Nutrient accumulation, export and cycling in *Jatropha curcas* L.[1]

Carlos Hissao Kurihara[2*], *Hamilton Kikuti*[3], *Flávio Ferreira da Silva Binotti*[4], *Cesar José da Silva*[5]

10.1590/0034-737X201663030013

ABSTRACT

The knowledge concerning nutrient accumulation rate allows defining the best amount and most appropriate time for its supply. Estimating nutrient amount in the aerial part of the plants is particularly important to species such as *Jatropha curcas* L., since there are no consistent calibration studies to indicate the amount of fertilizer to be applied. The objective of this study was to evaluate nutrient accumulation, export and cycling in *Jatropha curcas*. The experiment was carried out in Cassilândia, state of Mato Grosso do Sul, Brazil, during 52 months in a completely randomized design, with four replications and fifteen treatments, which consisted of different evaluation times. A large variation in the amount of nutrients accumulated in leaves was found due to senescence and leaf abscission in the driest and/or coldest period of the year. Nutrient accumulation in the aerial part is relatively low in the first 22 months. To meet *Jatropha curcas* requirements, fertilization during the first two years must provide 40; 50; 50; 21; 16; 5; 0.7; 0.3; 4; 8 and 1 kg ha^{-1} of N, P_2O_5, K_2O, Ca, Mg, S, B, Cu, Fe, Mn and Zn, respectively. From the third year of cultivation, topdressing fertilization should restitute 40, 110, 55 and 3 kg ha^{-1} of N, P_2O_5, K_2O and S, respectively. To replace the exported amount of nutrients, it should be supplied more 50, 100, 30 and 3 kg ha^{-1} of N, P_2O_5, K_2O and S, respectively, per ton of grain to be produced.

Key words: extraction; fertilization; nutritional demand.

RESUMO

Marcha de acúmulo, exportação e ciclagem de nutrientes em plantas de pinhão-manso (*Jatropha curcas* L.)

O estabelecimento da marcha de acúmulo de nutrientes permite definir a quantidade e a época mais adequada para seu fornecimento. A estimativa da extração de nutrientes pela parte aérea torna-se particularmente importante para espécies como o pinhão-manso, cultura para a qual ainda não existem resultados consistentes de trabalhos de calibração que permitam indicar doses de adubos a serem aplicadas. Com o objetivo de avaliar a marcha de acúmulo, a exportação e a ciclagem de nutrientes em plantas de pinhão-manso, conduziu-se um experimento a campo em Cassilândia, MS, por um período de 52 meses. Adotou-se o delineamento experimental inteiramente ao acaso, com quatro repetições e 15 tratamentos, correspondentes às épocas de avaliação. Verificou-se grande variação da quantidade de nutrientes acumulados nas folhas, por causa da senescência e da abscisão foliar nos períodos mais secos ou mais frios do ano. O acúmulo de nutrientes na parte aérea é relativamente baixo nos primeiros 22 meses. Para suprir a demanda, a adubação nos dois primeiros anos deve fornecer 40; 50; 50; 21; 16; 5; 0,7; 0,3; 4; 8 e 1 kg ha^{-1} de N, P_2O_5, K_2O, Ca, Mg, S, B, Cu, Fe, Mn e Zn, respectivamente. A partir do terceiro ano de cultivo, a adubação de cobertura deve visar à restituição de 40, 110, 55 e 3 kg ha^{-1} de N, P_2O_5, K_2O e S, respectivamente. Para a reposição da quantidade de nutrientes exportados, deve-se fornecer mais 50, 100, 30 e 3 kg ha^{-1} de N, P_2O_5, K_2O e S, respectivamente, por tonelada de grãos a ser produzida.

Palavras-chave: demanda nutricional; extração; adubação.

Submitted on September 9th, 2014 and accepted on February 1st, 2015

[1] Experiment financed by Embrapa/MCT/FINEP/PETROBRÁS.

[2] Embrapa Agropecuária Oeste, Dourados, Mato Grosso do Sul, Brazil. carlos.kurihara@embrapa.br

[3] Universidade Federal de Uberlândia, Uberlândia, Minas Gerais, Brazil. hkikuti@iciag.ufu.br

[4] Universidade Estadual de Mato Grosso do Sul, Unidade Universitária de Cassilândia, Cassilândia, Mato Grosso do Sul, Brazil. binotti@uems.br

[3] Embrapa Agropecuária Oeste, Dourados, Mato Grosso do Sul, Brasil. cesar.silva@embrapa.br

* Corresponding author: carlos.kurihara@embrapa.br

INTRODUCTION

Brazil is a country with potential to become one of the world's largest biodiesel producers due to the availability of adequate soil and climate for the cultivation of oilseed (Miragaya, 2005). However, biodiesel production is still essentially based in soybean crops, which has defined production system and consolidated supply chain. Therefore, *Jatropha curcus* L. may become an important alternative for the matrix of vegetable oils for the production of biodiesel due to the high oil content in grain and its excellent quality for this purpose.

In recent years, an expansion in the growing area of that plant species has been observed in the expectation of obtaining high productivity of oil associated with expectations of setting up producing biodiesel plants and the maintenance of high prices for other oil seeds, despite the lack of technical recommendations for the crop and the available genetic material being still quite heterogeneous and segregating. As a result, several failures after years of cultivation have been recorded, leading farmers to eradicate crops for growing other traditional species again.

For this reason, to establish technical recommendations for *Jatropha curcas* is urgent. However, there are practically no results of calibration tests conducted in the field, which would allow to set response curves and thereby to identify appropriate doses of nutrients. The few published studies on fertilization of this species are limited to only evaluating of the effects of some specific nutrients for a short period of time (Prates, 2010; Freiberger, 2012; Saraiva *et al*., 2013).

Moreover, since the establishment of the nutrient accumulation rate of a perennial crop over a relatively long period of evaluation, the amount to be supplied can be defined, in order to supply the demands both for growth plants and to restore export by the fruits. The evaluation of the amount of nutrients extracted by plants and exported by crops has typically been carried out only in the initial growing period of the plants (Laviola & Dias, 2008; Borghetti *et al*., 2010; Prates, 2010; Reis *et al*, 2010) sometimes under greenhouse conditions (Pacheco *et al.*, 2006; Silva et al., 2010; Freiberger, 2012). It has been shown in those studies that this oilseed is particularly demanding on N and K, followed by Ca and Mg in the aerial part (Pacheco *et al*., 2006 and Freiberger, 2012) and also in the fruits (Laviola & Dias, 2008 and Borghetti *et al.*, 2010).

