

DIVISÃO 3 - USO E MANEJO DO SOLO

Comissão 3.1 - Fertilidade do solo e nutrição de plantas

NUTRIENT EXTRACTION AND EXPORTATION BY CASTOR BEAN HYBRID LYRA⁽¹⁾

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SUMMARY

Information about nutrient extraction and exportation by crops, as well as the periods of highest nutrient demand is important for an adequate fertilization management. However, there are no studies on the nutrient uptake of short-stature hybrid castor bean. Therefore, the purpose of this study was to evaluate nutrient extraction and exportation by short-stature castor bean hybrid Lyra, in the spring-summer and fall-winter growing seasons. The experiments were conducted in the 2005/2006 spring-summer and 2006 fall-winter growing seasons on an Oxisol, in Botucatu, SP, in a randomized block design, with four replications. The plots consisted of plant samplings, which occurred 17, 31, 45, 59, 73, 97 and 120 days after emergence (DAE) in the spring-summer and 17, 31, 45, 59, 80, 100 and 120 DAE in fall-winter growing season. The growth of hybrid Lyra was slow and nutrient uptake lowest between emergence and the beginning of flowering. The period of highest dry matter (DM) accumulation rates and highest nutrient demand were observed 40 to 80 DAE, in both growing seasons. The order of nutrient extraction by the plants in the spring-summer growing season was: N>K>Ca>Mg>S>P>Fe>Mn>Zn>B>Cu>Mo. In fall-winter, S was more absorbed than Mg. Seed yield was higher in the spring-summer (2.995 kg ha⁻¹), but nutrient extraction and exportation per ton of seed were similar in both growing seasons. Around 58 % of N and 84 % of P, and approximately half of the S and B absorbed throughout the cycle were exported with the seeds. However, most of the other nutrients accumulated in the plants returned to the soil in plant residues.

Index terms: *Ricinus communis*, uptake curves, uptake rates, seed yield.

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RESUMO: *EXTRAÇÃO E EXPORTAÇÃO DE NUTRIENTES PELO HÍBRIDO DE MAMONA LYRA*

Informações sobre extração e exportação de nutrientes pelas culturas, bem como os períodos de maior exigência de cada um deles, são de suma importância para o manejo correto da adubação. No entanto, não existem pesquisas sobre marcha de absorção de nutrientes em híbridos de mamona de porte baixo. Assim, objetivou-se com este trabalho avaliar a extração e a exportação de nutrientes pelo híbrido de mamona Lyra, de porte baixo, nos cultivos de safra e safrinha. Os experimentos foram conduzidos na safra 2005/2006 e na safrinha de 2006 em um Latossolo Vermelho distroférico, em Botucatu, SP, em delineamento experimental em blocos casualizados, com quatro repetições. As parcelas foram constituídas pelas épocas de coletas de plantas, as quais foram realizadas aos 17, 31, 45, 59, 73, 97 e 120 dias após emergência (DAE) durante a safra e aos 17, 31, 45, 59, 80, 100 e 120 DAE na safrinha. O híbrido de mamona Lyra apresentou crescimento lento e menor absorção de nutrientes da emergência até o início do florescimento. O período de maiores taxas de acúmulo de matéria seca e de maior demanda por nutrientes foi de 40 a 80 DAE, em ambas as safras. A ordem de extração de nutrientes pelas plantas no cultivo de safra foi: N>K>Ca>Mg>S>P>Fe>Mn>Zn>B>Cu>Mo. Na safrinha, o S foi mais absorvido que o Mg. A produtividade de grãos foi maior no cultivo de safra (2.995 kg ha⁻¹), mas a extração e exportação de nutrientes por tonelada de grãos foram semelhantes nas duas épocas de cultivo. Entre 58 e 84 % do N e P e aproximadamente metade do S e B absorvidos ao longo do ciclo foram exportados com os grãos, porém a maior parte dos demais nutrientes acumulados nas plantas retornou ao solo com os restos culturais.

Termos de indexação: Ricinus communis, curvas de absorção, taxas de absorção, produtividade de grãos.

INTRODUCTION

For satisfactory yields of castor bean (*Ricinus communis* L.), the nutrient availability in the soil has to meet the crop requirements. However, the few studies focused on nutrient uptake by castor bean plants are restricted to macronutrients.

In the 50s, based on literature data, Canecchio Filho & Freire (1958) estimated that in a yield of 2.000 kg ha⁻¹ dry fruit (seeds + husk) yield, castor bean exports 80, 7.9, 26.7, 8.6 and 6.0 kg ha⁻¹ of N, P, K, Ca and Mg, respectively. In a subsequent study, Nakagawa & Neptune (1971) found that the nutrient amounts absorbed by this oilseed crop throughout the crop cycle (133 days) were 156 kg ha⁻¹ N, 5.3 kg ha⁻¹ P, 172 kg ha⁻¹ K, 13.8 kg ha⁻¹ Ca and 12.5 kg ha⁻¹ Mg, demonstrating the high nutrient demand during the growth and development of this crop. However, aside from not taking the micronutrients into consideration, the said studies involved cultivars with a long growth cycle, medium height and non-uniform maturity, suited for manual harvest only.

Therefore, since the production system of this oilseed crop has changed significantly with the development of new, short hybrids and cultivars, adequate for mechanized harvesting, with short growth cycle, high yield, uniform maturity and high

oil content in seeds (Moro, 2008; Silva et al., 2010), further studies on the mineral nutrition of this crop plant are required. Since short hybrids have a high yield and short growth cycle, the nutrient demand concentrated in a short period is possibly much higher than of traditional cultivars, with long growth cycle and indeterminate growth.

In the past few years, castor bean oil emerged as a possible energy source and the planting area of this oilseed crop was increased. New studies on mineral nutrition and fertilization with macronutrients and micronutrients were developed with short-stature castor bean cultivars (Lange et al., 2005; Lavres Júnior et al., 2005, 2009; Severino et al., 2006; Silva et al., 2007; Almeida Júnior et al., 2009; Chaves et al., 2009; Oliveira et al., 2010; Dantas Júnior et al., 2010). However, so far no data are available on the nutrient uptake of short-stature hybrids, not in spring-summer (main harvest) when this oilseed crop is grown in crop rotation/succession systems (Silva et al., 2010), nor in fall-winter (second growing season), when castor bean is an important alternative crop (Moro et al., 2011).

Therefore, it is essential to know the nutrient demand of short-stature hybrid castor bean throughout the long growth cycle, as well as the periods of highest nutrient demand and the amounts exported with the seeds. Underlying fertilization

management, this information makes balanced fertilization possible, ensuring the optimization of seed and oil yield of this oilseed crop. The purpose of this study was to evaluate nutrient extraction and exportation in short-stature castor bean hybrid Lyra, in the spring-summer (main harvest) and fall-winter (second growing season).

MATERIAL AND METHODS

The experiments were conducted on the Experimental Farm Lageado of the College of Agricultural Sciences, São Paulo State University (UNESP), in the city of Botucatu, SP (48° 26' W, 22° 51' S, 740 m asl). The soil of the experimental area was an Oxisol, used for six years in a no-tillage system. During the experiments, the maximum and minimum temperature and rainfall were recorded daily (Figure 1).

