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Physical and physicochemical attributes of noni fruits fertilized with cattle manure and potassium

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Noni has been introduced in Brazil just over a decade ago. Therefore, the information regarding crop fertilization and its influence on fruit quality is rare in the literature. Among macronutrients, potassium is highly concentrated in noni plants, and fertilization with cattle manure contributes to plant nutrition and fruit quality. This study sought to evaluate the effect of potassium fertilizer and cattle manure on the physical and physicochemical attributes of noni fruits. The treatments were distributed in randomized blocks, with four replications and two plants per plot, arranged in a factorial design 5 × 2 related to 0, 13.2, 37.5, 61.5 and 69.6 g plant⁻¹ potassium chloride doses in soils without and with 12 kg plant⁻¹ of cattle manure, with a C/N = 18:1 ratio. Cattle manure increased the average fruit weight from 99.6 to 113.4 g, expressing an increase of 13.9% for plants without and with organic compounds. Potassium chloride provided an increase of 61% in fruit weight and 31.25% in titratable acidity in fruits of plants without and with the highest dose of potassium chloride. Potassium chloride and cattle manure increased fruit mass, fruit length, fruit diameter, pulp mass, vitamin C and glucose contents in noni fruits.

Key words: Fruit quality, *Morinda citrifolia* L., organic mineral fertilizer.

INTRODUCTION

Noni (*Morinda citrifolia* L.) is a tropical fruit tree widely distributed in the islands of the South Pacific, Southeast Asia, Central America and parts of India (West et al., 2011). In these regions, its fruit has been used as an alternative source of medicine for centuries to combat

several diseases (Macpherson et al., 2007; West et al., 2011). The fruit of noni, classified as syncarp, has whitish-yellow to white coloring and a characteristic strong odor. It has a high concentration of vitamin C, antioxidants, proteins and carbohydrates (Canuto et al., 2010; Costa et

al., 2013; Palioto et al., 2015). It is used as a medicament, especially its concentrated juice. The culture of noni has been recently introduced in Brazil, therefore, the information about its cultivation and the quality of the achieved yield is still scarce in the literature (Silva et al., 2012; Silva et al., 2014a).

Among the macronutrients, potassium is highly concentrated in noni plants, being the second most abundant element in leaves and the first most abundant element in fruits (Cavalcante et al., 2014; Silva et al., 2014b). This is due to the importance of potassium in various physiological processes of the plant, such as the synthesis and translocation of carbohydrates, activation of enzymes and the formation of organic compounds, with an effect on fruit production and fruit quality (Gross, 1991; Jifon and Lester, 2009; Lester et al., 2010; Marschner, 2012).

Cattle manure is a major source of organic raw material. It is used in the Brazilian family farming, including in the northeastern semiarid. This activity, according to Galvão et al. (2008), is associated with its high availability on most farms, and the purchasing value in many cases does not significantly increase production costs. Kumar and Ponnuswami (2013) and Silva et al. (2014b) attribute to cattle manure, an adequate supply of organic matter, the nutrition of noni plants and may therefore contribute to the quality of the fruit, since the organic input improves the soil's physical and chemical properties and increases biochemical and edaphic microbiological activity (Mandal et al., 2007; Dunjana et al., 2012).

In soil fertilization, the use of organic materials added to mineral fertilizers, which significantly influence the root system architecture and the nutritional stage is crucial to the success of fruit production (Brito et al., 2005), for the application of organic sources and mineral fertilization influence on fruit quality of passion fruit plants. However, has little information about the effect of the organic and mineral fertilization on the physical and physicochemical quality noni fruit. Thus, this study sought to evaluate the effect of mineral fertilization with potassium chloride and organic fertilization, with cattle manure on the physical and physicochemical attributes of noni fruits.

MATERIALS AND METHODS

The experiment was conducted from July 2012 to November 2013 in a 40 m x 30 m experimental area in the Agriculture Sector of the Human, Social and Agricultural Sciences Centre of the Federal University of Paraíba, Bananeiras City, and Paraíba State, Brazil.

The rainy season is concentrated from April to August and the dry period is from September to January. The accumulated rainfall during the experiment was 1,175 mm. During the same period, daily temperature values and relative humidity were recorded and

average monthly data were obtained as shown in Figure 1. The values of average temperature and relative humidity of the air during the experimental period were, 25°C and 65%, respectively.

The soil of the area, according to the criteria of the Brazilian System of Soil Classification -SiBCS (Embrapa, 2013), was classified as an Oxisoil Dystrophic. Before the experiment installation, soil samples were collected for analysis of physical and chemical attributes as fertility (Table 1) and determined using the methods described by (Donagema et al., 2011).

Before the experiment, a liming with 3.3 t ha⁻¹ of limestone (47% of CaO, 2% of MgO and 91% of PRNT) was performed across the experimental area in the layer 0 to 20 cm to increase the percentage of soil saturation by exchangeable bases from 39.7 to 80.0%. After the limestone reaction, 40 cm x 40 cm x 40 cm holes, spaced 4 m between plants and between rows, were opened, the seedlings were transplanted 60 d after the seed planting. The treatments were distributed in randomized blocks with four replications and two plants of noni (*Morinda citrifolia* L.) cv. citrifolia per plot. They were arranged in a 5 x 2 factorial design related to 0, 13.2, 37.5, 61.5 and 69.6 g plant⁻¹ potassium chloride doses in order to increase the previous soil's K content from 20 to 45, 90, 135 and 150 mg dm⁻³, in soils without and with 12 kg plant⁻¹ of cattle manure with a C/N ratio of 18:1, as estimated by Donagema et al. (2011). This dose was used to increase the organic matter content of the soil from 1.69 to 4.00%. The result of the chemical analysis of the manure used is shown in Table 2.

