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Nutritional status of jatropha under cattle manure and natural phosphate in rainfed conditions

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Key words:
Jatropha curcas L.
alternative sources of fertilizer
mineral nutrition

A B S T R A C T
There is little information on the technical recommendation of fertilization for jatropha in the semi-arid region. This study aimed to evaluate the nutritional status of jatropha plants fertilized with cattle manure and natural phosphate under rainfed conditions. The experiment was set in a randomized block design, with three replicates, arranged in a 4 x 4 factorial scheme, corresponding to 4 doses of cattle manure (0, 4, 8 and 12 t ha^{-1}) and 4 doses of natural phosphate (0, 250, 500 and 750 kg ha^{-1}). The application of 8 t ha^{-1} of cattle manure, in isolation or associated with 500 kg ha^{-1} of natural phosphate, promotes adequate conditions to obtain jatropha plants with sufficient levels (g kg^{-1}) of N (29.8), P (5.1), K (33.8), Ca (17.1), Mg (14.0) and S (2.6) and micronutrients (Cu = 8.0 and Mn = 94.4 mg kg^{-1}) in its leaf tissue.

Palavras-chave:
Jatropha curcas L.
fontes alternativas de fertilizante
nutrição mineral

Estado nutricional do pinhão-manso sob matéria orgânica e fosfato natural em condições de sequeiro

R E S U M O
Há pouca informação para embasar a recomendação técnica de adubação para a cultura do pinhão-manso na região Semiárida. Objetivou-se, com este trabalho, avaliar o estado nutricional de plantas de pinhão-manso fertilizadas com esterco bovino e fosfato natural em condições de sequeiro. O ensaio foi conduzido em delineamento de blocos ao acaso, com 3 repetições e distribuído em esquema fatorial 4 x 4, composto por 4 doses de esterco bovino (0, 4, 8 e 12 t ha^{-1}) e 4 doses de fosfato natural (0, 250, 500 e 750 kg ha^{-1}). A aplicação de 8 t ha^{-1} de esterco bovino, isolada ou associada a 500 kg ha^{-1} de fosfato natural, propicia condições adequadas para a obtenção de plantas de pinhão-manso com níveis considerados suficientes (g kg^{-1}) de N (29,8), P (5,1), K (33,8), Ca (17,1), Mg (14,0) e S (2,6) e micronutrientes (Cu = 29,8 e Mn = 94,4 mg kg^{-1}) no tecido foliar desta oleaginosa.

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Introduction

Jatropha (*Jatropha curcas* L.) has been recommended as a promising alternative for oil, aiming at biodiesel production in many countries worldwide (Laviola et al., 2012). In the northeast region of Brazil, this oilseed plant has been studied as a promising alternative for the agricultural economy, since it is perennial, shows relative tolerance to droughts and produces almost the entire year.

Fertilization is one of the main technologies used to increase crop yield and profitability, although it has a high cost and can increase the risk of agricultural investments. Despite the expansion of studies on jatropha, fertilization recommendations under conditions of low water availability are still scarce. Among the sources of organic matter used in its fertilization, there is cattle manure (Sousa et al., 2012; Brito et al., 2013), which increases crop growth and yield (Balota et al., 2012; Prates et al., 2012), in isolation or associated with phosphate fertilization under irrigated conditions (Fernandes et al., 2013).

In basal fertilizations (at seeding), P is generally supplied to plants in the form of soluble phosphates. However, in order to overcome the problem of costs of these phosphates, which are obtained through conventional processes of solubilization of phosphate rocks, the use of alternative P sources has been proposed (Frandoloso et al., 2010; Geraldo Junio et al., 2013). The viability of these sources is related to the existence of large deposits of natural phosphate, with low cost (Silva et al., 2012), associated with its compensatory residual effect, compared with soluble phosphates (Resende et al., 2006). Fertilizers of lower reactivity, for providing P more slowly, could favor higher nutrient use efficiency by crops (Pacheco et al., 2012).

With respect to the study of phosphate fertilization using natural phosphate as a P source, the jatropha crop is not mentioned in the literature. For production of seedlings, Prates et al. (2012) observed that natural phosphate does not influence quality of seedlings in the first three months of plant growth. However, it has been observed that jatropha shows considerable response to phosphate fertilization.

