O₅) were applied according to the recommendations of Costa & Costa (2007).

Seedlings transplantation was performed using two plants per pit and thinning occurred 120 days after flowering, leaving only the most vigorous hermaphrodite plant, according to Marin (2004).

Plants were irrigated by a drip irrigation system using two emitters per plant with flow rate of 3.74 L h⁻¹ each. The applied water depths were daily determined according to the reference evapotranspiration (ET₀), obtained from the multiplication of the Class A pan evaporation and the adopted K_p, which was 0.75. The obtained ET₀ values were multiplied by the crop coefficient of papaya in its respective development stages, according to Marin (2004). Always when the amount of rain exceeded the evaporation of the pan, irrigation was suspended. Plants were subjected to the cultural practices recommended by Marin (2004).

For the determination of the nutritional status of papaya plants, “F” leaves (leaf base with the first flower fully developed) were collected 120 days after transplantation, when plants were in full flowering (Malavolta et al., 1997), at the laboratory of Plant Science of the UFPI/CPCE. Then, the contents of macronutrients were determined according to the methodology described by Malavolta et al. (1997).

Harvest was performed from October 2012 to February 2013, along with the determination of the production of fruits plant⁻¹ (kg plant⁻¹), considering fruits collected weekly in the maturation stage 3, when the yellow color covered only 25 to 50% of the surface of the peel (Marin, 2004). Then, the fruits were selected, counted and weighed on a precision scale (0.01 g), for the determination of the mass of fruits per plant.

The data were subjected to analysis of variance in order to identify significant effects between N sources and doses, by F test, and comparison of means of N sources by Tukey test. N doses were evaluated based on simple polynomial regression analysis, using the programs Assistat and Sigmaplot.

RESULTS AND DISCUSSION

As observed in Table 2, there was individual effect of N sources only on leaf contents of N and K and on production