The fertilization with potassium chloride and organic matter was made in three equal applications of 0, 4.4, 12.5, 20.5 and 23.2 g plant⁻¹ of KCl and 4 kg plant⁻¹ of cattle manure, adding another 200 g related to 5% humidity. The first fertilization was performed pre plant during the whole filling on July 7, 2012. The second and the third fertilizations were performed during the growing period at 30 (August 1, 2012) and 270 days after transplanting the seedlings (July 4, 2013). In all three fertilizations, 40 g plant⁻¹ of P₂O₅ from single superphosphate (20% of P₂O₅, 10% of S and 18% of Ca) were applied. Nitrogen fertilization corresponded to the applications of 30 g plant⁻¹ of N as ammonium sulfate (20% of N, 21% of S) at 30 days after transplanting (August 2012) and in April and June 2013, as suggested by Cavalcante et al. (2014) for noni crops in 2010. At 510 days after the installation of the experiment, in November 2013, eight fruits per treatment were collected at the physiological maturity stage. After reaching commercial maturity, that is, a white-porcelain color (Silva et al., 2012; Silva et al., 2014a), fruits were packed in polystyrene trays, then taken to the laboratory to measure length and diameter with a Digimess® digital caliper. The mass of the fruit and the pulp was measured in a semi-analytical balance. After pulping fruits, the physicochemical properties of soluble solids (SS) were determined by direct readings of the juice with a digital portable refractometer model RHB0-80B. The titratable acidity (TA) was measured in a 10 mL juice sample by adding 1 ml of phenolphthalein and titration with NaOH at 0.1 N. The ratio SS/TA was obtained by the ratio between soluble solids and titratable acidity. Vitamin C was determined by titration of DFI solution (2, 6-diclofenolindofenol) in 1 ml of juice diluted in 50 ml of 0.5% oxalic acid. The levels of glucose and sucrose were obtained in juice by the Lane Enyon method (AOAC, 2005) and identified by the Somogyi-Nelson method (Southgate, 1991).

Data were submitted to analysis of variance by "F" test at 5% probability. The means concerning cattle manure were compared by "F" test, which is conclusive for two factors, and means referring to doses of potassium chloride were compared by polynomial regression using the statistical software SISVAR version 5.3

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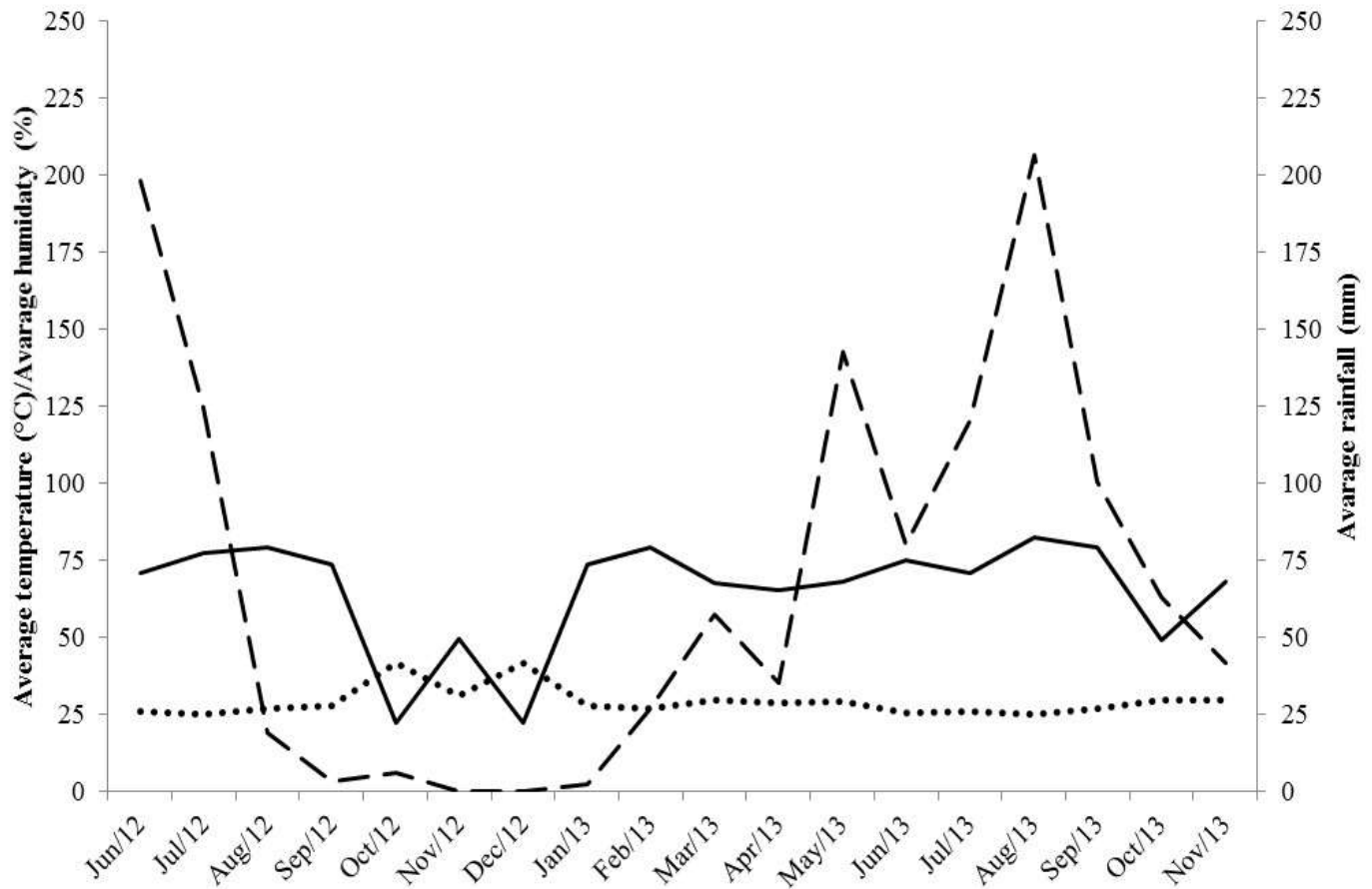