Prior to the experiment installation in the spring-summer and fall-winter growing seasons, samples were taken from the 0.0–0.20 m layer to determine the soil chemical properties (Raij et al., 2001). For the spring-summer growing season, the following results were found: Organic Matter (O.M.), 24.0 g dm⁻³; pH (CaCl₂), 5.1; P (resin), 16.0 mg dm⁻³; K⁺, Ca²⁺, Mg²⁺, H + Al and Cation Exchange Capacity (CEC), 1.5, 31, 17, 38 and 87 mmol_c dm⁻³, respectively; and base saturation of 56 %. In fall-winter, the soil analysis results were O.M., 36.0 g dm⁻³; pH (CaCl₂), 5.1; P (resin), 28.0 mg dm⁻³; K⁺, Ca²⁺, Mg²⁺, H + Al and CEC, 1.3, 26, 13, 51 and 92 mmol_c dm⁻³, respectively; and base saturation of 45 %.

Before castor bean sowing, the field was sprayed with glyphosate (1.8 kg ha⁻¹ i.a.). In spring-summer, the seeds were sown in no-tillage on oat straw, on 23/12/2005, and in fall-winter, on corn straw, on 3/04/2006; in rows spaced 0.50 m apart and 45,000 plants ha⁻¹. In both growing seasons, seeds of the commercial hybrid Lyra were treated with carboxin-thiran (60 g i.a. 100 kg⁻¹ seeds), and thiametoxan (210 g i.a. 100 kg⁻¹ seeds).

The hybrid Lyra has a short growth cycle (140 days), average height of 1.40 m, indehiscent fruits with a thin, easy-to-remove husk and average yield of 2,000 kg ha⁻¹; flowering occurs 30–35 days after emergence (DAE); approximately 60 % of the flowers are female; and it is well-adapted to stress.

Mineral fertilization was applied at a rate of 250 kg ha⁻¹ of the N-P-K 08-28-16 + 4.5 % S + 0.5 % Zn, based on the soil chemical analysis and on the recommendations of Savy Filho et al. (1999). In spring-summer, emergency occurred on 08/01/2006 and in fall-winter growing season, emergency occurred on 23/04/2006. Topdressing fertilization was performed with 50 kg ha⁻¹ of N (ammonium nitrate) at 20 DAE, when the plant had 4–5 fully expanded leaves. The fertilizer was applied to the soil surface and spread along the sides and within a 10 cm distance from the plant rows.

During the crop cycle, fungicides were applied in the experimental area according to the technical recommendations for the specific crop (Lima & Batista, 1997). In both growing seasons, flowering occurred around 25 DAE.

The experiment was conducted in a randomized block design with four replications. The plots consisted of the plant samplings (assessments),

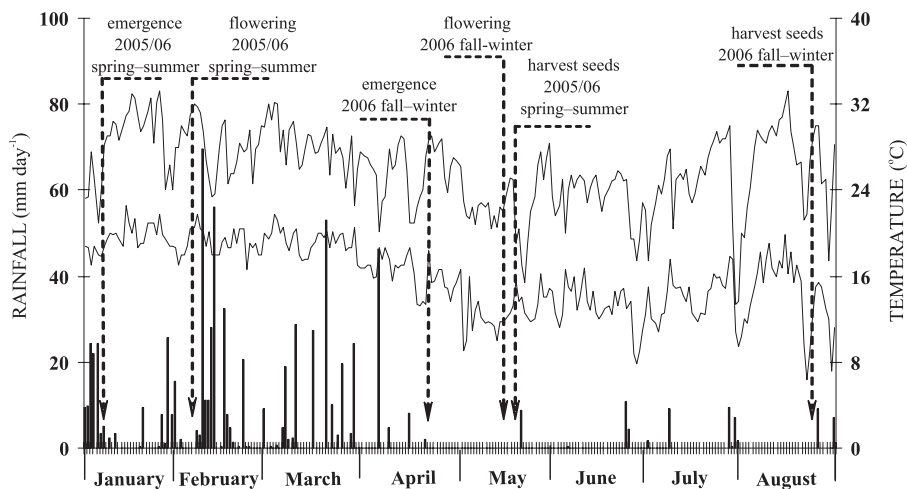


Figure 1. Rainfall (■) and maximum (—) and minimum (---) temperatures recorded during the experiment, and timeline of emergence, flowering and harvest of castor bean hybrid Lyra in the 2005/2006 spring-summer and 2006 fall-winter growing seasons.

which occurred 17, 31, 45, 59, 73, 97 and 120 DAE in the spring-summer, and 17, 31, 45, 59, 80, 100 and 120 DAE in the fall-winter growing season. Each plot had ten 5-m long rows. Only the eight central rows were considered for evaluation, leaving 1 m on either side. At each plant sampling (assessment), the shoots of four plants in sequence in a row were removed. Plants sampled had in all sides plants competitive and had no sign of disease.

The sampled plants were separated into stem, leaves and raceme, washed and dried to constant weight in a forced-air oven at 65 °C. Based on dry matter (DM) data of four plants and on the plant density, the accumulated DM of each plant part and shoot were calculated. The samples were ground in a Wiley mill and the levels of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Mo and Zn were determined (Malavolta et al., 1997). Based on the nutrient levels and the accumulated DM amounts, the amounts of macronutrients and micronutrients accumulated in each plant part and in shoot were calculated.

In both growing seasons, the final harvest occurred 120 DAE. For the assessment of seed yield, all plants contained in the eight central rows of the plots were collected, leaving 1 m on either side, and the seeds weighed. To calculate the seed yield, the seed weight of the four plants sampled during the last sample period (120 DAE) was added to the seed weight of the other plants of the eight central rows of the plot. The yield data were converted to kg ha⁻¹, considering the plant population, and were adjusted for the moisture content of 80 g kg⁻¹ (wet basis). The nutrient exportation with seeds was derived from the seed yield data and nutrient levels.

The data were subjected to ANOVA. The effects of the plant samplings on the variables DM and nutrient accumulation were assessed by regression analysis using the Gaussian model with three parameters, described by the equation (1):

$$y = ae^{-0.5\left(\frac{x-x_0}{b}\right)^2} \quad (1)$$

where y = DM or nutrient accumulation; a = corresponds to the value of maximum accumulation; x_0 = corresponds to the value of x , in DAE, which provides the maximum y ; and b = corresponds to the amplitude in the value of x , in DAE, between the inflection point and the maximum point.

The rates of DM and nutrient accumulation in the shoot and raceme were obtained by the first derivative of the fitted equation for DM and nutrient accumulation, leading to the inflection and maximum points for each equation. The inflection point represents the day of the development cycle of the plant when the rate of daily DM or nutrient

accumulation reaches the maximum. From the beginning of the cycle until the inflection point, the daily accumulation rate increased. Thereafter, this rate decreased. The maximum point represents the day of the plant development cycle when DM or nutrient accumulation reaches the maximum value.