The objective of this study was to evaluate in the field the nutrient accumulation rate of jatropha plants for a period of 52 months in soil and climate conditions of Cassilândia in the state of Mato Grosso do Sul. The amount of nutrients that must be supplied to meet the demands for jatropha plants, both in the planting and the annual fertilizations in topdressing are also evaluated.

MATERIAL AND METHODS

The experiment was conducted at the Experimental Field of the State University of Mato Grosso do Sul (UEMS), University Unit of Cassilândia, state of Mato Grosso do Sul in a medium texture typical Haplortox soil.

Physical and chemical characterization of the soil was made according to Silva *et al.* (1999) in a soil sample collected at the depth of 0 to 0.2 m, and the following results were obtained: 0.0; 1.4; 1.0 and 0.18 $cmol_c dm^{-3}$ of Al, Ca, Mg and K, respectively; 3.4; 1.1; 31; 98 and 0.8 mg dm^{-3} of P, Cu, Fe, Mn and Zn (extracted by Mehlich-1), respectively; 46% of saturation of bases and 10 to 63 g kg^{-1} of organic matter and clay, respectively.

Seedlings were transplanted to the experimental area on November 21, 2008 with two true leaves, in spacing of 4 x 2 m and a population of 1,250 plants per hectare. Planting fertilization was the application of 82, 125, 55, 101, 2, 2 and 4 kg ha^{-1} of N, P_2O_5, K_2O, S, B, Cu and Zn, respectively, using ammonium sulfate, triple superphosphate, potassium chloride, borax, copper sulfate and zinc sulfate as the source. Nitrogen, sulfate and potassium were split into three application times (in the planting of seedlings and 53 and 90 days after planting). Topdressing fertilization was carried out with 38 kg ha^{-1} of N and P_2O_5, 25 kg ha^{-1} of K_2O and 45 kg ha^{-1} of S at the beginning of the second year, and with 45 kg ha^{-1} of N and P_2O_5 of 30 kg ha^{-1} of K_2O and 54 kg ha^{-1} of S in the other years, using the same sources.

The experimental design was completely randomized with four replications and 15 treatments, corresponding to the evaluation periods (0, 90, 146, 235, 375, 459, 593, 669, 738, 873, 1,047, 1,146, 1,277, 1,431 and 1571 days after transplanting - DAT). The first evaluation was performed in jatropha seedlings before transplanting; after planting the seedlings, was allocated the experimental units for the other sampling times. Thus, the time (DAT) was used as factor under study.

The experimental unit was consisted of twelve plants per replication in the first sampling (0 DAT), three plants in the second evaluation (90 DAT), two plants between the third (146 DAT) and the thirteenth (1,277 DAT), and only one plant in the last two measurements (1,431 and 1,571 DAT). At each sampling time, stem was cut at a height of about 0.05 m above the soil surface, followed by separation of leaves and branches. Branches and stem were, then, cut into pieces of 0.03 to 0.15 m. In the period from January 13 and May 22, 2012 (between 1,147 and 1,277 DAT), the weekly collection of leaves on the soil surface (litter) was carried out under the canopy projection area of the plants. All the collected material was analysed at 1,277 DAT.

From October 24, 2012 to March 12, 2013, corresponding to 1,432 and 1,571 DAE, respectively, fruits were harvested (capsules and grains) from the plants evaluated at 1,571 DAE for productivity evaluation in the fifth cultivation year. The plant material collected from each experimental unit was packed in paper bags and dried for about 21 days, followed by drying in a forced-air oven at 65 °C for about 120 hours for determination of dry matter production.

A subsample was withdrawn from each partitioned plant material (leaves, stems, capsules, grains and litter) of the experimental unit, sequentially washed in water, acid solution (HCl 0.1 mol L^{-1}) and distilled water; after drying in a forced air circulation oven, dry mass of the plant was determined and the material was ground in a Wiley-type mil. After, the sample was sieved in a 0.85 mm (20 mesh) for subsequent determination of nutrient content, according to Malavolta *et al*. (1997).

In each partitioned plant material the amount of accumulated macro and micronutrients was estimated by the product between the nutrient content and dry matter yield, and expressed in kg ha^{-1} and g ha^{-1}, respectively. The accumulation of nutrients in litter of the jatropha plant was estimated by the product between the nutrient content, determined in litter samples collected from the soil surface under the canopy projection area, and the accumulated dry matter yield of leaves in the plant canopy until 1,571 DAT.

The data of the variables nutrient content in leaves, branches and stems, as well as to the variables amount of nutrients accumulated in branches, stems and aerial part as function of the time (DAT) were submitted to regression analysis that was done by means of SAEG software. V. 9.1 – 2007. Among the tested regression models (linear, quadratic and exponential), it was defined for each set of variables, that one with the highest coefficient of determination, whose estimators of equation parameters were significant to at least 5% of probability. Mean and standard deviation were calculated for dry mass of capsules and grains in the fifth year of cultivation, dry mass of leaves at 1,571 DAT and accumulation of nutrients in capsules, grains and litter.

RESULTS AND DISCUSSION

Leaf nutrient content varied in the different evaluation times, however, with no adjustment of a regression model (Figures 1 and 2). Nutrient content in the stems were not influenced by the age of the plants, except for P, Mg and S, which tended to decrease, and Mn, whose concentration increased linearly. For P, Mg and S, the relative dilution of concentration in the stems is most likely associated with increases in the absorption rate at a less intensity rate than that of the dry matter accumulation rate. On the other hand, it is supposed that the opposite might have occurred for Mn.

The average leaf content observed for macro (29; 2.2; 25; 12; 9.6 and 1.6 g kg^{-1} of N, P, K, Ca, Mg and S, respectively) and micronutrients (31; 9; 226; 310 and 25 mg kg^{-1} of B, Cu, Fe, Mn and Zn, respectively) tended to differ, to a greater or lesser extent, from those checked by Saturnino *et al*. (2005) of 64; 3.4; 24; 14; 5.3 and 1.9 g kg^{-1} of N, P, K, Ca, Mg and S and, respectively, and 70, 6, 168, 117 and 28 mg kg^{-1} of B, Cu, Fe, Mn and Zn respectively; however, discrepancies found in the contents of N, P, Mg, B, Cu, Fe and Mn may be associated with availability of these nutrients in the soil and also to the fact that Saturnino *et al*. (2005) evaluated samples of leaf collected below the first inflorescence.