Figure 1. Average monthly values of relative humidity (—), air temperature (····) and rainfall (- - -) from June 2012 to November 2013 during the experiment.

Table 1. Characterization of the chemical attributes as fertility and physical soil before the experiment.

Chemical attributes - fertility		Physical attributes	
pH in H ₂ O (1:2.5)	5.23	Sand (g kg ⁻¹)	653
P (mg kg ⁻¹)	3.30	Silt (g kg ⁻¹)	229
K ⁺ (cmol _c kg ⁻¹)	0.05	Clay (g kg ⁻¹)	118
Ca ²⁺ (cmol _c kg ⁻¹)	1.80	Ada (g kg ⁻¹)	24.8
Mg ²⁺ (cmol _c kg ⁻¹)	1.16	Soil density (g cm ⁻³)	1.29
Na ⁺ (cmol _c kg ⁻¹)	0.01	Particle density (g cm ⁻³)	2.71
SB (cmol _c kg ⁻¹)	3.01	Degree of flocculation (%)	78.9
Al ³⁺ + H ⁺ (cmol _c kg ⁻¹)	4.58	Index of dispersion (%)	21.1
Al ³⁺ (cmol _c kg ⁻¹)	0.46	Total porosity (%)	52.4
CEC (cmol _c kg ⁻¹)	7.59	Macroporosity (%)	40.1
V (%)	39.7	Microporosity (%)	12.3
N (%)	0.09	U _{FC} - 0.01 MPa (%)	12.3
OC (%)	0.98	U _{PWP} - 1.50 MPa (%)	3.8
OM (%)	1.69	Available water (%)	8.5
EC _{se} (dmS cm ⁻¹)	0.05	Textural classification:	Sand loam

SB = Sum of bases; CEC = Cation exchange capacity; V = Exchangeable base saturation; OC = Organic carbon; OM = Organic matter in the soil; EC_{se} = Electrical conductivity in the soil saturation extract; Ada = Clay dispersed in water; UFC = Water content at field capacity, tension of -0.01 MPa; Upwp = Water content at the permanent wilting point, tension of -1.50 MPa.

Table 2. Chemical characterization of the cattle manure used in the experiment.

Chemical characterization								
pH	OM	N	P	K ⁺	Ca ²⁺	Mg ²⁺	Na ⁺	C:N
H ₂ O (1:2.5)	-----g dm ⁻³ -----		-mg dm ⁻³ -		-----cmol _c dm ⁻³ -----			
8.58	323.86	10.44	2.07	2.49	4.65	5.25	1.19	18:1

OM = Organic matter in the cattle manure; C:N = Carbon/nitrogen ratio.

(Ferreira, 2014).

RESULTS AND DISCUSSION

According to the summary of variance analyses (Table 3), the interaction between cattle manure × doses of potassium (M × K) had significant effects on fruit diameter (FD) and pulp mass (PM) of noni fruits. It is also stated that average fruit weight (FW) and fruit length (FL) were not influenced by this interaction, but responded to single effects of cattle manure (M) and potassium chloride doses (K).

The application of cattle manure in the soil provided the plants develop of increased mass (133.4 g) over the plants without the organic fertilizer (99.6 g), as observed in Figure 2a. Thus, it appears that the organic fertilizer application in the form of cattle manure promoted an increase of 33.93% on average fruit weight compared to treatment without their manure. Cattle manure, despite a low chemical composition in terms of nitrogen and potassium, but high on calcium and magnesium (Table 2), increases the soil fertility level and the availability of nutrients to plants (Galvão et al., 2008; Silva et al., 2014b). This input, in addition to improving soil structure, increases the pore space of the soil, and stimulates root development (Mosaddeghi et al., 2009) and promotes the absorption of water and nutrients by plants, thus, reflecting in fruits with an increased mass, such as in noni fruits.