RESULTS AND DISCUSSION

Growth and DM accumulation

In both growing seasons, the DM accumulation in the shoot was low in the first 40 DAE, but was intensified after flowering (25 DAE), due to the raceme growth (Figure 2). In spring-summer, 74 DAE the DM accumulation rate in the shoot reached 122 kg ha⁻¹ day⁻¹, whereas in the fall-winter growing season 62 DAE, the maximum DM accumulation rate was 37 kg ha⁻¹ day⁻¹ (Figure 2). During the spring-summer, when water availability was higher, the shoot accumulated DM almost until the end of the cycle, reaching 8,600 kg ha⁻¹ DM, compared to 2,200 kg ha⁻¹ in fall-winter growing season. In fall-winter, the DM accumulation increased until 100 DAE, when the accumulation rate became zero and the amount of DM remained stable until the end of the cycle (Figure 2).

In spring-summer, the racemes showed strong growth between 50 and 90 DAE, when the DM accumulation rate reached 76.1 kg ha⁻¹ day⁻¹ (Figure 2). Nevertheless, i.e., in the fall-winter, the racemes showed higher DM accumulation rate between 50 and 80 DAE, in a shorter period than in spring-summer and at rates of 31.1 kg ha⁻¹ day⁻¹ only, which led to a reduced raceme growth and seed yield (Figure 2 and Table 1). Despite the lower raceme growth in the fall-winter, at the end of the cycle it was found that these organs accounted for 73 % of the DM of the whole plant, whereas in spring-summer, the racemes accounted for only 49 %. These findings demonstrated that under reduced water availability, as is the case in the fall-winter growing season, the plants change the DM partition and assign a greater proportion of carbohydrate intake to the development of racemes, since the developing seeds act as a photoassimilate sink, leading to a reduction in the leaf area and leaf dry matter (Taiz & Zeiger, 2004; Dantas Júnior et al., 2010).

Macronutrient accumulation

In both growing seasons the macronutrient accumulation was low until the beginning of raceme formation (25 DAE), coinciding with the period of low DM accumulation (Figures 2, 3 and 4). After flowering (25 DAE) the macronutrient uptake increased in both growing seasons. The

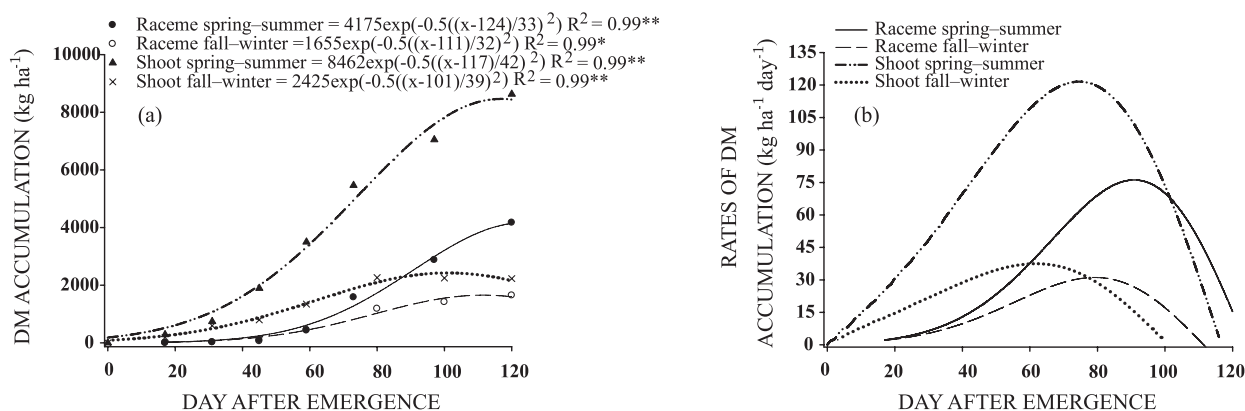


Figure 2. Dry matter (DM) accumulation in racemes and shoot (a), and DM accumulation rates in racemes and shoot (b) of the castor bean hybrid Lyra in the 2005/2006 spring-summer and 2006 fall-winter growing seasons. ** and * are: significant at $p \leq 0.01$ and $p \leq 0.05$ by the F test.

accumulation rates reached maximum values between 60 and 70 DAE in the spring-summer growing season (Figures 3 and 4). In fall-winter, the maximum daily uptake of K, Ca, Mg and S occurred between 55 and 60 DAE, whereas for N and P the daily uptakes was highest 70 and 90 DAE, respectively. Therefore, the daily uptake indicated that N or N and K topdressing can be applied later, or more frequently throughout the cycle, since N fertilization in this study was performed 20 DAE and the N and K demand of the castor bean hybrid was highest between 60 and 70 DAE (Figure 3). Although the period of maximum P uptake occurred 70 DAE (spring-summer) and 90 DAE (fall-winter), this nutrient should be supplied at sowing, because its low availability in the early stages, besides reducing the number of leaves, delays fruit production in primary racemes (Nakagawa et al., 1982), which accounts for at least 30 % of the total yield (Nakagawa et al., 1977).

Based on the amounts accumulated and accumulation rates, it can be seen that most macronutrients in the shoot reached the maximum values between 100 and 110 DAE, regardless of the growing seasons (Figures 3 and 4). Only P and Ca showed a behavior different from the other nutrients; there was practically no Ca uptake 85 DAE, whereas P was the only nutrient absorbed until the end of the crop cycle. Nakagawa & Neptune (1971) also reported an increased P accumulation by the castor bean cultivar Campinas until the end of the cycle.

It was observed, particularly in the fall-winter growing season, that the accumulated amounts of N, P and K by the plants remained constant until the end of the cycle, whereas Ca, Mg and S accumulations were reduced due to leaf senescence, once the greatest accumulation of these nutrients occurs in the leaves and stems, as indicated by

the lower accumulation rates of the racemes than of the shoot (Figures 3 and 4). Therefore, only a small amount of Ca, Mg and S absorbed by plants is allocated to seed growth. After absorption, these nutrients are transported by the xylem and accumulate in larger quantities in leaves and stems, due to their low redistribution in the tissues, in the case of Ca and S, or because they are part of the chlorophyll molecule (Malavolta, 2006).

A different behavior was observed for N, P and K, in the final stage of the fall-winter growing season, with greater accumulation rates in the racemes than in the shoot, indicating the mobilization of these nutrients already accumulated in other plant parts. According to Nakagawa et al. (1982), P previously accumulated in the leaf, petiole and stem is transferred to the inflorescence of castor bean during plant development. The cause of this translocation is that a significant nutrient amount accumulated in the leaves during growth is transferred during senescence to reproductive or growth organs, and leaf death only occurs after the nutrients are remobilized to other plant parts by senescence processes (Souza & Fernandes, 2006). In other plants, the remobilization of N, P and K from the leaves during leaf senescence was 80 % (Himmelblau & Amasino, 2001). In citrus plants, the content of mobile elements such as N, P, K is lower in the leaves near the fruits, as a result of the mobilization process from the leaf reserves of these elements to the fruits (Malavolta, 2006).