On the other hand, Prates (2010) found in 12-month old *Jatropha curcas* plants, grown in Haplaquult soil, quite distinct foliar contents (3; 1.2; 0.9; 30 and 2.0 g kg^{-1} of N, P, K, Ca and Mg, respectively, and 2, 37, 95 and 5 mg kg^{-1} of Cu, Fe, Mn and Zn, respectively), which highlights the influence of physical and chemical soil properties and fertilization on nutrient absorption capacity of the root system of this crop. The sequence found for the average leaf nutrient concentrations, N> K> Ca> Mg> P> S> Mn> Fe> B> Zn> Cu was similar to that obtained in greenhouse conditions in leaf samples of the whole plant, collected 60 days after sowing, by Camargo *et al*. (2013), differing only in relation to the order of nutritional requirement of Ca and Mg and between B and Zn.

In order to evaluate the nutritional requirement of jatropha, amount of nutrients accumulated in the leaves and stems and branches were evaluated in different sampling times. It was found that the nutrient accumulation in the leaves (Figure 3) fluctuated considerably over the evaluation period, with higher values in summer, followed by a sharp decrease in autumn and winter (September/2010, April/2011 and May/2012 corresponding to 669, DAT 873 and 1,277 DAT, respectively), because of senescence, and leaf abscission which naturally occurs in the driest or coolest periods (Arruda *et al*., 2004; Saturnino *et al*., 2005). In Figure 3, it is clear the sharp accumulation of manganese, iron and potassium in the leaves, observed at 146, 235 and 459 DAT, while the other nutrients tend to accumulate more significantly only from 738 DAT (24 months). The maximum amount of nutrient accumulation in leaves, observed in the period between 1,431 and 1,571 DAT were 52, 4, 29, 16, 18 and 2 kg ha^{-1} of N, P, K, Ca, Mg and S, respectively, and 41, 15, 354, 456 and 54 g ha^{-1} of B, Cu, Fe, Mn and Zn, respectively, resulting in the extraction order: N> K> Mg> Ca> P> S> Mn> Fe>Zn> B> Cu. This sequence of magnitude of nutrient extraction is very similar to that obtained by Laviola & Dias (2008).

In the stems and branches of jatropha, linear or quadratic increases were found according to the age of the plants (Figures 4 and 5), and the maximum quantities observed at 1,571 DAT were 67, 10, 116, 59, 33 and 4 kg ha^{-1} of N, P, K, Ca, Mg and S, respectively. For micronutrients, a maximum accumulation of 131, 35, 626, 5,706 and 203 g ha^{-1} of B, Cu, Fe, Mn and Zn, respectively, were found, resulting in the following order of extracting by the stems: K> N> Ca > Mg> P> Mn> S> Fe> Zn> B> Cu.

It is observed in Figures 4 and 5, that for N, P, Ca, B, Fe, Mn and Zn, the accumulation in the aerial part showed quadratic increments, but in the first 22 months (669 DAT), its demand was relatively low. From the third year of growth, the accumulation of these nutrients in the aerial part becomes more pronounced. Thus, it is plausible to state that the estimates of the amounts of nutrients necessary for the planting fertilization of in order to supply their demand in the first year of plant growth can be used to indicate the topdressing fertilization in the second year of cultivation.

Freire (2001), Oliveira *et al.* (2005), Santos *et al.* (2008) and Silva *et al*. (2009) propose to estimate the amount of nutrients required for the growth and development of plants by dividing the value of the demand (accumulation) estimated for the aerial part by their respective recovery rates, by the plant, of the elements applied into the soil via fertilizers. The recovery rate indicates the efficiency