As to the nutritional status of this species, some studies mention that organic matter, whether as cattle manure or other sources, promotes significant effects on leaf contents of macro and micronutrients, particularly in seedlings (Lima et al., 2011a). However, these studies do not mention the use of natural phosphates. Most studies on phosphate fertilization have been conducted using seedlings (Prates et al., 2012) or in combination with salinity and in pot conditions (Souza et al., 2012).

For field conditions, there are no conclusive results on the best dose of cattle manure and natural phosphate to promote adequate nutritional balance for jatropha. On the other hand, under field and rainfed conditions, there are reports in the literature mentioning how jatropha plants respond to fertilization and what are the effects of fertilization on its nutritional status.

This study aimed to evaluate the nutritional status of jatropha plants fertilized with cattle manure and natural phosphate under rainfed conditions.

Material and Methods

The experiment was carried out under semi-arid conditions in the Cariri region, at the Experimental Field of Embrapa Cotton, located in the municipality of Patos-PB, Brazil (7°0'37" S; 37°20'14" W; 242 m). The area has a hot and humid climate, with maximum temperature of 37 °C, minimum of 26 °C and mean monthly rainfall of 140 mm recorded between January and April. According to Köppen's classification, the predominant climate in the region is hot semi-arid, Bsh (Gomes et al., 2013) and this condition characterizes the landscape. Rainfalls and temperatures observed in the year of the study are shown in Figure 1.

For the implantation of the experiment, 2,000 seedlings were produced and, at 90 days of age were selected with respect to homogeneity. Then, they were transplanted to the field in the agricultural year of 2010, at the beginning of the rainy period. The substrate used for production of seedlings consisted of the mixture of subsoil of the same area and peanut shells enriched with mineral fertilizer, according to the recommendation of Lima et al. (2009). Seedlings were cultivated in polyethylene bags with dimensions of 22 x 13 cm.

The experiment consisted of a factorial combination of 4 doses of cattle manure (0, 4, 8 and 12 t ha^{-1}) and 4 doses of natural phosphate (0, 250, 500 and 750 kg ha^{-1} corresponding, respectively, to 0, 70, 140 and 210 kg ha^{-1} of P_2O_5), in a randomized block design with three replicates. The experimental plots consisted of 16 plants distributed in 4 rows, in the configuration of 3 x 1 m. The evaluated area in each plot consisted of the 2 central rows, represented by 4 plants. Cattle manure doses were calculated according to the recommendation of the Laboratory for Soil and Water Analysis of the Embrapa Cotton, which suggested the use of 2 t ha^{-1} for soils considered of low natural fertility, with low contents of organic matter and sandy loam texture, currently classified as Chromic Luvisols.

Organic matter was provided in the form of cattle manure, as basal fertilization (30 cm depth), when seedlings were transplanted during the rainy season, according to the established doses, together with natural phosphate. The cattle manure used in the experiment contained 10.2, 2.0, 12.4, 6.6, 4.2 and 2.5 g kg^{-1} of N, P, K, Ca, Mg and S, respectively. The natural phosphate (from Araxá, MG) was chemically analysed in the Laboratory of Soil and Water Analysis of the São Paulo State University "Júlio Mesquita Filho" (UNESP),

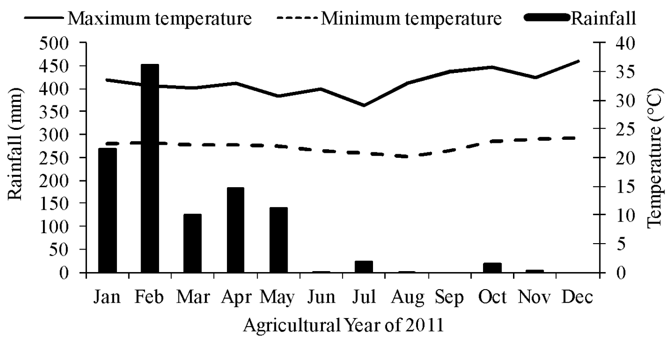

Figure 1. Rainfall and mean temperatures recorded from January to December 2011 at the experimental unit of Embrapa Cotton

at the campus of Jaboticabal-SP, and showed N ≤ 1 g kg^{-1} and contents of soluble P (soluble in citric acid at 2%), S, K, Mg and Ca around 53, 37, 1.7, 6.2 and 625 g kg^{-1}, respectively. As to micronutrients, the natural phosphate showed, on average, 3010, 20, 14 and 145 mg kg^{-1} of Fe, Mn, Cu and Zn, respectively, in its chemical composition.