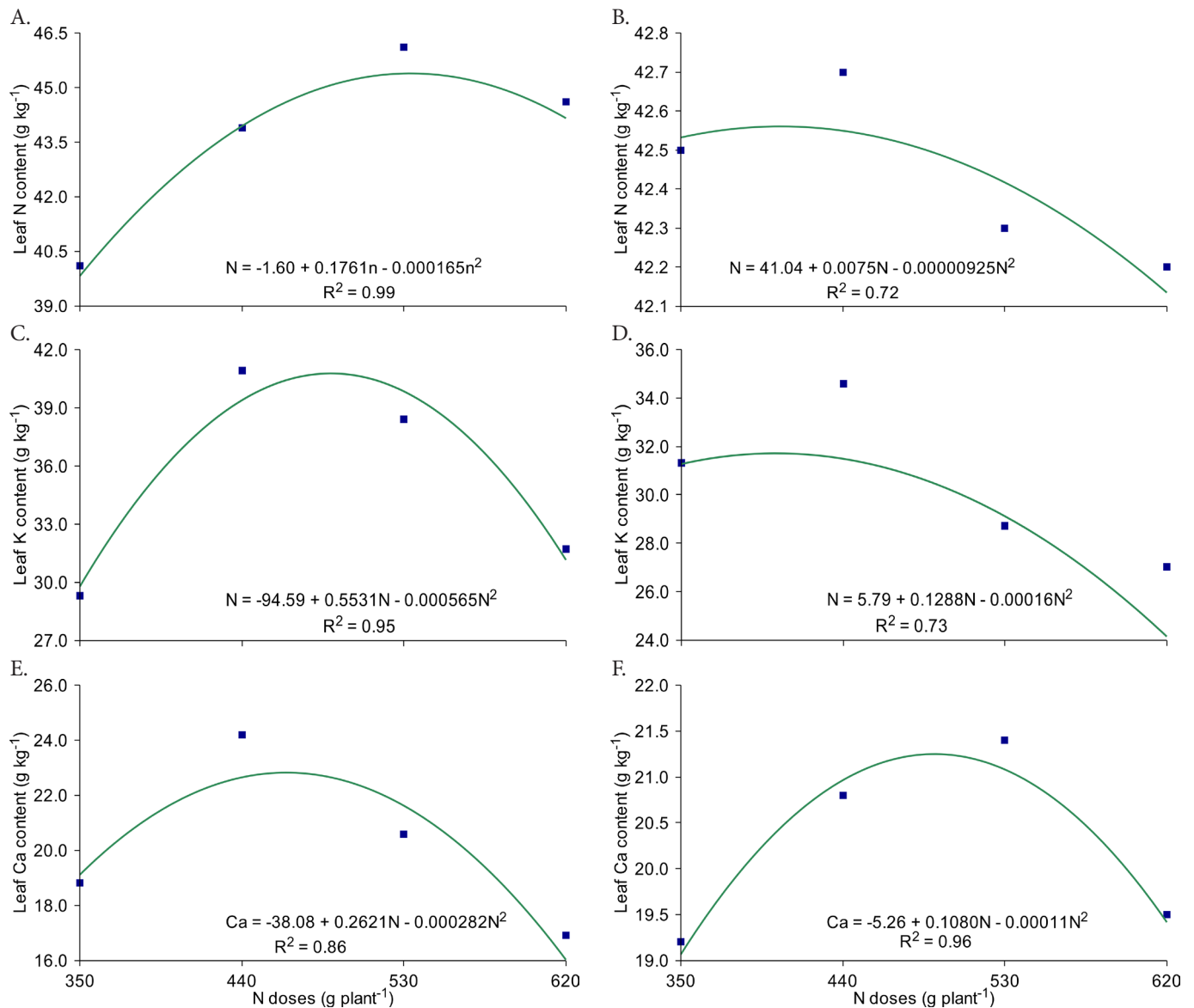


Figure 2. Leaf contents of nitrogen (A and B), potassium (C and D) and calcium (E and F) of Formosa papaya cultivated under different doses of coated and conventional urea. A, C and E: coated urea fertilization; B, D and F: conventional urea fertilization

($p < 0.01$), while N doses promoted significant differences for the leaf contents of N, K and Ca and production ($p < 0.01$), and for the contents of P, Mg and S ($p < 0.05$). For the interaction between the studied sources and doses, there was significant effect on the contents of N, K and Ca at 0.01 probability level.

There was an increment of 2.52% in N contents for plants fertilized with polymer-coated urea in comparison to conventional urea (Table 2). The superiority of coated urea occurred because polymer-coated granules have resins that allow long time of solubilization, thus releasing the nutrient, gradually and by diffusion, through the micropores to the soil solution (Hu et al., 2012), with reduction of leaching losses, especially in sandy soils (Osman & El-Rahman., 2009), as the soil of the experimental area (Table 1). These results agree with those observed for other fruit crops of economic importance, such as peach (Kandil et al., 2010) and guava (Osman & El-Rahman, 2009).

It should be pointed out that the texture of the soil cultivated with papaya, 920 g kg⁻¹ of sand (Table 1), favors

the efficiency of coated fertilizers, since N losses through leaching along the profile in the form of nitrate ($N-NO_3^-$) and through volatilization of ammonia ($N-NH_3$) are intensified in sandy soils, a common phenomenon in orchards of fruit crops (Barlow et al., 2009). Leaf N contents were also significantly affected by the N doses applied to the soil. For the coated fertilizer, the maximum estimated dose of N was 533.63 g plant⁻¹, which corresponds to the maximum N content of 45.38 g kg⁻¹ in the leaf dry matter. For the N contents as a function of the application of conventional urea (Figure 2B), the maximum estimated value was 405.40 g of N plant⁻¹, promoting leaf N content of 42.56 g kg⁻¹.

The lowest leaf N contents observed with the increment in N doses from the maximum estimated doses for both sources can be attributed to the N sufficiency achieved by the plant, according to the range proposed by Malavolta et al. (1997). According to Morgan et al. (2009), at the highest N doses applied, reactions of dissolution with greater increase in the pH of the site are expected, favoring the formation and,

consequently, the emission of N-NH₃, decreasing the use of N applied as mineral fertilizer by papaya plants.