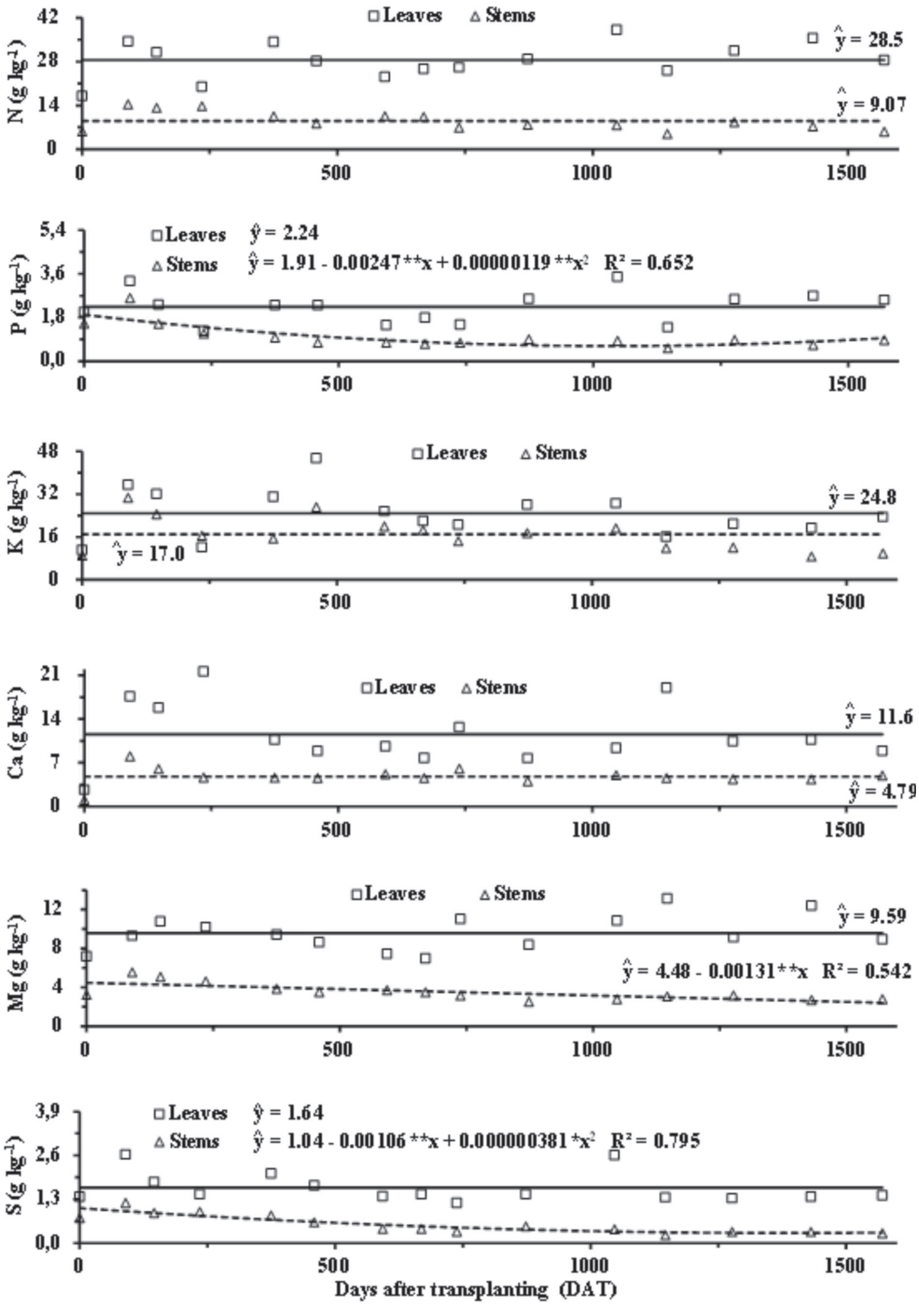

Figure 1: Macronutrient contents in leaves and stems of jatropha plants, according to the number of days after seedling transplanting in a typical medium texture Haplortox.

of the plant in the nutrient absorption from the fertilizer (Silva *et al*., 2009), since it does not absorb 100% of the applied nutrient (Santos *et al*., 2008). It has adopted recovery rates of 0.65; 0.10; 0.80; 0.50; 0.55; 0.45 and 0.05 kg kg^{-1} of N, P, K, Ca, Mg, S and micronutrients (Freire, 2001; Oliveira *et al*., 2005; Santos *et al*., 2008). Thus, from the data of extraction by the aerial part of *Jatropha curcas* plants, set at 12 months of age (Figures 4 and 5), and by considering the aforementioned recovery rates, it was estimated that in the planting fertilization of jatropha as well as topdressing fertilization in the second year should be enough to supply 40; 50; 50; 21; 16; 5; 0.7; 0.3; 4; 8 and 1 kg ha^{-1} of N, P_2O_5, K_2O, Ca, Mg, S, B, Cu, Fe, Mn and Zn, respectively. The supply of Ca and Mg, however, can be disregarded, since under proper conditions of base saturation, the availability of these nutrients is not limiting because they are supplied in sufficient quantities by the application of lime.

Values of nutrients recovery rates are, to some extent, arbitrary, considering that this variable is influenced by edaphic (pH, nutrient content and organic matter), weather (temperature, radiation, precipitation), biological (mycorrhizal), plant (species, cultivar, age and root morphology), and management (dose, source and method of application of fertilizer) factors according to Oliveira *et al*. (2005) and Santos *et al*. (2008). However, due to the lack of studies on the fertilization at planting conducted in the field for all nutrients, the adoption of these fertilization indications, as a first approximation are recommended.

By considering that in the first two years of cultivation, jatropha was fertilized with the total of 158, 200, 105, 191, 2, 2 and 4 kg ha^{-1} of N, P_2O_5, K_2O, S, B, Cu and Zn, it can be inferred that the quantities supplied were more than enough to supply the demand by the plants. For Ca, Mg, Fe and Mn, despite not being supplied by fertilization, it is noted that the planting of seedlings was performed in soil with

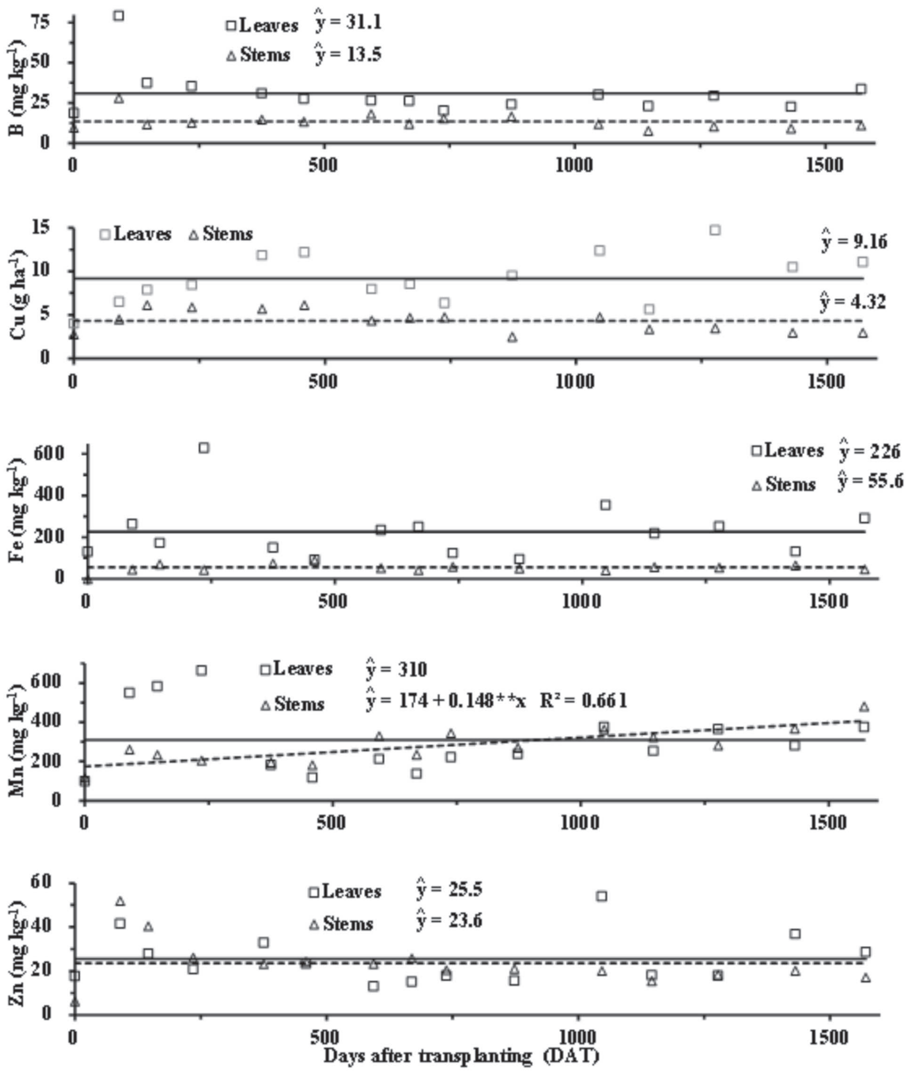

Figure 2: micronutrients Contents in the leaves and stems of jatropha plants, according to the number of days after transplanting the seedlings in a typical medium texture Haplortox.

good availability so no nutritional limitation was found for the growth of plants.