Sixteen months after applying the treatments with cattle manure and natural phosphate (August 2011), the soil was sampled under the canopy projection in the layer of 0-20 cm and showed no acidity, medium content of organic matter, high content of P and absence of exchangeable Al (Table 1).

In the beginning of the dry season (August 2011), leaf contents of N, P, K, Ca, Mg, S, Cu, Fe, Mn and Zn were determined in order to evaluate nutritional status of crop, as a function of the applied organic and phosphate fertilization.

For nutritional status evaluation, the fifth leaf from the apex to the base of vegetative branches was collected in the mid-section of the plants; one leaf per plant in each replicate, in a total of eight leaves, according to the recommendation of Lima et al. (2011b).

The sampled leaves were identified, placed in paper bags, washed with deionized water to remove impurities and dried in a forced-air oven at 65 °C. Then, the material was ground in a Willey-type mill, placed in polyethylene recipients with hermetic lid and subjected to nitric-perchloric digestion for the determination of P, K, Ca, Mg, S, Fe, Cu, Zn and Mn contents (Malavolta et al., 1997) and to sulfuric digestion for the determination of N content (Jackson, 1965).

The obtained data were subjected to analysis of variance and regression, according to Santos et al. (2008). Maximum and/or minimum points of the regression equations were estimated through the derivative of “Y” with respect to “X”.

Results and Discussion

The application of cattle manure and natural phosphate caused significant interactions on leaf contents of N, K, Ca, Mg and S (Table 2). Only P contents were influenced by the isolated applications of cattle manure and natural phosphate.

Leaf N contents increased quadratically in the absence of natural phosphate and linearly for the other phosphate doses (Figure 2A). In the absence of natural phosphate, the dose of cattle manure that promoted the highest content was approximately 10.2 t ha^{-1}, with maximum N content of 29.8 g kg^{-1} (Figure 2A). Since cattle manure contains reasonable amounts of N in its chemical composition and the intense rains during the agricultural year of 2011 provided adequate moisture conditions, favorable to N absorption, it is possible to infer that this fact favored cattle manure mineralization and provided sufficient amounts of N to plants, increasing its content in leaf.

The increase in cattle manure doses promoted linear increment on leaf N contents for the doses of 250, 500 and 750

Table 2. Summary of the analysis of variance for leaf contents of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) (g kg^{-1}), in jatropha plants cultivated under semi-arid conditions and fertilized with cattle manure (CM) and natural phosphate (NP)

Source of variation	Mean square						
	DF	N	P	K	Ca	Mg	S
Cattle manure (CM)	3	448.3^{**}	1.4^{*}	105.7^{*}	7.3^{ns}	2.1^{ns}	0.2^{ns}
Natural phosphate (NP)	3	10.9^{*}	6.3^{**}	80.2^{*}	41.9^{**}	6.4^{**}	0.5^{**}
Blocks	2	4.9^{ns}	5.4^{**}	94.2^{*}	3.7^{ns}	4.6^{*}	0.1^{ns}
CM x NP	9	8.8^{*}	0.6^{ns}	68.1^{*}	12.4^{*}	4.3^{**}	0.2^{*}
Residue	30	3.1	0.4	27.04	4.6	1.2	0.1
CV%	-	7.05	14.03	15.38	13.48	8.64	14.99

^{ns}Not significant; **Significant at 0.01 probability level; CV – Coefficient of variation; DF – Degrees of freedom

kg ha^{-1} of natural phosphate, indicating significant interaction between these fertilizers and cattle manure. Although the natural phosphate has low amount of N in its composition, N contents were favored as the doses of natural phosphate and cattle manure increased. Despite the importance of this result, there is no reference about it in the literature, and it is possible to infer that the presence of P in large amounts in the soil solution, provided by the natural phosphate, favored N absorption by plants.