The values of leaf N contents, from 40.0 to 53.1 g kg⁻¹, are consistent with 42.6, 44.9 and 45.0 g kg⁻¹ reported by Falcão & Borges (2006), Almeida et al. (2002) and Campostrini et al. (2001). Malavolta et al. (1997) described the range of 40 to 50 g kg⁻¹ as ideal for papaya at flowering. Therefore, the plants cultivated in the present study, regardless of the N source applied to the soil, had adequate N supply.

The mean K content in papaya plants that received coated urea as N source was 13.32% higher compared with plants cultivated under conventional urea (Table 2). N application in the form of urea promoted higher K contents in the leaves, probably because this source has part of the N in the nitric form, which may have favored the absorption of the cation K⁺, as reported by Marschner (2005). The increment in leaf K contents with the application of polymer-coated N fertilizer was also observed by Kandil et al. (2010), with superiority of 9.14% in comparison to the application of conventional urea.

The K contents of 35.07 g kg⁻¹ observed in this study are higher than 27.30 g kg⁻¹ of K in the leaves of 'Baixinho de Santa Amália' papaya at 120 days after transplantation and higher than the range of 25.0 to 30.0 g kg⁻¹ of K, considered as adequate to supply the plants with K, according to Malavolta et al. (1997), although no visual symptom of excess was identified in the plants.

The increment in the absorption of N and K due to the application of polymer-coated fertilizers may contribute to the reduction of the losses of these nutrients through leaching, thus decreasing the effects of environmental pollution of nitrate, which is easily leached through the drainage of rainwater or irrigation, especially in sandy soils (Luna et al., 2013).

K contents increased until 40.77 and 31.71 g kg⁻¹ (Figures 2C and 2D) referring to the maximum estimated doses of 489.47 and 402.31 g plant⁻¹ of N for the sources coated urea and conventional urea, respectively, with reductions in leaf K contents with the application of doses higher than the respective maximum estimated doses. Additionally, for the maximum estimated K doses, the application of coated urea resulted in an increment of 22.22% in leaf N contents, compared with conventional urea, which represents increase of 9.06 g kg⁻¹ in leaf K content. Santos et al. (2014), evaluating N doses at different planting spacings of Formosa papaya, cv. Caliman, also observed increments in K contents with the increase in N fertilization.

The increase in leaf K contents as a function of N application can be explained by the fact that N is transported to plant shoots in the form of potassium nitrate (KNO₃) (Marschner, 2005) and the monthly application of K contributed to its ideal supply during crop development.

As to leaf Ca contents (Figure 2E), the maximum value for coated urea was 22.82 g kg⁻¹, promoted by the N dose of 464.04 g plant⁻¹, while for conventional urea (Figure 2F), the maximum N dose was 490.91 g plant⁻¹, with leaf Ca content of 21.24 g kg⁻¹. These values are within the range adopted as sufficient for papaya (Malavolta et al., 1997) and are similar to 22.82 g kg⁻¹, obtained by Falcão & Borges (2006).

For P contents in the shoot dry matter of Formosa papaya (Figure 3A), the increment in N doses increased P contents