These results are in accordance with the results obtained by Costa et al. (2015) in pitaia red (*Hylocereus undatus* (Haw.) Britton and Rose), where the authors observed that the application of organic fertilizer in the form of cattle manure, provided the formation of fruits with high mass, which was attributed to the high concentration of nutrients such as nitrogen and phosphorus. The addition of potassium chloride resulted in a linear increase of 0.709 g⁻¹ in fruit mass per unit increase of mineral fertilizer to the soil (Figure 2b). The values increased from 80.7 to 130 g and represented an increase of 61.1% in fruits of plants in soils with and without the maximum KCl dose of 69.6 g plant⁻¹ in each application and 0.88% per unit increase in potassium chloride. This is due to a higher outflow of sucrose to the apoplast in function of the availability of potassium, increasing the translocation of sugars to drain-tissues, in

this case, the fruit promotes further growth (Taiz and Zeiger, 2013).

The highest fruit mass of plants treated with cattle manure (Figure 2a) and with the highest potassium chloride dose (Figure 2b) exceeded the value of 50 g fruit⁻¹ obtained by Silva et al. (2012) for noni plants in an unfertilized soil and indicates the feasibility of the respective inputs. Organic manure according to Kumar and Ponnuswami (2013) is responsible also for improving other physical traits in noni fruits like size, diameter, length and volume. The effects of cattle manure and potassium chloride on fruit length (Figure 3) were similar to those observed for the average noni fruit mass. The fertilization with cattle manure promoted increase in the length of the fruit noni with values of 75.5 mm, compared to treatments without fertilization - 69.2 mm; the application of fertilizer increased by 9.1% the length of the fruits (Figure 3a). At potassium chloride doses promoted a linear growth in fruit length (Figure 3b). Values increased from 65.5 mm in plants without KCl to 67.8, 72.2, 76.6 and 78.0 mm, respectively, in plants fertilized with 13.2, 37.5, 61.5 and 69.6 g plant⁻¹ of KCl. The values are in the range 40 to 100 mm observed for noni fruits harvested by Macpherson et al. (2007) and Cavalcante et al. (2014) in Australia and in Brazil.

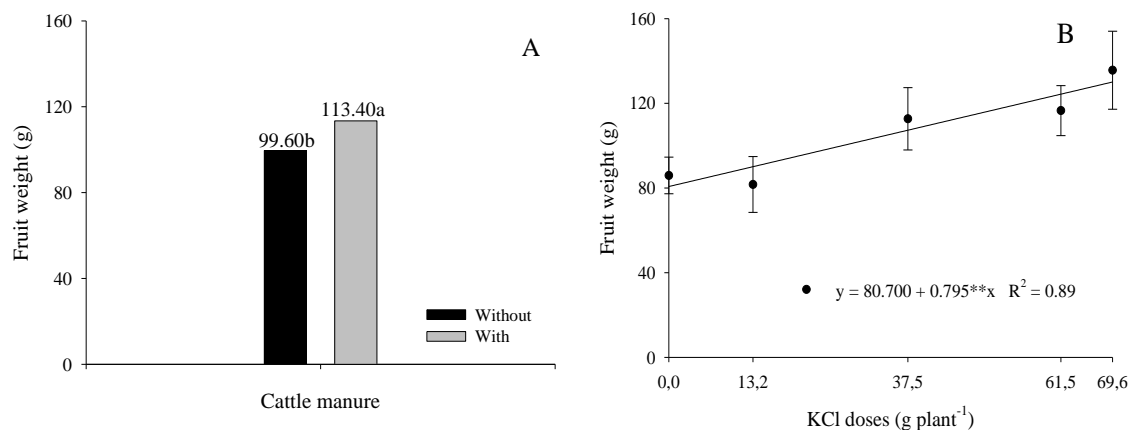
The increase in potassium chloride doses stimulated the development of the diameter of noni fruits. They were greater in fruits of plants treated with cattle manure (Figure 4). Plants in the soil without cattle manure, the increase was from 48.7 to 54.4 mm in plants with and without the highest potassium chloride dose. On the other hand, plants in the soil with the organic compound, fruit diameter increased linearly from 49.9 to 55.3 mm in plants of the soil without the highest dose of KCl.

By comparison, the results resemble the 50 to 60 mm variation in fruit diameter presented by Silva et al. (2014a) upon fertilizing noni plants with cattle manure with and without potassium fertilization. In the situations with absence and presence of cattle manure, there were increase of 11.70 and 10.82%, respectively, in plants with the highest dose of KCl and without this mineral fertilizer. The highest values of length and fruit diameter in plants treated with KCl and cattle manure express the requirement of potassium for growth, yield, quality, participation in various metabolic processes and the highest concentration of cations in fruits (Jifon and Lester, 2009; Marschner, 2012). As for cattle manure, besides promoting

Table 3. Analysis of variance of physical characters of noni fruits in soils with or without cattle manure (M) as a function of potassium chloride (K).

SV	DF	Mean Square			
		FW	FL	FD	MP
Blocks	3	355.17 ^{ns}	0.55 ^{ns}	0.18 ^{ns}	264.25*
Cattle manure (M)	1	1905.50**	3.96**	0.32*	1005.30**
Potassium chloride (K)	4	4056.96**	2.97**	0.76**	3021.13**
M × K	4	257.79 ^{ns}	0.46 ^{ns}	0.31**	361.13**
Residue	27	131.20	0.30	0.07	80.92
Total	39				
Mean		106.49	7.64	5.18	77.05
CV (%)		10.76	7.23	5.12	11.71

SV = Source of variation; DF = Degree of freedom; CV = Coefficient of variation; ns = Not significant.