N contents ranged from 11,2 to 37,7 g kg^{-1}, which are considered as optimal by the literature (Laviola & Dias, 2008; Lima et al., 2011b). One of the possible explanations for this is the fact that cattle manure presented on average 10.2 g kg^{-1} of N, in its chemical composition. It indicates that organic fertilization supplied plants with satisfactory amounts of N, which could be used in metabolic activities and even partially accumulated. Increases in leaf N contents were also reported by Hussein et al. (2012), who observed that the application of 5 kg $plant^{-1}$ of cattle manure promoted substantial increases in leaf N contents of irrigated jatropha at 180 days after emergence under field conditions. In this study, the application of 8 t ha^{-1} of cattle manure promoted adequate nutritional status in jatropha plants with respect to N, 16 months after seedlings were transplanted to the field under rainfed conditions.

For leaf K contents, there was significant interaction between the applied doses of cattle manure and natural phosphate (Table 2). Organic fertilization favored the increase of K contents in jatropha plants, since the applied cattle manure has 12.4 g kg^{-1} of K, on average. According to the response surface, there was a significant effect of the interaction between cattle manure and natural phosphate application, with maximum dose estimated at 11.14 t ha^{-1} associated with 595.52 kg ha^{-1} of natural phosphate. According to the results, the interaction between cattle manure and natural phosphate promoted maximum K content of approximately 33.8 g kg^{-1} (Figure 2B). Hussein et al. (2012) also observed significant increases in leaf K contents of jatropha plants cultivated under field conditions

Table 1. Characteristics of the soil (collected in the layer of 0-20 cm) in the experimental area

pH 1:2.5	Sorption complex									
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SB	H + Al	T	V	P	OM
	$mmol_c\ dm^{-3}$							%	mg dm^{-3}	g kg^{-1}
7.7	31.1	18.2	2.8	6.1	58.2	0.0	58.2	100	51.3	14.7

SB – Sum of bases; T – Cation exchange capacity; V% - Base saturation; OM – Organic matter

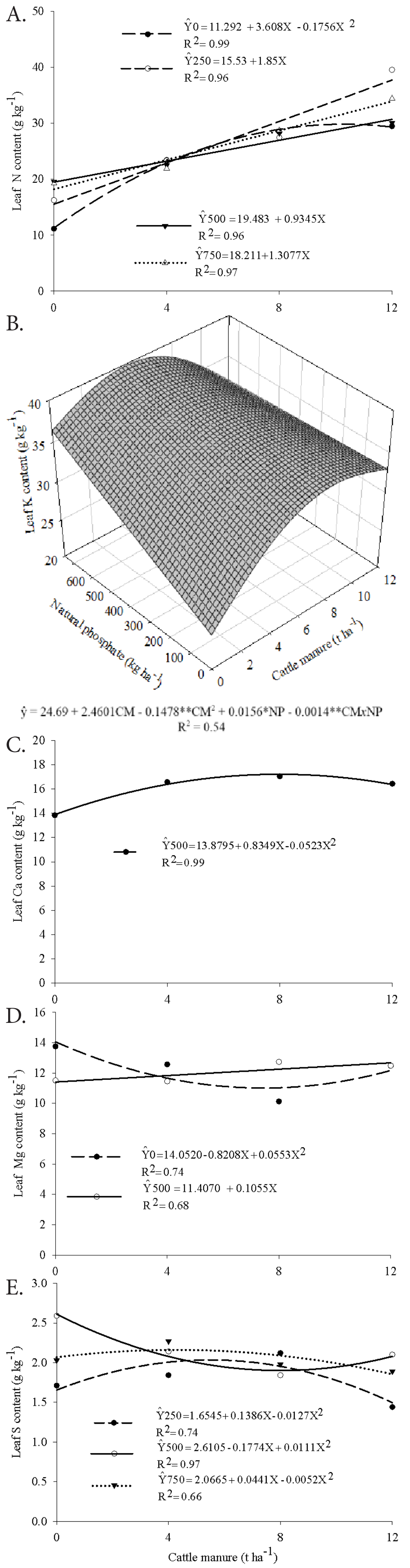

Figure 2. Leaf contents of nitrogen – N (A), potassium – K (B), calcium – Ca (C), Magnesium –Mg (D) and sulfur – S (E) in jatropha plants as a function of cattle manure application, in the presence of natural phosphate

and irrigation, fertilized with 5 kg plant^{-1} of cattle manure, which confirms that cattle manure is an excellent alternative for the organic fertilization of jatropha.