In the spring-summer growing season, nutrient uptake was greater than in fall-winter, with amounts of 180, 21, 78, 77, 35 and 31 kg ha⁻¹ of N, P, K, Ca, Mg and S, respectively (Figures 3 and 4). In fall-winter, these values were 67, 7, 28, 24, 9.4 and 17 kg ha⁻¹ for N, P, K, Ca, Mg and S, respectively. In both growing seasons, N, K and Ca were the most

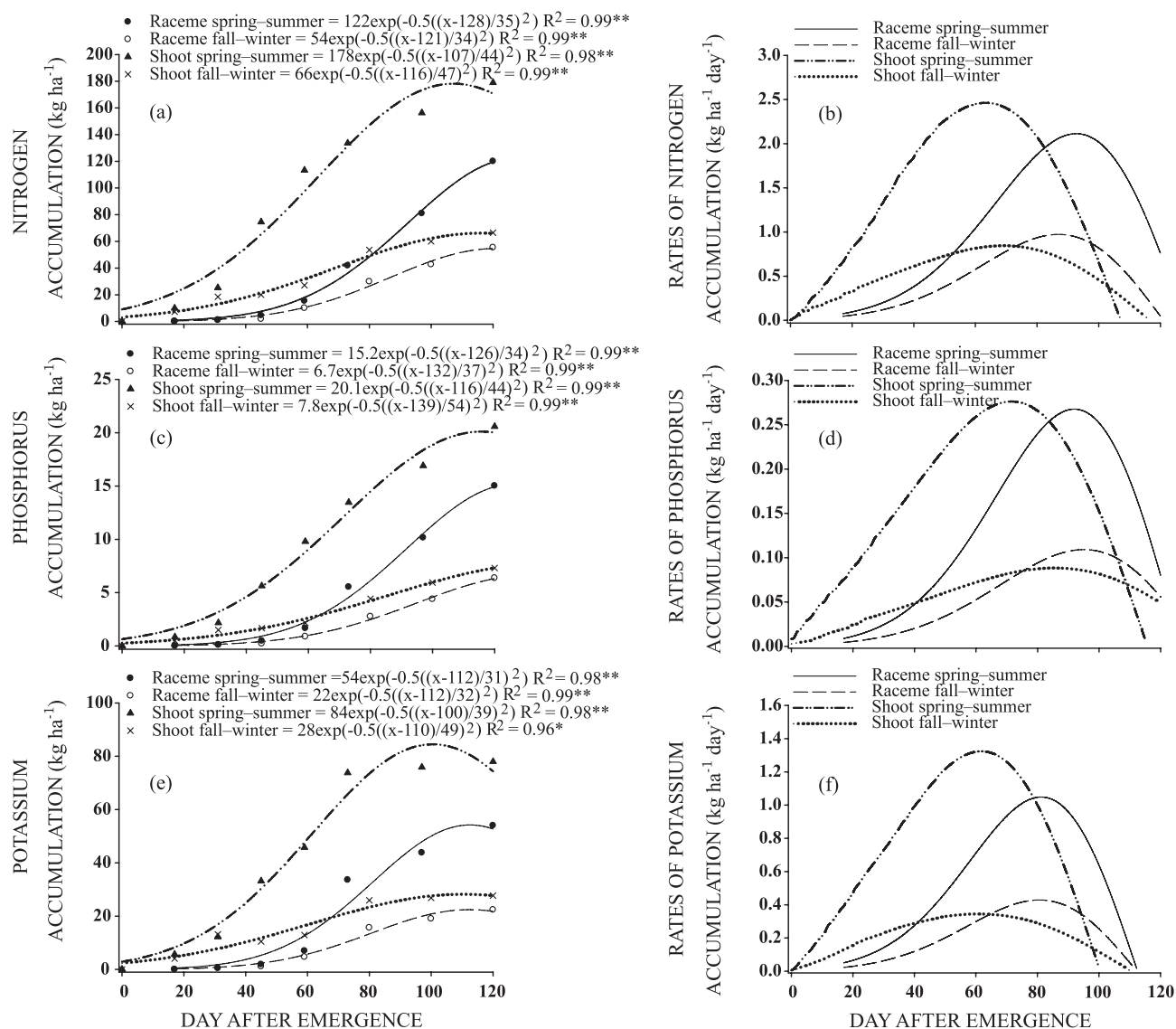


Figure 3. Accumulation and accumulation rates of nitrogen (a and b), phosphorus (c and d) and potassium (e and f) in racemes and shoot of the castor bean hybrid Lyra in the 2005/2006 spring-summer and 2006 fall-winter growing seasons. ** and * are significant at $p \leq 0.01$ and $p \leq 0.05$ by the F test.

intensively absorbed macronutrients by hybrid Lyra, as also reported by Lavres Júnior et al. (2005) for the castor bean cultivar Iris, confirming the high demand of this oilseed crop for the above nutrients. Nakagawa & Neptune (1971) observed that K was the most intensively absorbed nutrient by castor bean followed by N, Ca, Mg and P, indicating that the order of nutrient absorption may vary according to the season and crop system, and also to the cultivar and/or hybrid used.

Except for K in both growing seasons and for N and Mg in fall-winter, it was found that the amounts of the other macronutrients absorbed by hybrid Lyra were larger than reported by Nakagawa &

Neptune (1971) for the medium-stature cultivar Campinas (Figures 3 and 4). The authors found that, throughout the cycle, this cultivar extracted $156 \text{ kg ha}^{-1} \text{ N}$, $5.3 \text{ kg ha}^{-1} \text{ P}$, $172 \text{ kg ha}^{-1} \text{ K}$, $13.8 \text{ kg ha}^{-1} \text{ Ca}$ and $12.5 \text{ kg ha}^{-1} \text{ Mg}$. These results showed that short-stature hybrids differ from traditional cultivars in terms of nutrient uptake.

With regard to fertilization, it was found that the amounts of N (70 kg ha^{-1}) and K (33 kg ha^{-1}) applied by fertilization were larger than the total requirements of this hybrid in the fall-winter growing season, but not in the spring-summer, when uptake was greater and the nutrient amounts absorbed by plants were larger than those supplied