**Figure 2.** Average mass of noni fruits in soils without and with cattle manure (A) and potassium chloride doses (B).

the physical improvement due to soil structuring, aggregate stability and increase of soil's macroporous space (Dunjana et al., 2012), it encourages root growth and biochemical and microbiological activity of the soil (Mandal et al., 2007), promoting nutrient absorption and resulting in larger fruits. Regardless of the presence or absence of cattle manure, the pulp mass of noni fruits increased linearly by 0.546 and 0.680 g per unit increase of potassium chloride, being higher in fruits of plants with cattle manure (Figure 5).

The pulp mass from treatments with and without manure increased from 52.14 to 90.14 g fruit⁻¹ and from 57.3 to 104.63 g fruit⁻¹ in plants with and without the highest dose of KCl. These increase due to higher potassium fertilization, account for 72.9 and 82.6% increases, respectively, in plants with and without organic fertilization. The results are in agreement with Silva et al. (2014a) upon establishing the fertilization with potassium chloride, and cattle manure which promotes significant

increases in pulp yield of noni fruits. According to the summary of analyses of variance, the interaction cattle manure × potassium doses, except from acidity, interfered significantly on the chemical characteristics of noni fruits, as indicated in Table 4.

In plants treated without soil organic fertilizer, the soluble solid contents in fruits, with increasing doses of potassium chloride, did not adjust to any type of regression which has the mean value of 4.84°Brix. In treatments with cattle manure, the contents increased up to a dose of 41.14 g plant⁻¹ of KCl, with a maximum value of 5.31°Brix (Figure 6a). By relating the values of 5.31 to 4.84, it is verified that soluble solid content in the pulp of noni fruits increased by 9.71% due to cattle manure application. The application of potassium chloride with cattle manure contributed to the increase in solid soluble contents of noni fruits due to the induction of synthesis and translocation of carbohydrates and activation of enzymes. It also contributed to the formation of organic

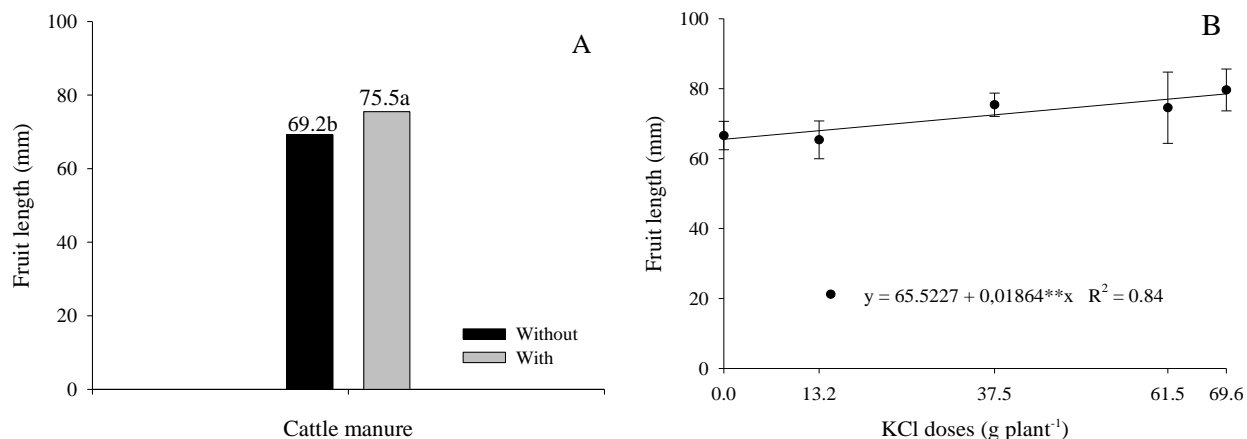


Figure 3. Average length of noni fruits in soils without and with cattle manure (A) and potassium chloride doses (B).

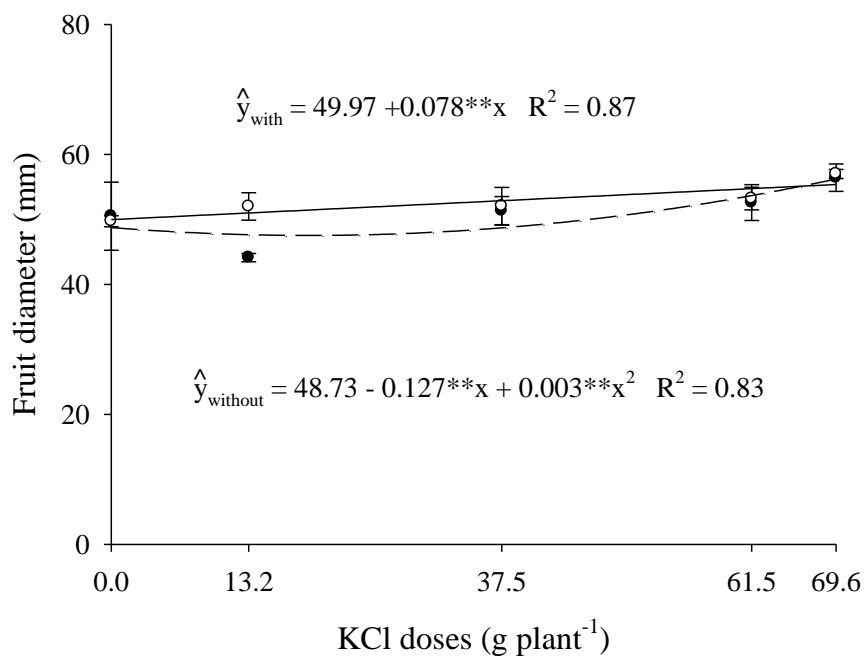


Figure 4. Noni fruit diameter in soils with (—) or without (- -) cattle manure as a function of potassium chloride.

acids, which was also found for yellow passion and melon fruits (Brito et al., 2005; Jifon and Lester, 2009). Even considering the soluble solid contents in the fruits, the values were lower than all values obtained by Kumar e Ponnuswami (2013) in fruits of noni under different irrigation regimes and sources of organic manure, which ranged from 7.21 to 10.53°Brix.