According to the previously mentioned author, fertilization with this source of organic matter, besides improving physical and chemical properties of soil, provided sufficient amounts of K to guarantee plants with good nutritional status. The leaf K contents obtained in this study are still above the value considered as sufficient by Laviola & Dias (2008), which is 13.7 g kg^{-1}. In 3-years-old jatropha plants cultivated under rainfed conditions, Lima et al. (2011b) observed mean K contents of approximately 34.2 g kg^{-1}, which are slightly higher compared to obtained in the present study.

The application of cattle manure and natural phosphate caused interaction between both factors on leaf Ca contents. However, the interactions observed between cattle manure and the doses of 0, 250 and 750 kg ha^{-1} of natural phosphate presented coefficients of determination (R^2) < 0.52, therefore, their curves are not shown here. For the dose of 500 kg ha^{-1} of natural phosphate a quadratic response (R^2 = 0.99) was observed and maximum leaf Ca content of 17.1 g kg^{-1} was obtained with the cattle manure dose of 6.59 k ha^{-1} (Figure 2C).

Considering the results for the chemical composition of the fertilizers, significant amounts of Ca were added to the soil. In spite of that, Ca absorption by plants was low. According to the literature, the presence of large amounts of Ca in the soil solution increases Ca absorption by plants (Marschner, 2002). The leaf Ca contents observed in this study (14.0 to 17.1 g kg^{-1}) are lower than the values obtained by Laviola & Dias (2008), around 19 g kg^{-1}, for 2- and 3-years-old adult jatropha plants under field conditions. For jatropha plants over 3 years old cultivated under rainfed conditions, Lima et al. (2011b) observed mean Ca contents around 14 g kg^{-1}, which are similar to those in the present study.

As to plant nutritional status with respect to leaf Mg contents (Figure 2D), the application of cattle manure promoted different responses depending on the dose of natural phosphate used. In the absence of natural phosphate and at the dose of 500 kg ha^{-1}, there was a quadratic and linear response of leaf Mg contents, which ranged from 11.4 to 14.1 g kg^{-1} (Figure 2D). For the combinations of cattle manure with the natural phosphate doses of 250 and 750 kg ha^{-1}, although interactions were significant but the values of R^2 were < 0.17 and for this reason the curves are not presented.

These Mg contents were similar to those observed by Laviola & Dias (2008) and higher than those reported by Lima et al. (2011b) in adult jatropha plants in full flowering stage, who consider as adequate Mg contents between 4.8 and 8.9 g kg^{-1}, respectively. This can be explained by the high Mg contents in the cattle manure (4.2 g kg^{-1}) and in the natural phosphate (6.2 g kg^{-1}).

Organic and natural phosphate fertilization promoted increase in leaf S contents of jatropha plants, 16 months after transplantation, under rainfed conditions. According to Figure 2E, significant interactions between these two nutrient sources were observed, with quadratic responses of S contents. The highest S contents, 2.1 and 2.6 g kg^{-1}, were observed at cattle manure doses of 4.24 and 0 t ha^{-1} associated with natural phosphate doses of 750 and 500 kg ha^{-1}, respectively. On the other hand, the lowest leaf S contents were around 1.70 g kg^{-1}, was observed at the cattle manure dose of 0 t ha^{-1} associated with 250 kg ha^{-1} of natural phosphate. These results agree with those reported by Laviola & Dias (2008) and Lima et al. (2011b), who observed leaf S contents from 1.1 to 2.0 g kg^{-1} in adult plants at the flowering stage and in 2- to 3-years-old plants in full flowering.

Leaf P contents varied differently according to the doses of cattle manure and natural phosphate (Figure 3A and B). A quadratic response was observed for the application of cattle manure, with maximum value for the dose of 6.2 t ha^{-1}, corresponding to mean P content of 4.6 g kg^{-1}. The content of P in the chemical composition of the cattle manure (2.0 g kg^{-1}) probably was one of the factors responsible for these results. Positive effects of cattle manure application on the nutritional status of jatropha plants, with respect to leaf P contents, were also reported by Hussein et al. (2012), who observed that the application of 5 kg plant^{-1} of cattle manure promoted significant increase in leaf P contents of jatropha under field conditions and irrigation. Similar results were observed in the present study; the application of 6 t ha^{-1} of cattle manure promoted adequate P contents in jatropha plants.