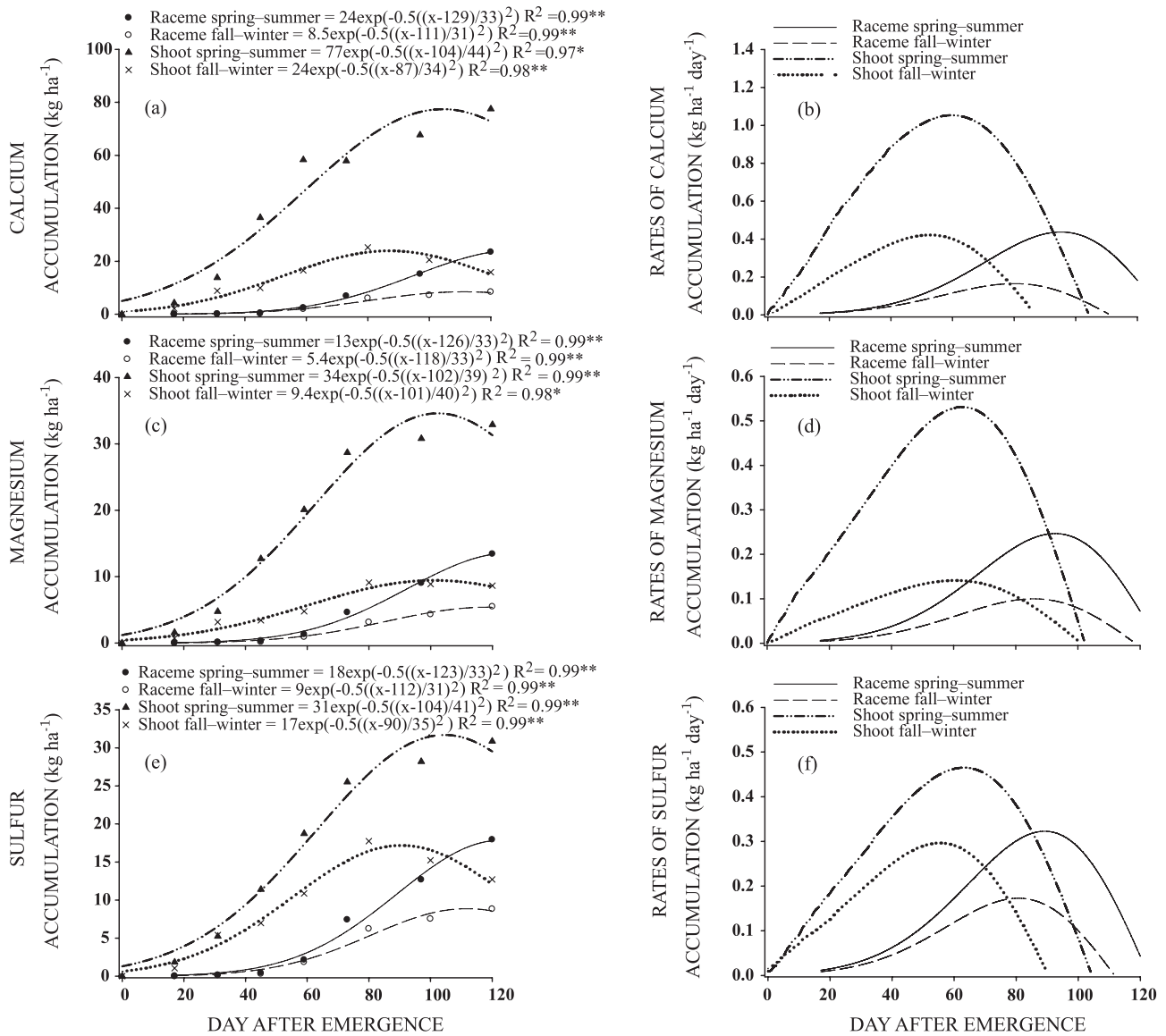


Figure 4. Accumulation and accumulation rates of calcium (a and b), magnesium (c and d) and sulfur (e and f) in racemes and shoot of the castor bean hybrid Lyra in the 2005/2006 spring-summer and 2006 fall-winter growing seasons. ** and * are: significant at $p \leq 0.01$ and $p \leq 0.05$ by the F test.

by fertilization (Figure 3). The amount of P applied by fertilization (30.6 kg ha^{-1}) was larger than the amount of P absorbed, but the amount of S applied by fertilization (11.3 kg ha^{-1}) was smaller than the amounts extracted by the plants in both growing seasons (31 and 17 kg ha^{-1} in spring-summer and fall-winter, respectively) (Figures 3 and 4). Thus, particular attention should be paid to N and K fertilization, mainly in the spring-summer growing season, and regarding sulfate fertilization, in both growing seasons, because in these cases the nutrient uptake was higher than the fertilizer rates applied.

Micronutrient accumulation

Until the beginning of flowering, the amounts of micronutrients accumulated in the shoot were small in both growing seasons, but with the formation and development of the racemes, nutrient accumulation became more intense (Figures 2, 5 and 6). The amounts of micronutrients extracted from the soil differed between the two seasons, indicating that the nutritional requirements of this hybrid vary according to the growing season.

The micronutrients B in spring-summer and Zn in both growing seasons were accumulated in