The titratable acidity increased linearly by 0.0020% in citric acid per unit increase of potassium fertilization. The values increased from 0.48 to 0.63% in fruits of plants with and without the highest dose of potassium chloride

(69.6 g plant⁻¹), which is equivalent to an increase of 31.25% (Figure 6b). These results are above the 0.39% value obtained by Silva et al. (2012) and the 0.32% value obtained by Canuto et al. (2010) for noni fruits without any mineral or organic fertilization. The soluble solids/titratable acidity ratio of fruits of treatments with cattle manure (Figure 7) decreased linearly by 0.0521 per unit increase of KCl, from 10.5395 to 6.9133, when he linked the lowest and highest dose of potassium fertilizer, with losses of 34.40%. Fortaleza et al. (2005) presented a similar decrease upon verifying a reduction in the

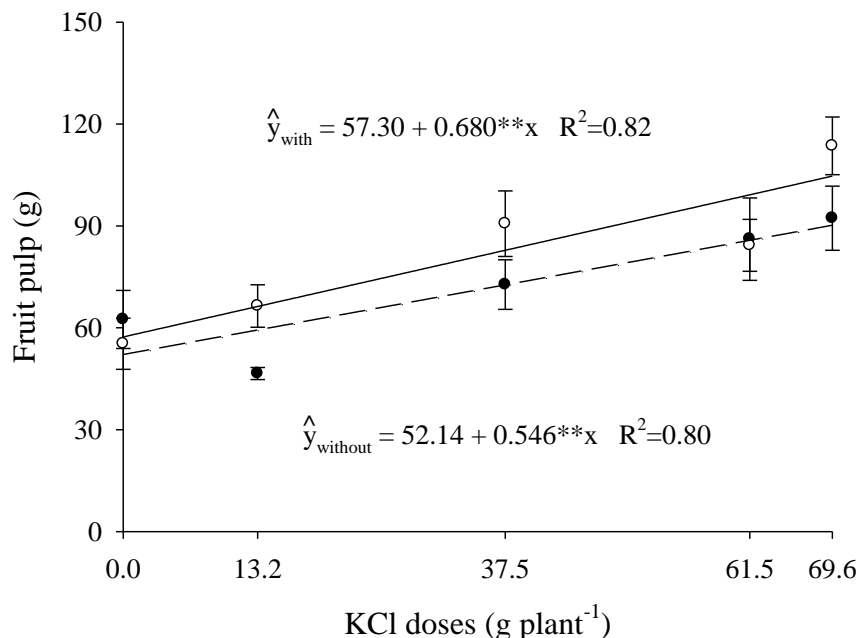


Figure 5. Noni fruit pulp in soils with (—) or without (- - -) cattle manure as a function of potassium chloride.

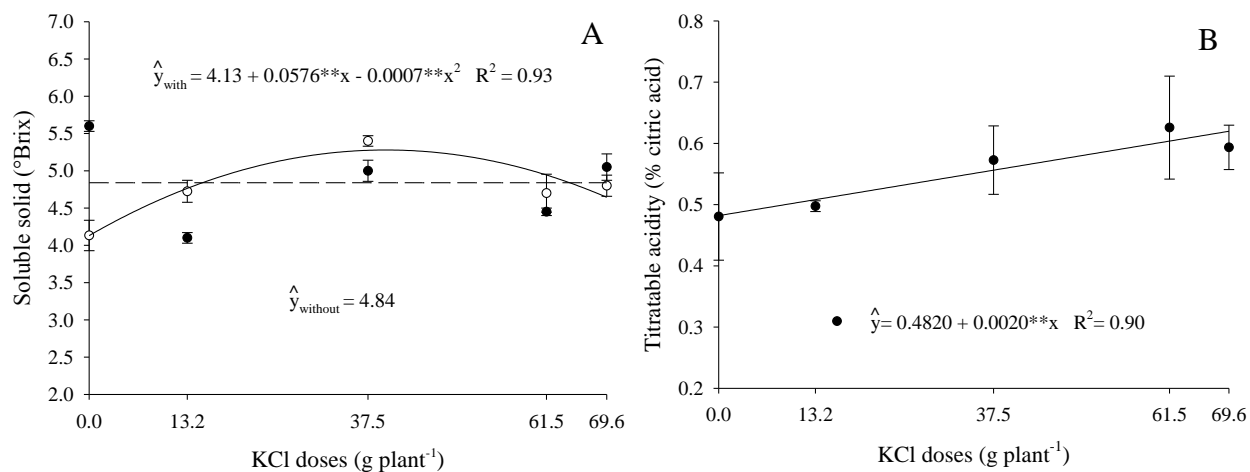


Figure 6. Soluble solid (A) and Titratable acidity (B) of noni fruits in soils with (—) or without (- - -) cattle manure as a function of potassium chloride.