The application of higher doses of cattle manure (above 6.2 t ha^{-1}) promoted reduction in leaf P contents (Figure 3A), probably through the complexation of P with organic matter, which prevents its absorption, or through the effect of competition with other ions in higher concentrations in the soil solution, particularly Ca. According to Pavinato & Rosolem (2008), there are evidences for the existence of various mechanisms of organic matter on P availability, so that soil organic compounds in decomposition can adsorb inorganic phosphate and form ternary complexes, mediated by bridges of cations, like Fe and Al.

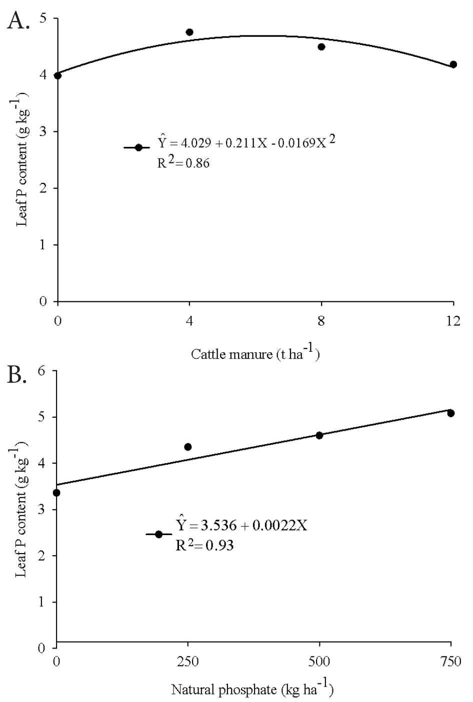

Figure 3. Leaf contents of phosphorus (P) in jatropha plants as a function of the application of cattle manure (A) and natural phosphate (B)

Leaf P contents increased linearly with the increase in the doses of natural phosphate (Figure 3B). P contents ranged from 3.5 to 5.1 g kg^{-1} between the doses of 0 and 750 kg ha^{-1} of natural phosphate. The percent increase in P contents was 46% between the highest and the lowest doses . The high content of P in the natural phosphate (53 g kg^{-1}), as well as its availability caused by the greater contact between the fertilizer and the higher P concentration in the soil solution due to the higher water availability in the evaluated year (Figure 1), probably contributed significantly to these results.

In general, natural phosphate was highly efficient at supplying P to plants during the studied period, since only its content of soluble P was considered in the calculations. P solubility in the soil solution was probably favored by the higher rainfall frequency in January, the highest one in the agricultural year of 2011 (Figure 1), the higher permanence of this fertilizer in the soil, since its application occurred in April 2010, and its form of application, in the transplanting holes at 30 cm depth. This mechanism may have favored better P use by plants.

The maximum value of P content obtained in this study (5.1 g kg^{-1}) is higher than the value reported in the literature as adequate for adult jatropha plants. Laviola & Dias (2008) and Lima et al. (2011b) mention P contents above 2.8 g kg^{-1} as adequate, in leaves collected from the third node of flowering branches of plants over three years of age.

For micronutrients, organic and phosphate fertilization, through the application of cattle manure and natural phosphate, promoted significant effects only on the leaf contents of Cu and Mn (Table 3).

The interaction between doses of cattle manure and natural phosphate was significant for Cu content in leaf (Figure 4A). The addition of cattle manure doses in the absence of natural phosphate promoted high leaf Cu contents, with maximum values around 8 mg kg^{-1} at the dose of 6.3 t ha^{-1} of cattle manure.

When associated with 500 kg ha^{-1} of natural phosphate, the increase in cattle manure doses promoted a negative effect on Cu contents, with minimum value of 5.27 mg kg^{-1} at 7.0 t ha^{-1} of cattle manure (Figure 4A). The other interactions between doses of natural phosphate (250 and 750 kg ha^{-1}) and cattle manure presented values of $R^2 < 0.29$ and hence their curves are not presented and discussed here.