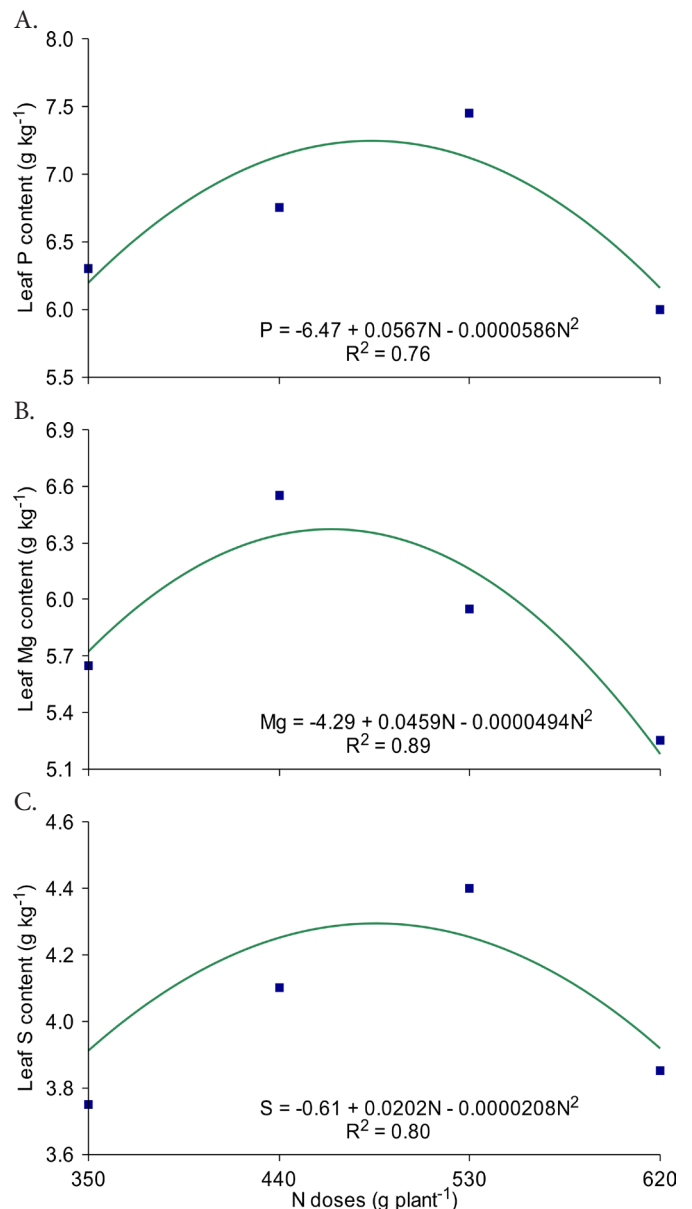


Figure 3. Leaf contents of phosphorus (A), magnesium (B) and sulfur (C) of Formosa papaya as a function of different doses of top-dressing nitrogen fertilization

until the maximum estimated dose of 483.78 g of N plant⁻¹, corresponding to the maximum content of 7.25 g kg⁻¹ of P, which are within the range considered as sufficient for papaya (Malavolta et al., 1997) and higher than the range of 5.0 to 7.0 g kg⁻¹ of P, recommended by Costa & Costa (2007) for plants with age from 120 to 140 days after transplantation.

The increment of leaf P contents with the increase in N doses in the soil was probably due to the synergism between N and P contents in the plants (Marschner, 2005), since N fertilization has a positive effect on leaf P contents.

Regardless of the studied N source, Mg contents (Figure 3B) in the leaf dry matter of Formosa papaya increased with the increment in N dose until the maximum estimated value of 464.57 g plant⁻¹ of N, which promoted Mg content of 6.37 g kg⁻¹. These maximum results are lower than 10.0 g kg⁻¹, described by Malavolta et al. (1997) as sufficient for the nutrition of papaya plants. The fact that leaf Mg contents are below the range considered as ideal for the crop and, in contrast, the

ideal K contents are above it, is related to the inhibition of Mg^{2+} absorption caused by the high K^+ contents (Marschner, 2005).

Sulfur (S) contents in the leaf dry matter of Formosa papaya (Figure 3C) also increased as a function of N doses applied to the soil, and the maximum estimated dose was $485.58 \text{ g plant}^{-1}$, which corresponds to the S content of 4.29 g kg^{-1} . Therefore, it is superior to the maximum mean of 3.86 g kg^{-1} of S, reported by Santos et al. (2014), who evaluated the nutritional status of Formosa papaya (hybrid Caliman 01) as a function of N fertilization. On the other hand, the maximum S values were higher than that observed by Santana et al. (2004) in papaya plants from the 'Solo' group, cultivated under the application of conventional fertilizer.