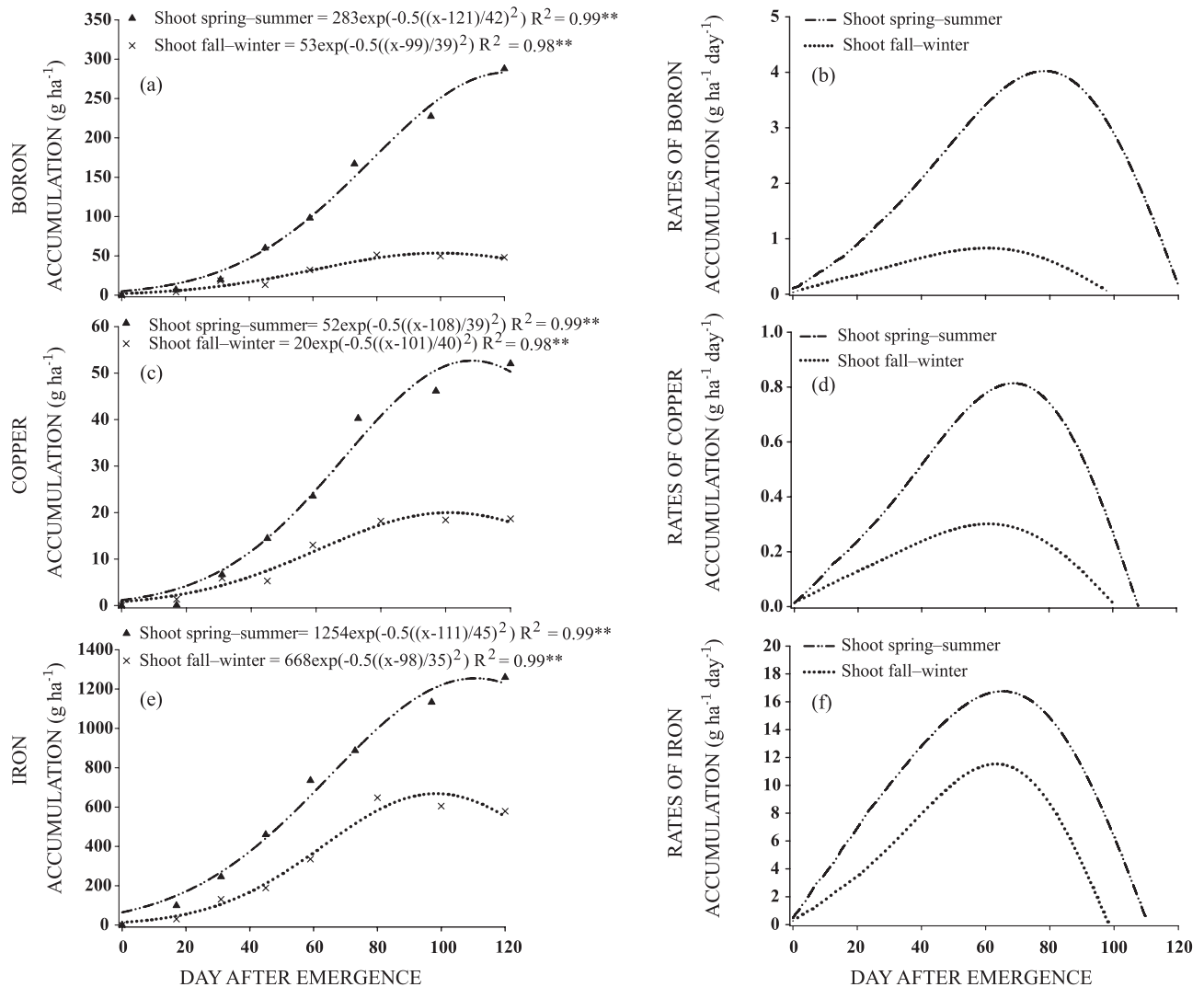


Figure 5. Accumulation and accumulation rates of boron (a and b), copper (c and d) and iron (e and f) in shoot of the castor bean hybrid Lyra in the 2005/2006 spring-summer and 2006 fall-winter growing seasons. **: significant at $p \leq 0.01$ by the F test.

the shoot only until the end of the cycle (Figures 5 and 6). Mn was the micronutrient accumulated in the earliest stage during the cycle in both growing seasons, because until 83 DAE the plants had already absorbed the total amount required during the cycle. The maximum accumulation of the other micronutrients occurred between 90 and 110 DAE. In the final stage of the cycle, there was a reduction in the amounts of most micronutrients accumulated, due to leaf senescence.

Although hybrid Lyra absorbed micronutrients during the whole cycle or almost until the end of the cycle, a critical period was observed, when the plants need practically all types of available micronutrients in satisfactory amounts, i.e., between 40 and 80 DAE, when accumulation rates are highest (Figures 5 and

6). Thus, fertilization with micronutrients should adequately supply micronutrients during the critical stage of plant growth with maximum micronutrient uptake rates in this oilseed crop.

The amounts of micronutrients extracted by the plants during the spring-summer growing season had the following order: Fe>Mn>Zn>B>Cu>Mo, with average values of 1,260, 960, 420, 288, 52 and 3.28 g ha⁻¹, respectively (Figures 5 and 6). In fall-winter, the order of extraction was the same, but the amounts were smaller, i.e., 670 g ha⁻¹ Fe, 259 g ha⁻¹ Mn, 88 g ha⁻¹ Zn, 53 g ha⁻¹ B, 20 g ha⁻¹ Cu and 0.47 g ha⁻¹ Mo. The greatest Fe and Mn uptake reflect high accumulation rates, greater than those of the other micronutrients. In a study with castor bean plants grown in nutrient solution, Lange et al. (2005)

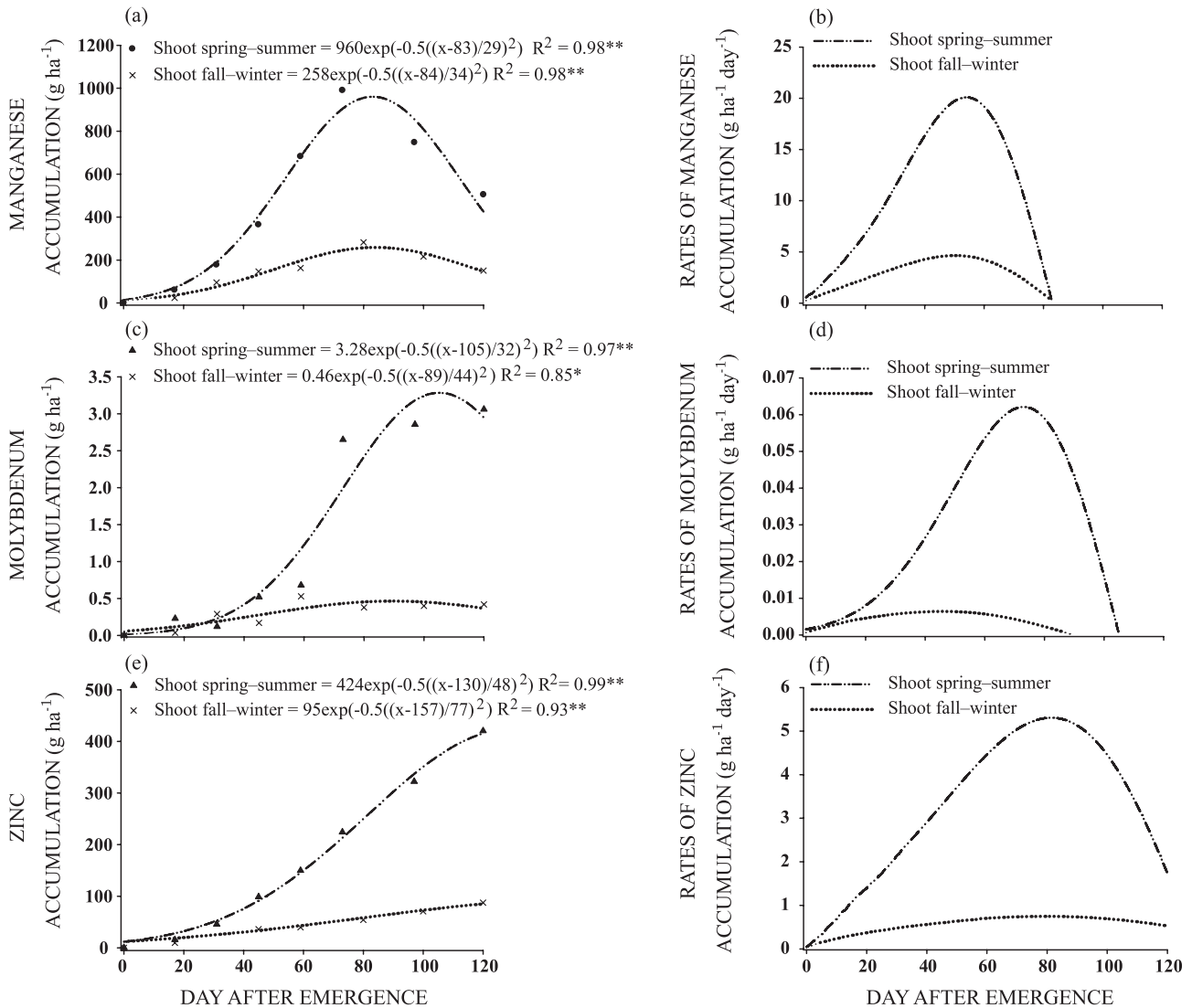


Figure 6. Accumulation and accumulation rates of manganese (a and b), molybdenum (c and d) and zinc (e and f) in shoot of the castor bean hybrid Lyra in the 2005/2006 spring-summer and 2006 fall-winter growing seasons. ** and * are: significant at $p \leq 0.01$ and $p \leq 0.05$ by the F test.

observed that the first signs of deficiency occurred in a treatment without Fe and Mn, indicating the greater demand for these micronutrients. Although Zn and B are the third and fourth most absorbed micronutrients by castor bean, only Zn application induced yield increases (Souza & Natale, 1997).