According to Ferreira (2003), sufficient soil moisture is necessary for higher release of Cu to plants from cattle manure

Table 3. Summary of the analysis of variance for the leaf contents of copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) (mg kg^{-1}) in jatropha plants cultivated under semi-arid conditions and fertilized with cattle manure (CM) and natural phosphate (NP)

Source of variation	Mean square				
	DF	Cu	Fe	Mn	Zn
Cattle manure (CM)	3	0.9^{ns}	754.9^{ns}	1112.9**	2.5^{ns}
Natural phosphate (NP)	3	11.4**	824.5^{ns}	136.9^{ns}	35.3^{ns}
Blocks	2	2^{ns}	5735.7**	21.8^{ns}	52*
CM x NP	9	3.2**	1133.5^{ns}	837.6**	9.4^{ns}
Residue	30	1.04	778.4	92.1	11.9
CV%	-	17.21	15.39	12.03	17.38

^{ns}Not significant, **Significant at 0.01 probability level; CV – Coefficient of variation; DF – Degrees of freedom

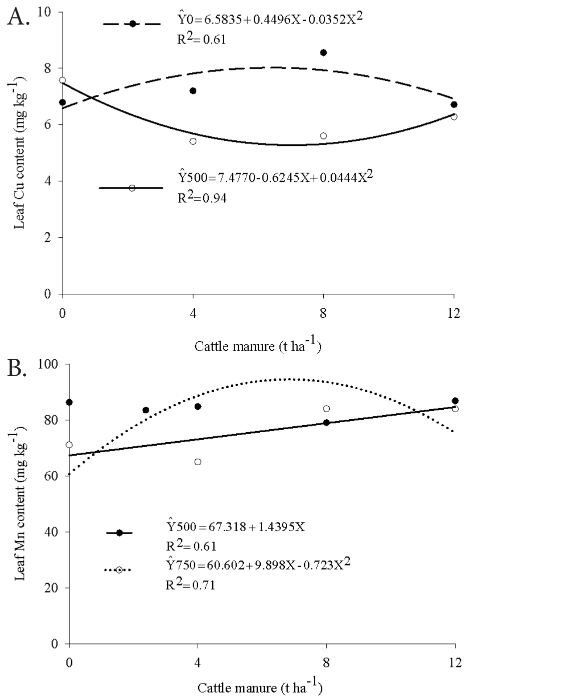

Figure 4. Leaf contents of copper – Cu (A) and manganese – Mn (B) in jatropha plants as a function the application of cattle manure, in the presence of natural phosphate

mineralization. Since intense rains occurred in the agricultural year of 2011 and during an unusual period for the semi-arid region (Figure 1), thus the release of sufficient amounts of Cu to jatropha plants due to cattle manure mineralization was observed in the present study. The obtained results are within the range cited by Laviola & Dias (2008) and Lima et al. (2011b), which is 10 mg kg^{-1} in the leaf blade of plants in full flowering and fruiting.

Leaf Mn contents (Figure 4B) were also influenced by interaction between the applied doses of cattle manure and natural phosphate. A quadratic response was observed for the natural phosphate dose of 750 kg ha^{-1} and for dose of 500 kg ha^{-1} a linear reponse occured. The maximum Mn content (94.4 mg kg^{-1}) occurred at the cattle manure dose of 6.8 t ha^{-1}. On the other hand, for the dose of 500 kg ha^{-1} of natural phosphate leaf Mn contents varied from 68 to 82 mg kg^{-1}. According to chemical composition, the natural phosphate added 20 mg kg^{-1} of Mn to the soil, which, added to the contents from cattle manure fertilization, contributed to the increase in leaf Mn contents. The interactions for doses of 0 and 250 kg ha^{-1} of natural phosphate, although were significant, but presented low values of R^2 (< 0.59) and therefore, are not discussed here.

The Mn contents observed in the present study, in general, were lower than the values observed by Laviola & Dias (2008), around 314.5 mg kg^{-1}, and by Lima et al. (2011b), around 116 mg kg^{-1}, in leaf tissues of 2- to 3-years-old jatropha plants in full flowering. One possible explanation for this is the inexistence of cultivars defined for this crop, since the ability for absorption, transport and distribution of each nutrient is a genotype-dependent characteristic. In addition, factors like soil, fertilization and rainfall of the region can also have influenced these results.

Conclusion

The application of 8 t ha^{-1} of cattle manure, in isolation or associated with 500 kg ha^{-1} of natural phosphate, is adequate for the establishment of sufficient levels (g kg^{-1}) of N (29.8), P (5.1), K (33.8), Ca (17.1), Mg (14.0) and S (2.6), and micronutrients (Cu = 8.0 and Mn = 94.4 mg kg^{-1}) in jatropha leaf tissues.

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