SS/TA ratio value in fruit pulps of sour passion fruit genotypes with an increase in K_2O doses applied to the soil. In the treatments without cattle manure, the SS/TA ratio increased up to the estimated potassium dose of $29.11 \text{ g plant}^{-1}$, reaching the maximum value of 9.4858 (Figure 7). Despite the increase in treatments without organic matter, the results of SS/TA of noni fruits were lower than the 28.12 value obtained by Canuto et al. (2010) and the 26.69 value obtained by Silva et al. (2012). This lower value is the response of the high

titratable acidity, as indicated in Figure 6b.

In treatments without cattle manure, the increase in potassium fertilization increased the levels of vitamin C to $135.6 \text{ mg } 100 \text{ mL}^{-1}$ of juice at the estimated maximum dose of $53.6 \text{ g plant}^{-1}$ of KCl. Higher doses compromise of the vitamin C content of fruits (Figure 8). The beneficial effects of K supplementation through potassic fertilization to plants can be related to a series of factors, such as improving the photosynthetic CO_2 assimilation by leaves, higher translocation assimilates and there is improvement

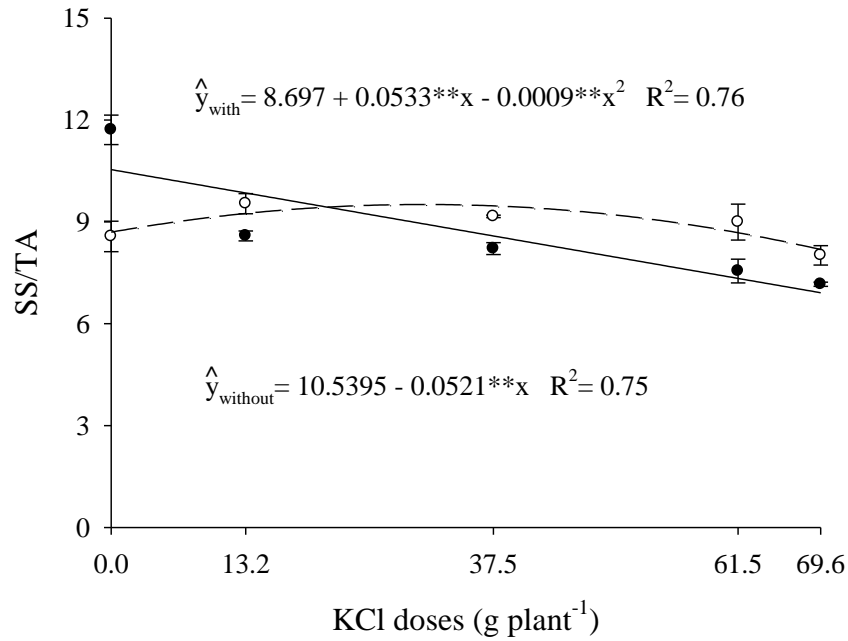


Figure 7. SS/TA (soluble solids/titrable acidity) ratio of noni fruits in soils with (—) or without (- - -) cattle manure as a function of potassium chloride.

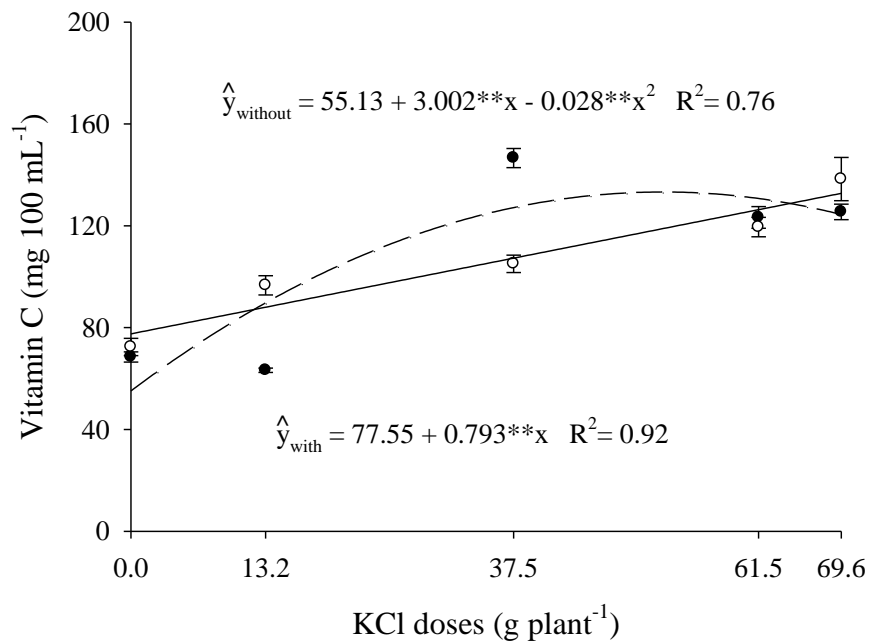


Figure 8. Vitamin C of noni fruits in soils with (—) or without (- - -) cattle manure as a function of potassium chloride.

in water relations between the leaves and the fruits, thus, contributing to higher enzyme activity which interferes in the availability of substrate for the biosynthesis of vitamin C (Gross, 1991). Similar results were presented by