Comparing the S values shown in Figure 3C with 6.0 g kg^{-1} of S, considered by Malavolta et al. (1997) as sufficient for the crop, the plants were deficient in S. Although the P source used in the experiment was single superphosphate (10% of S), it was not enough for an adequate supply of S and, probably, the balance between N supply through urea application and S through P fertilization was not adequate as well, thus causing an apparent N accumulation in the plant (Table 2). This situation was also evidenced by Jamal et al. (2010) and Santos et al. (2014), who observed that significant relationships between N and S in the soil, caused by higher doses of N fertilization, result in lower S availability.

The mean production of fruits per plant, for both N sources, increased with the increments in N doses, and the coated fertilizer (Figure 4) was superior to the conventional fertilizer at all of the studied N doses. Thus, coated urea promoted maximum estimated production of $8.08 \text{ kg plant}^{-1}$, corresponding to the N dose of 525 g plant^{-1} , while the maximum production promoted by conventional urea fertilization was only $6.42 \text{ kg plant}^{-1}$ for a maximum N dose of $500.9 \text{ g plant}^{-1}$.

The increment in fruit production promoted by the application of coated urea is due to the fact that polymer-coated fertilizers reduce N losses through leaching and volatilization, showing greater efficiency in the yield of some crops (Osman & El-Rahman, 2009). Additionally, Brito Neto et al. (2011) claim that the gradual supply of N, with better spatial distribution in the soil during the productive stage, is of great importance for the papaya crop, favoring the synchronization between the supply of this nutrient and the physiological demand of the plant, such as the formation of flowers and fruits.

The highest estimated production of Formosa papaya is consistent with the value of $8.0 \text{ kg plant}^{-1}$, reported by Brito

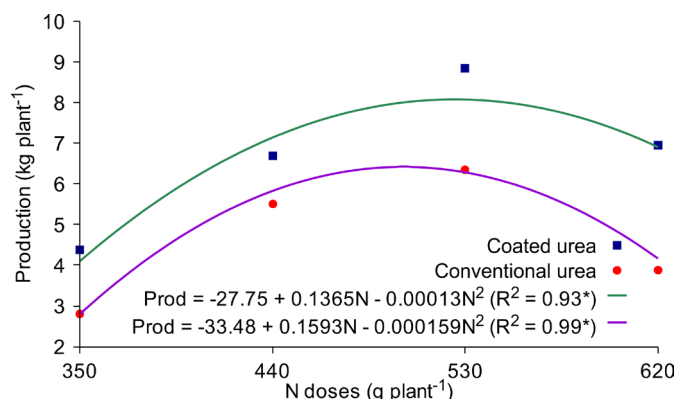


Figure 4. Fruit production of Formosa papaya cultivated under different doses of coated and conventional urea

Neto et al. (2011) in a study with 'Sunrise Solo' papaya as a function of N doses, and lower than $17.34 \text{ kg plant}^{-1}$, reported by Souza et al. (2007) for Formosa papaya, cv. Tainung 01, fertigated with different combinations of N fertilization. The lower production may be attributed to the short period of harvest, with duration of 120 days, mainly associated with the low relative air humidity, according to the data recorded during the cultivation period (Figure 1B), because Reis & Campostrini (2008) claim that the mean relative air humidity recommended for the flowering stage of papaya is 60 to 85%. Values below this range promote high rates of flower abortion, which was observed during the flowering of papaya plants.

CONCLUSIONS

1. N sources and doses improve the nutritional status with macronutrients and the production of Formosa papaya, hybrid Caliman 01.
2. The increase in N doses for the coated source applied as top-dressing promotes higher N contents and fruit production, compared with conventional urea.
3. Based on the contents of macronutrients considered as adequate for the nutrition of the crop, associated with the maximum fruit production, the supply of 525 g plant^{-1} of N is recommended in the form of coated urea.

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