The nutritional requirement of jatropha plants found at 52 months of age was 102, 13, 144, 70, 44 and 5 kg ha^{-1} of N, P, K, Ca, Mg and S, respectively and 172, 48, 980, 6,162 and 238 g ha^{-1} of B, Cu, Fe, Mn and Zn, respectively. Quantitatively, the sequence of nutrients extracted in the aerial part was: K> N> Ca> Mg> P> Mn = S> Fe> Zn> B> Cu. This result differed from that obtained by Reis *et al*. (2010), who found, in Quartzipsamment soil, in the municipality of Diamantina, state of Minas Gerais, in jatropha plants at 19 months of age, a sequence of extracted nutrients of N> Mg> K> Ca> S> P. On the other hand, Pacheco *et al*. (2006) established a very similar sequence of nutrient extraction, in whole plants of jatropha, including the roots, at five months of age: K> N> Ca> Mg> P> S> Fe> Mn> Zn > B> Cu. Similarly, Freiberger (2012) established that the accumulation of order in the aerial part of jatropha plants with 150 DAT was K> N> Mg> Ca> P> S> Fe> Mn> B> Zn> Cu.

It is noteworthy that, on the average of all the nutrients, the maximum amount accumulated in the leaves corresponded to 29.5% of the amount calculated for the aerial part, while the maximum dry matter production of leaves (1759 kg ha) represented only 12.8% of the biomass of leaves and stems (13,693 kg ha^{-1}). However, this accumulation of nutrients proportionately higher in leaves is because its concentration in this plant organ is larger

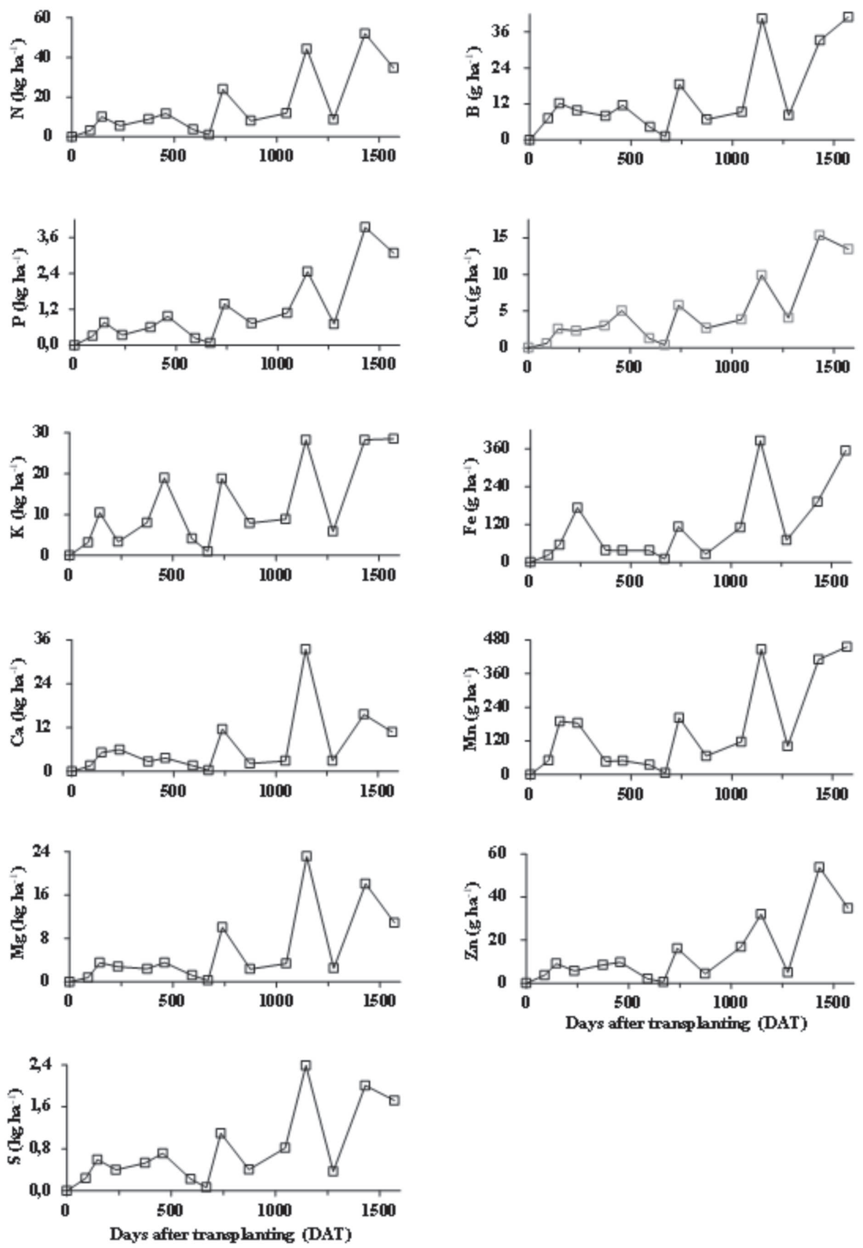

Figure 3: Amount of accumulated nutrients in leaves of jatropha plants, according to the number of days after transplanting the seedlings in typical medium texture Haplortox.

(Figures 1 and 2). Exception for the manganese, whose leaf content at 1,571 DAT was lower than in the stem, so that the maximum amount accumulated in the first (456 g ha^{-1}) corresponded to only 7.4% of the accumulation in the aerial part (6,162 g ha^{-1}).

In order to estimate the export of nutrients, we calculated a cumulative amount in the capsules and grains (Table 1), when the plants were in the fifth year of cultivation. Due to the low productivity of biomass obtained from 358 and 913 kg ha^{-1} of capsules and grains, respectively, the total quantity of nutrients exported at harvest was also not significant (25, 4, 18, 6, 5, and 1 kg ha^{-1} of N, P, K, Ca, Mg, S, respectively and 27, 16, 130, 162 and 30 g ha^{-1} Cu, Fe, Mn and Zn, respectively). It is noted that the low productivity of jatropha grains obtained was not related to the occurrence of climatological or nutritional issues but with high variability in this species even in domestication, whose available genetic material is still very heterogeneous and segregating. Similar yields were also obtained by Silva (2011), Dalchiavon *et al.* (2013) and Saraiva *et al.* (2013).