Consta'n-Aguilar et al. (2014) in a study of the physical and chemical quality of tomato cherry (*Solanum lycopersicum* L.), where they observed that increased doses of K₂O, increased vitamin C content of fruit. In the

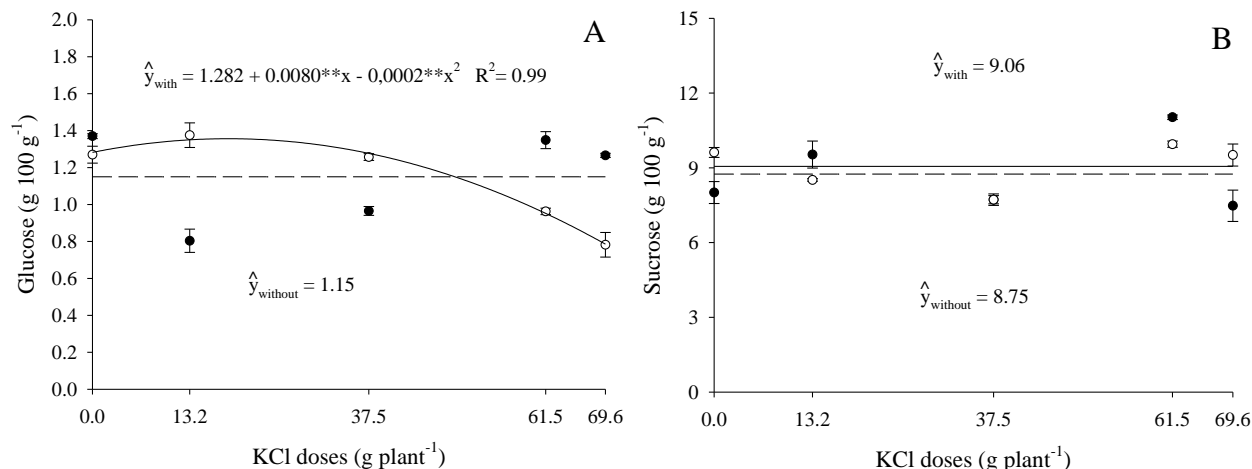


Figure 9. Glucose (A) and Sucrose (B) of noni fruits in soils with (—) or without (- -) cattle manure as a function of potassium chloride.

soil with cattle manure, the vitamin C content increased linearly by 0.793 mg 100 mL⁻¹ per unit increase of potassium fertilization, reaching the maximum value of 132.74 mg 100 mL⁻¹ of juice at the highest KCl dose of 69.6 g plant⁻¹.

The highest values of vitamin C in fruits of plants fertilized with 53.6 and 69.6 g plant⁻¹ of potassium chloride in treatments with and without cattle manure corresponded to increase of 147 and 71.16% in the vitamin C content compared to fruits of plants not fertilized with potassium. Jifon and Lester (2009) and Ali et al. (2012) recorded similar tendencies upon verifying that the potassium fertilization of melons (*Cucumis melo* L.) and blackberries (*Rubus* spp.) increased the vitamin C content of fruits. Comparing the results, vitamin C contents at 113.00, 23.10 and 12.16 mg 100 mL⁻¹ were higher than contents obtained by West et al. (2011), Costa et al. (2013) and Palioto et al. (2015) for noni fruits without any mineral or organic fertilization. These values express the importance of mineral and organic fertilization for the quality of noni fruits. Except for glucose levels of fruits from plants of treatments with cattle manure, glucose and sucrose contents did not adjust to any mathematical model with the increase of potassium chloride doses applied to the soil (Figure 9).

Glucose values, under organic fertilization conditions, increased up to 1.36 g 100 g⁻¹ of pulp at the estimated maximum KCl dose of 20 g plant⁻¹. However, values decreased with higher doses of the mineral fertilizer. As to absence of cattle manure, data were represented by the average content of 1.15 g 100 g⁻¹ of pulp, and indicated an inferiority of 18.26% of fruits of treatments with and without cattle manure (Figure 9a).

The increase in glucose in noni fruits in function of potassium chloride doses is associated with photosynthesis in leaves, resulting in the production of sugars,

photoassimilate transports from leaves to fruits, activation of enzymes and substrate availability for ascorbic acid and β -carotene biosynthesis (Jifon and Lester, 2009; Lester et al., 2010). As for sucrose (Figure 9b), average levels were 9.06 and 8.75 g 100 g⁻¹ of pulp with the increase in potassium doses, expressing a modest superiority of 3.54% of fruits of treatments with and without cattle manure. In comparison, the contents 1.36 and 9.06 g 100 g⁻¹ of glucose and sucrose in fruits of treatments with cattle manure and potassium exceed 1.30 and 0.99 g 100 g⁻¹ of glucose and sucrose, respectively, as reported by West et al. (2011) for noni fruit pulps.

Conclusion

The dose of 69.6 g plant⁻¹ of potassium chloride and cattle manure increased fruit mass, fruit length, fruit diameter, pulp mass, vitamin C and glucose contents in noni fruits. The increase in potassium chloride increased the titratable acidity and decreased the soluble solids/titratable acidity ratio in the pulp of fruits. The cattle manure increased the weight and length in noni fruits.

Conflict of interests

The authors have not declared any conflict of interests.

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