Seed yield and nutrient exportation

The seed yield was found to be almost 2.5 times higher in the spring-summer than the fall-winter growing season, due to the greater rainfall intensity and distribution (Table 1 and Figure 1). The reduced water availability in the soil in the fall-winter impaired the normal plant growth (Figure 2), and since castor bean flowering is sympodial, and a raceme grows from each branch (Savy Filho, 2005),

seed yield decreased significantly, compared to the spring-summer growing season (Table 1). Severino et al. (2006) and Silva et al. (2010) obtained a castor bean yield above 2,000 kg ha⁻¹ when sown in February, but water availability was probably satisfactory and ensured a proper crop development.

With regard to the nutrient content in seeds, it was found that although the amounts of most nutrients were higher in the fall-winter, the exported quantities were lower than in the spring-summer growing season, once the seed yield was higher in the spring-summer (Table 1).

Except for K, the nutrient amounts exported in the spring-summer were larger than estimated by Canecchio Filho & Freire (1958) and Nakagawa & Neptune (1971) for a seed yield of 2,000 kg ha⁻¹. In

Table 1. Seed yield, seed nutrient content, nutrient exportation per area, nutrient extraction and exportation per ton seed and relative nutrient exportation by castor bean hybrid Lyra in the 2005/2006 spring-summer and 2006 fall-winter growing seasons

Growing season	Seed yield	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Mo	Zn
	kg ha ⁻¹	Seed content (g kg ⁻¹)						Seed content (mg kg ⁻¹)					
2005/2006 spring-summer	2,995	34.7	4.8	7.4	4.7	3.8	5.7	52.8	7.6	200.0	63.3	0.13	55.4
2006 fall-winter	1,201	41.3	5.1	9.1	4.2	3.8	7.1	23.1	10.9	234.5	78.2	0.19	50.7
		Exportation per area (kg ha ⁻¹)						Exportation per area (g ha ⁻¹)					
2005/2006 spring-summer	2,995	104	14	22	14	11	17	158.0	23.0	599.0	190.0	0.39	166.0
2006 fall-winter	1,201	50	6	11	5	5	9	28.0	13.0	282.0	94.0	0.23	61.0
		Extraction (kg ton ⁻¹ seed) ⁽¹⁾						Extraction (g ton ⁻¹ seed) ⁽¹⁾					
2005/2006 spring-summer	2,995	60.0	7.0	26.0	25.7	11.7	10.4	96.0	17.4	421.0	321.0	1.10	140.2
2006 fall-winter	1,201	56.0	6.0	23.3	20.0	8.0	14.0	44.0	17.0	558.0	216.0	0.39	73.4
		Exportation (kg ton ⁻¹ seed)						Exportation (g ton ⁻¹ seed)					
2005/2006 spring-summer	2,995	34.7	4.7	7.4	4.7	3.7	5.7	53.0	7.5	200.0	63.3	0.13	55.4
2006 fall-winter	1,201	42.0	5.0	9.0	4.2	4.2	7.5	23.0	11.0	234.5	78.3	0.19	51.0
		Relative exportation (%) ⁽²⁾											
2005/2006 spring-summer	2,995	58	67	28	18	32	55	55	43	48	20	12	40
2006 fall-winter	1,201	75	84	39	21	53	53	52	65	42	36	49	69

⁽¹⁾Data based on seed yield and the values of maximum nutrient accumulation in the figures 3, 4, 5, and 6. ⁽²⁾Relative exportation in relation to maximum amounts absorbed, in the Figures 3, 4, 5, and 6.

both growing season, the order of exported amounts was: N > K > S > P > Ca > Mg > Fe > Mn > Zn > B > Cu > Mo, indicating that the macronutrients N and K and the micronutrients Fe, Mn and Zn are absorbed and exported in larger amounts by the castor bean hybrid Lyra (Figures 3, 4, 5, 6 and Table 1).

A high variation was observed between the values of nutrient extraction and exportation per area, in the growing seasons studies (Table 1). However, the variation between the growing seasons was lower for nutrient extraction and exportation per ton of seed produced, indicating that the amounts extracted and exported depended on the seed yield. Moreover, these findings are important for the fertilization management of this oilseed crop, allowing the estimation, based on the expected yield and the efficient nutrient use, of the amounts of fertilizers that should be applied in the cultivation of this oilseed crop.

It was found that most P and N absorbed during the cycle was exported with the seeds, and in the fall-winter the percentage of nutrients removed from the field in the seeds was higher (Table 1). The relative exportation of P was highest because this nutrient is usually accumulated in larger amounts in the

seeds than in the plant biomass (Haag et al., 1967). In fruits of castor bean grown in low-fertility sandy soils, it was found that 80 % of the P contained in the castor bean fruits was accumulated in the seeds (Hocking, 1982), confirming the evidence that castor bean seeds are a strong P sink.

Approximately half of the amounts of S and B absorbed in both growing seasons were exported at seed harvest (Table 1). Except for Zn and Mg in the fall-winter growing season, it was stated that for the other nutrients, the amount exported with the seeds was smaller than 50 % of the total absorbed, indicating that of the total nutrient amount accumulated in the plants during the cycle, a significant part returns to the soil in the plant residues, mitigating depletion.

Considering the dynamics of nutrient accumulation of hybrid Lyra, it can be seen that P should be fertilized at sowing, since P is essential for the formation of primary racemes and, consequently, for yield. Particularly in soils more prone to leaching, N and K topdressing should be fertilized at a later stage, or more frequently during the cycle, once the uptake rates are highest between 60 and 70 DAE. Attention should be paid to the amounts of N, K and S applied during the spring-summer

growing season when the absorbed were larger than the fertilized amounts, which may lead to soil depletion, depending on the frequency of cultivation of this hybrid in the field. Micronutrients should, whenever necessary, be fertilized so as to ensure a high availability for the plants, particularly from 40 to 80 DAE.

CONCLUSIONS

1. The growth of castor bean hybrid Lyra was slow and nutrient uptake lowest between emergence and the beginning of flowering. The period of highest DM accumulation rates and nutrient demand was between 40 and 80 DAE, in both growing seasons.

2. The order of nutrient extraction by hybrid Lyra plants in the spring-summer growing season was: N>K>Ca>Mg>S>P>Fe>Mn>Zn>B>Cu>Mo. In fall-winter, S was more absorbed than Mg.

3. Seed yield was higher in the spring-summer (2,995 kg ha⁻¹), but nutrient extraction and exportation per ton of seed were similar in both growing seasons.

4. Around 58 % of N and 84 % of P, and approximately half of the S and B absorbed throughout the cycle were exported with the seeds. However, most of the other nutrients accumulated in the plants returned to the soil in plant residues.