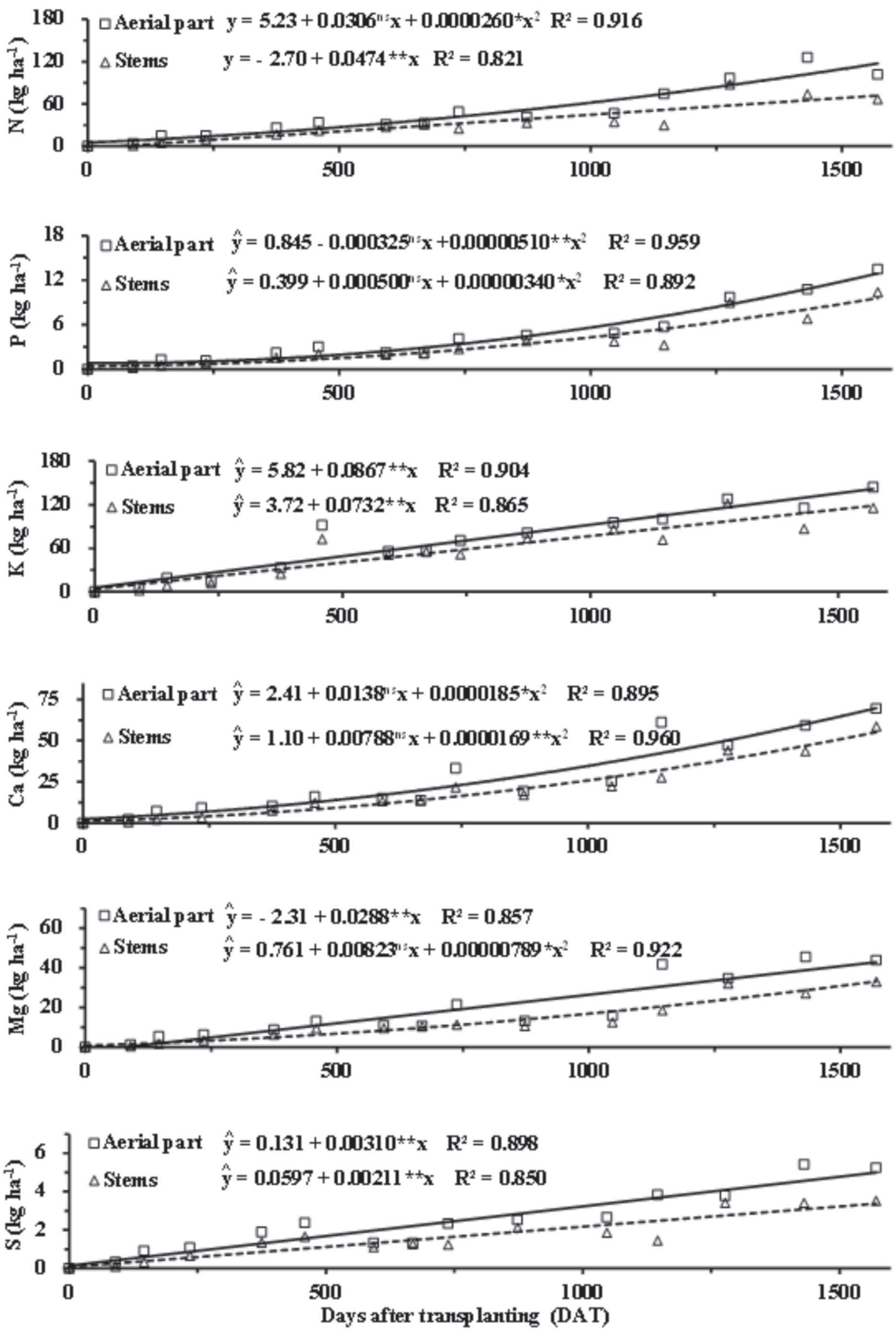

Figure 4: Amount of macronutrients accumulated in the stems and aerial part of jatropha plants, according to the number of days after transplanting the seedlings in a typical medium texture Haplortox.

From this estimates and from the recovery rates of nutrients mentioned above, according to Freire (2001), Oliveira *et al*. (2005) and Santos *et al*. (2008), it was calculated that the quantity of nutrient to be supplied annually in topdressing aiming at reposition of the exported nutrients should be sufficient to provide 50, 100, 30 and 3 kg ha^{-1} of N, P_2O_5, K_2O and S, respectively, per ton of grain to be produced. To maintain soil fertility, it is also necessary to restore the amount of nutrients extracted by the aerial part. Thus, considering the average values of annual nutrient accumulation observed in the period from 738 and 1,571 DAE (Figures 4 and 5), it can be estimated the need to apply annually, in topdressing from the third year of cropping, over 40, 110, 55 and 3 kg ha^{-1} of N, P_2O_5, K_2O and S, respectively.

The order of nutrient accumulation observed in fruits (N> K> Ca> Mg> P> S> Mn> Fe> Zn> B> Cu) was similar to that found by Laviola & Dias (2008), differing only with respect to P Mg, B and Zn. The nutrients K, Fe and Mn were exported in greater quantities by the capsules, while the others were mainly exported by the grains, due to differences in the contents in these two parts of the plant. These results are in agreement with those partially obtained by Borghetti *et al*. (2010), who also found higher levels of K in the capsule than in beans; however, they observed that the export of N by fruits was lower than K. In addition, these authors also found differences in nutrient content in the grains and capsules because of the fruit ripening season.