LITERATURE CITED

- ALMEIDA JÚNIOR, A.B.; OLIVEIRA, F.A.; MEDEIROS, J.F.; OLIVEIRA, M.K.T. & LINHARES, P.C.F. Efeito de doses de fósforo no desenvolvimento inicial da mamoneira. R. Caatinga, 22:217-221, 2009.
- CANECCHIO FILHO, V. & FREIRE, E.S. Adubação da mamoneira: Experiências preliminares. Bragantia, 17:243-259, 1958.
- CHAVES, L.H.G.; JÚNIOR, G.B.; LACERDA, R.D.; CABRAL, P.C. & CUNHA, T.H.C.S. Resposta da mamoneira adubada com zinco e cobre. Eng. Amb., 6:306-319, 2009.
- DANTAS JÚNIOR, E.E.; CHAVES, L.H.G.; COSTA, F.A.M.; MESQUITA, E.F. & ARAÚJO, D.L. Crescimento de duas cultivares de mamoneira adubadas com potássio, cobre e zinco. R. Caatinga, 23:97-107, 2010.
- HAAG, H.P.; MALAVOLTA, E.; GARGANTINI, H. & BLANCO, H.G. Absorção de nutrientes pela cultura do feijoeiro. Bragantia, 26:381-391, 1967.
- HIMELBLAU, E. & AMASINO, R.M. Nutrients mobilized from leaves of *Arabidopsis thaliana* during leaf senescence. J. Plant Physiol., 158:1317-1312, 2001.
- HOCKING, P.J. Accumulation and distribution of nutrients in fruits of castor bean (*Ricinus communis* L.). Ann. Bot., 49:51-62, 1982.
- LANGE, A.; MARTINES, A.M.; SILVA, M.A.C.; SORREANO, M.C.M.; CABRAL, C.P. & MALAVOLTA, E. Efeito de deficiência de micronutrientes no estado nutricional da mamoneira cultivar 'Iris'. Pesq. Agropec. Bras., 40:61-67, 2005.
- LAVRES JÚNIOR, J.; BOARETTO, R.M.; SILVA, M.L.S.; CORREIA, D.; CABRAL, C.P. & MALAVOLTA, E. Deficiências de macronutrientes no estado nutricional da mamoneira cultivar Íris. Pesq. Agropec. Bras., 40:145-151, 2005.
- LAVRES JÚNIOR, J.; NOGUEIRA, T.A.R.; CABRAL, C.P. & MALAVOLTA, E. Deficiências de macronutrientes no crescimento e na produção da mamoneira cultivar Íris. R. Bras. Ci. Agr., 4:405-413, 2009.
- LIMA, E.F. & BATISTA, F.A.S. Mamona (*Ricinus communis* L.). Controle de doenças. In: VALE, F.X.R. & ZAMBOLIM, L., eds. Controle de doenças de plantas: grandes culturas. Viçosa, MG, Universidade Federal de Viçosa, 1997. v.1. p.535-551.
- MALAVOLTA, E. Manual de nutrição mineral de plantas. São Paulo, Agronômica Ceres, 2006. 638p.
- MALAVOLTA, E.; VITTI, G.C. & OLIVEIRA, S.A. Avaliação do estado nutricional de plantas: Princípios e aplicações. Piracicaba, Potafós, 1997. 308p.
- MORO, E.; CRUSCIOL, C.A.C. & CARVALHO, L.L.T. Épocas de aplicação de nitrogênio para híbridos de mamona no sistema plantio direto em safrinha. Semina: Ci. Agr., 32: 391-410, 2011.
- MORO, E. Manejo da adubação nitrogenada em híbridos de mamona de porte baixo cultivados na safra e na safrinha em sistema plantio direto. Botucatu, Universidade Estadual Paulista, Faculdade de Ciências Agronômicas, 2008. 118p. (Tese de Mestrado)
- NAKAGAWA, J. & NEPTUNE, A.M.L. Marcha de absorção de nitrogênio, fósforo, potássio, cálcio e magnésio na cultura da mamoneira (*Ricinus communis* L.) cultivar Campinas. Anais ESALQ, 28:323-337, 1971.
- NAKAGAWA, J.; NEPTUNE, A.M.L. & MURAOKA, T. Absorção e translocação de fósforo em dois cultivares de mamoneira (*Ricinus communis* L.), "Campinas" e "Guarani". Anais ESALQ, 39:319-335, 1982.
- NAKAGAWA, J.; NEPTUNE, A.M.L.; VIEIRA, F.R. & BATALIA, O.C. Efeitos de doses de fósforo em mamoneira (*Ricinus communis* L.) cv. 'Campinas'. Anais ESALQ, 34:159-177, 1977.
- OLIVEIRA, J.P.M.; SCIVITTARO, W.B.; CASTILHOS, R.M.V. & OLIVEIRA FILHO, L.C.I. Adubação fosfatada para cultivares de mamoneira no Rio Grande do Sul. Ci. Rural, 40:1835-1839, 2010.
- RAIJ, B.van; ANDRADE, J.C.; CANTARELLA, H. & QUAGGIO, J.A. Análise química para avaliação da fertilidade de solos tropicais. Campinas, Instituto Agronômico de Campinas, 2001. 284p.
- SAVY FILHO, A. Mamona: Tecnologia agrícola. Campinas, Emopi, 2005. 105p.

- SAVY FILHO, A.; BANZATO, N.V.; BARBOZA, M.Z.; MIGUEL, A.M.R.O.; DAVI, L.O.C. & RIBEIRO, F.M. Mamona: In: COORDENADORIA DE ASSISTÊNCIA TÉCNICA INTEGRAL - CATI. Oleaginosas no estado de São Paulo: Análise e diagnóstico. Campinas, CATI, 1999. 39p. (Documento Técnico, 107)
- SEVERINO, L.S.; FERREIRA, G.B.; MORAES, C.R.A.; GONDIM, T.M.S.; FREIRE, W.S.A.; CASTRO, D.A.; CARDOSO, G.D. & BELTRÃO, N.E.M. ,Crescimento e produtividade da mamoneira adubada com macronutrientes e micronutrientes. Pesq. Agropec. Bras., 41:563-568, 2006.
- SILVA, A.G.; CRUSCIOL, C.A.C.; SORATTO, R.P.; COSTA, C.H.M. & FERRARI NETO, J. Produção de fitomassa e acúmulo de nutrientes por plantas de cobertura e cultivo da mamona em sucessão no sistema plantio direto. Ci. Rural, 40:2092-2098, 2010.
- SILVA, T.R.B.; LEITE, V.E.; SILVA, A.R.B.D.A. & VIANA, L.H. Adubação nitrogenada em cobertura na cultura da mamona em plantio direto. Pesq. Agropec. Bras., 42:1357-1359, 2007.
- SOUZA, S.R. & FERNANDES, M.S. Nitrogênio. In: FERNANDES, M.S., ed. Nutrição mineral de plantas. Viçosa MG, Sociedade Brasileira de Ciência do Solo, 2006. p.215-252.
- SOUZA, E.C.A. & NATALE, W. Efeito do boro e do zinco na cultura da mamoneira. Científica, 2:327-333, 1997.
- TAIZ, L. & ZEIGER, E. Fisiologia vegetal. 3.ed. Porto Alegre, Artmed, 2004. 719p.