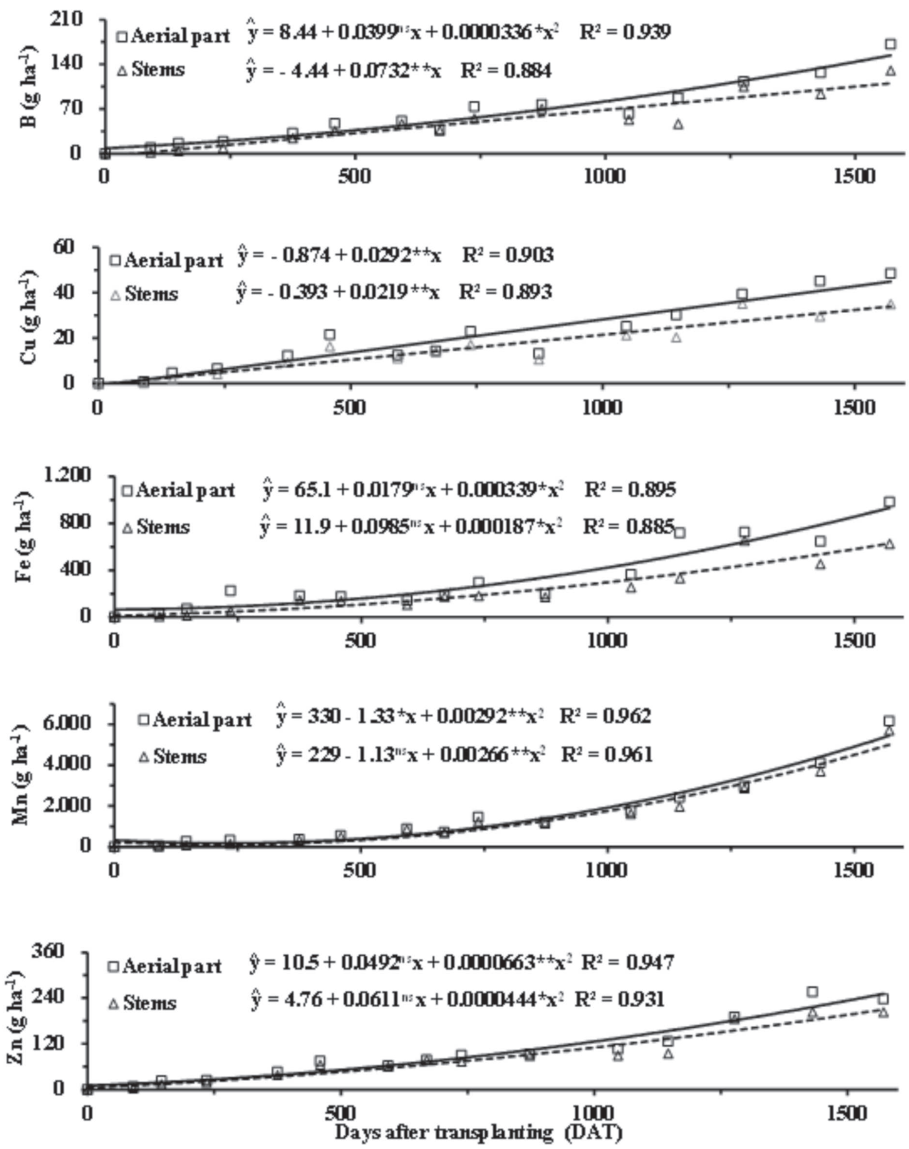

Figure 5: Amount of accumulated micronutrients in stems and the aerial part of jatropha plants according to the number of days after seedling transplanting in a typical medium texture Haplortox.

The potential for nutrient recycling by means of senescent leaves of jatropha plant (Table 1) was estimated by the product of the dry mass of leaves on the plant canopy, observed on 1,571 DAT (1,216 kg ha^{-1}), and nutrient content in the litter collected from the soil surface under the crown projection area, from January 13 and May, 22, 2012 (from 1,147 and 1,277 DAT). The average amount of Ca, Mg, B and Cu that can be recycled through litter (Table 1) is very similar or even higher than the accumulated amount in the leaves, estimated in the period between 1,431 and 1,571 DAT (Figure 3). However, it is important to consider that in conditions of potential production of 4,000 g per plant of grains, as described by Tominaga *et al*. (2007), which would represent, for a population of 1,250 plants ha^{-1}, 5,000 kg ha^{-1} of grains, the amount of nutrients recycled by litter estimated in Table 1, would be insufficient to meet all the demand for aerial part. For a jatropha cultivar that allows a high production potential, maintenance fertilization becomes a mandatory practice for the adequate supply of the nutritional requirement of the plant, without damage to soil fertility.

Table 1: Dry mass yield (kg ha^{-1}) and macro (kg ha^{-1}) and micronutrients (g ha^{-1}) accumulation in capsules, grains and jatropha plants[1]

Variable	Capsules	Grains	Litter
Plant dry matter	358 ± 36	913 ± 121	1.216 ± 230
N	2.8 ± 0.4	22 ± 3	23 ± 3
P	0.1 ± 0.01	3.6 ± 0.3	1.5 ± 0.4
K	11 ± 1	7.1 ± 0.8	15 ± 3
Ca	1.5 ± 0.1	4.0 ± 0.6	23 ± 7
Mg	2.5 ± 0.3	3.0 ± 0.3	14 ± 2
S	0.1 ± 0.02	1.0 ± 0.1	1.0 ± 0.1
B	11 ± 2	16 ± 2	44 ± 7
Cu	2.8 ± 0.3	12.8 ± 1.0	15 ± 3
Fe	80 ± 37	50 ± 8	243 ± 63
Mn	108 ± 14	54 ± 9	389 ± 100
Zn	4.7 ± 0.7	26 ± 2	19 ± 3

[1] Mass values for mean and standard deviation. Dry matter production and accumulation of nutrients in capsules and grains evaluated in the fifth year of cultivation. Accumulation of nutrients in senescent leaves (litter) of jatropha plant estimated by multiplying the nutrient levels determined in litter collected samples of soil surface under the crown projection are, from January 13 and May 22, 2012 (between 1,147 and 1,277 DAT) and the dry matter production of leaves on the plant canopy, given the 1,571 DAT

CONCLUSIONS

There is a wide variation in the amount of nutrients accumulated in leaves of jatropha plants due to senescence and leaf abscission in the driest or coldest periods in the year.

The accumulation of N, P, Ca, B, Fe, Mn and Zn in the aerial part is relatively low in the first 22 months. From the third year of growth, the demand for these nutrients becomes more pronounced.

To meet the demand for nutrients necessary for the growth of jatropha plants, planting and topdressing fertilization in the second year must provide 40; 50; 50; 21; 16; 5; 0.7; 0.3; 4; 8 and 1 kg ha^{-1} of N, P_2O_5, K_2O, Ca, Mg, S, B, Cu, Fe, Mn and Zn, respectively. From the third year of cultivation, topdressing fertilization should be targeted to restore 40, 110, 55 and 3 kg ha^{-1} of N, P_2O_5, K_2O and S, respectively. To restore the exported amount of nutrients, it must be supplied over 50, 100, 30 and 3 kg ha^{-1} of N, P_2O_5, K_2O and S, respectively, per ton of grain to be produced.

ACKNOWLEDGEMENTS

The authors would like to thank Universidade Estadual de Mato Grosso do Sul - UEMS, for the opportunity of carrying out the experiment at Unidade Universitária de Cassilândia, MS. They also thank Embrapa, MCT/ FINEP and PETROBRÁS for the financial support to this research.

REFERENCES

Arruda FP de, Beltrão NE de M, Andrade AP de, Pereira WE & Severino LS (2004) Cultivo de pinhão manso (*Jatropha curcas* L.) como alternativa para o semi-árido nordestino. Disponível em: <http://www.cnpa.embrapa.br/ojs/index.php/RBOF/article/view/107/115>. Acessado em: 5 de julho de 2014.

Borghetti RA, Assis MO de, Santos Neto JA dos & Cardoso RR (2010) Teor e acúmulo de macronutrientes em frutos de pinhão-manso em diferentes épocas de maturação. In: 29ª Reunião Brasileira de Fertilidade do Solo e Nutrição de Plantas, 13ª Reunião Brasileira sobre Micorrizas, 11º Simpósio Brasileiro de Microbiologia do Solo, 8ª Reunião Brasileira de Biologia do Solo, Guarapari. Anais, SBCS. CD-ROM.

Camargo R de, Maldonado ACD, Dias PAS, Souza MF & França MS (2013) Diagnose foliar em mudas de pinhão-manso (*Jatropha curcas* L.) produzidas com biossólido. Disponível em: <http://www.scielo.br/pdf/rbeaa/v17n3/06.pdf>. Acessado em: 7 de julho de 2014.

Dalchiavon FC, Dallacort R, Colleti AJ, Montanari R & Paz-Ferreiro J (2013) Growth and productivity of purging nut (*Jatropha curcas* L.) crop grown on an Oxisol in Tangará da Serra (MT, Brasil). Disponível em: <http://www.udc.es/files/iux/almacen/articulos/cd37_art09.pdf>. Acessado em: 11 de novembro de 2015.

Freiberger MB (2012) Crescimento inicial e nutrição do pinhão-manso em função da adubação NPK. Dissertação de Mestrado. Universidade Estadual Paulista, Botucatu. 68p.

Freire FJ (2001) Sistema para cálculo do balanço nutricional e recomendação de corretivos e fertilizantes para cana-de-açúcar. Tese de Doutorado. Universidade Federal de Viçosa, Viçosa. 162p.

Laviola BG & Dias LA dos S (2008) Teor e acúmulo de nutrientes em folhas e frutos de pinhão-manso. Revista Brasileira de Ciência do Solo, 32:1969-1975.

Malavolta E, Vitti GC & Oliveira SA de (1997) Princípios, métodos e técnicas de avaliação do estado nutricional. In: Avaliação do estado nutricional da plantas: princípios e aplicações. 2ª ed. Piracicaba, Potafos. p.115-230.

Miragaya JCG (2005) Biodiesel: tendências no mundo e no Brasil. Informe Agropecuário, 26:7-13.

Oliveira FHT de, Novais RF, Alvarez V VH & Cantarutti RB (2005) Desenvolvimento de um sistema para recomendação de adubação para a cultura da bananeira. Revista Brasileira de Ciência do Solo, 29:131-143.

Pacheco DD, Saturnino HM, Mendes LD, Soares FR, Paula TOM de, Prates FB de S & Souza LCA de (2006) Produção de massa vegetal e composição mineral de plantas de pinhão-manso. In: 3º Congresso Brasileiro de Plantas Oleaginosas, Óleos, Gorduras e Biodiesel, Varginha. Anais, UFLA. p.624-627.

Prates FB de S (2010) Crescimento, desenvolvimento e nutrição de pinhão manso adubado com lodo de esgoto e silicato de cálcio e magnésio. Dissertação de Mestrado. Universidade Federal de Minas Gerais, Montes Claros. 93p.

Reis T de M, Silva E de B, Souza PT de, Santos SR & Tanure LPP (2010) Acúmulo de matéria seca e macronutrientes em mudas de pinhão manso cultivado na Serra do Espinhaço Meridional, MG. In: 29ª Reunião Brasileira de Fertilidade do Solo e Nutrição de Plantas, 13ª Reunião Brasileira sobre Micorrizas, 11º Simpósio Brasileiro de Microbiologia do Solo, 8ª Reunião Brasileira de Biologia do Solo, Guarapari. Anais, SBCS. CD-ROM.

Santos FC dos, Neves JCL, Novais RF, Alvarez VVH & Sediyama CS (2008) Modelagem da recomendação de corretivos e fertilizantes para a cultura da soja. Revista Brasileira de Ciência do Solo, 32:1661-1674.

Saraiva A de S, Dornelas DF, Dornelas BFM, Gonçalves RC, Erasmo EAL, Sarmento R de A & Nunes TV (2013) Growth and production of physic nut (*Jatropha curcas* L.) under phosphorus levels applied to the base. Journal of Biotechnology and Biodiversity, 4:240-248.

Saturnino HM, Pacheco DD, Kakida J, Tominaga N & Gonçalves NP (2005) Cultura do pinhão-manso (*Jatropha curcas* L.). Informe Agropecuário, 26:44-78.

Silva AP da, Alvarez VVH, Souza AP de, Neves JCL, Novais RF & Dantas JP (2009) Sistema de recomendação de fertilizantes e corretivos para a cultura do abacaxi – Fertcalc-Abacaxi. Revista Brasileira de Ciência do Solo, 33:1269-1280.

Silva FC da, Eira PA da, Raij B Van, Silva CA, Abreu CA de, Gianello C, Pérez DV, Quaggio JA, Tedesco MJ, Abreu MF de & Barreto W de O (1999) Análises químicas para avaliação da fertilidade do solo. In: Silva FC da (Ed.) Manual de análises químicas de solos, plantas e fertilizantes. Brasília, Embrapa Comunicação para Transferência de Tecnologia. p.75-169.

Silva JAN (2011) Consórcio de pinhão-manso com espécies forrageiras e produtoras de grãos. Dissertação de Mestrado. Universidade Federal da Grande Dourados, Dourados.101p.

Silva TO da, Primo DC, Menezes RSC & Pedrotti A (2010) Biomassa e acúmulo de nutrientes em plantas de pinhão-manso submetidas a adubos orgânicos em solos distintos da Região Nordeste. In: 29ª Reunião Brasileira de Fertilidade do Solo e Nutrição de Plantas, 13ª Reunião Brasileira sobre Micorrizas, 11º Simpósio Brasileiro de Microbiologia do Solo, 8ª Reunião Brasileira de Biologia do Solo, Guarapari. Anais, SBCS. CD-ROM.

Tominaga N, Kakida J & Yasuda EK (2007) Cultivo de pinhão-manso para produção de biodiesel. Viçosa, CPT. 220p.