Original Article

TOLERANCE OF PHYSIC NUT PLANTS TO ALUMINUM ACTIVITY IN NUTRIENT SOLUTION

TOLERÂNCIA DE PLANTAS DE PINHÃO-MANSO À ATIVIDADE DE ALUMÍNIO, EM SOLUÇÃO NUTRITIVA

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ABSTRACT: Plants have different levels of tolerance to phytotoxic effects of aluminum and the exploitation of this characteristic is of significant importance to the use of acid soils. This research aimed to evaluate the effect of aluminum activity in nutrient solution on growth of physic nut young plant. After seven days of adaptation, plants were submitted to Al concentrations of 0; 200; 400; 600; 800 and 1,000 μmol L^{-1}, corresponding to Al^{3+} activity solution, of: 14.5, 21.4; 46.6; 75.6; 108.3 e 144.8 μmol L^{-1}, respectively. The increased activity of Al^{3+} decreased linearly the number of leaves, plant height, leaf area, shoot dry matter and root length of physic nut plant. Physic nut young plants are sensitive to high aluminum activity in solution. The root length, number of leaves, shoot dry matter and total dry matter were variables more affected by Al activity in solution, and can be used to discriminate the tolerance levels to aluminum in physic nut plants. The accumulation of aluminum increased in a activity-dependent manner; however, its translocation from root to shoot was low.

KEYWORDS: *Jatropha curcas* L. Exchangeable acidity. Aluminum toxicity. Aluminum absorption.

INTRODUCTION

The physic nut (*Jatropha curcas* L.) is a perennial species, monoecious and belonging to the family Euphorbiaceae; the same as castor oil plant (HELLER, 1996). It is a fast growing shrub with deciduous habit that can reach up to 5 m high. Physic nut is distributed over the arid and semiarid areas of South America and in all tropical regions. In the last years, it has received special attention because its high seed oil content and quality. Therefore, physic nut is a crop with importance for biodiesel production, being considered potentially as a universally accepted source of energy (KUMAR; SHARMA, 2008). As interest in the plant as a biofuel source has increased, the demand for technical information on the crop is increasingly required.

Physic nut is considered a rustic crop that can grow under diverse soil and climate conditions and thrive in low-fertility soils (ARRUDA et al., 2004). However, to achieve high yield levels, plant requires rich soils and good physical condition (KUMAR; SHARMA, 2008). Thus, the acidity correction and soil fertility are critical for success and profitability in this culture (LAVIOLA; DIAS, 2008; SOUZA et al., 2011; BALOTA et al., 2012). This finding becomes even more relevant because the main producing regions of physic nut in Brazil are located in soils, characterized by low base saturation and high levels of Al^{3+}, sufficient to alter the normal growth of many species of cultivated plants.

Little is known about this plant tolerance to aluminum toxicity in soil so far. Arruda et al. (2004) report that in acid soils with pH below 4.5, roots of physic nut do not grow; being necessary the liming of soil. The aluminum (Al) toxicity is considered one of the main factors limiting plant growth in acid soils of tropical regions, mainly by causing root growth inhibition (GIANNAKOULA et al., 2008). Toxic levels of aluminum are present in 50% of areas with agricultural potential; in addition, the acidity in soil has worsened with the extensive use of ammonia fertilizer (ZHANG et al., 2007). Thus, knowledge and selection of tolerant species to aluminum is an alternative that offers possibility of success for deployment of these crops in these agricultural areas.

Several researches have been conducted using nutrient solution in order to determine perennial species' tolerance to Al. With regard to growth in the presence of aluminum, works performed with citrus (Santos et al., 1999), grapevine (TECCHIO et al., 2006), apple tree (DANTAS et al., 2001; STOLF et al., 2008), coffee (BRACCINI et al., 1998; MATTIELLO et al., 2008), mango (NAING et al., 2009) and physic nut (STEINER et al., 2012), showed that the results obtained in most cases, reveals the harmful effects of aluminum to the development of both shoot and root system of plants. These effects include

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reductions in dry matter mass, number and length of roots and root area, which often are associated with increases in the average radius and root volume (SIVAGURU et al., 1992). In the shoot, there was reduction in dry matter mass and plant height (DANTAS et al., 2001).

Researches with castor beans, a species belonging to the family Euphorbiaceae, reported high sensitivity of this species the presence of exchangeable Al in soil (LIMA et al., 2007). However, physic nut plants for these studies are still incipient and not conclusive. This research was developed aiming to evaluate the effect of aluminum activity in nutrient solution on growth of physic nut young plants.

MATERIAL AND METHODS

The experiment was carried out under greenhouse conditions, localized in the Universidade Estadual do Oeste do Paraná, in Marechal Cândido Rondon, Paraná, Brazil (24º31' S, 54º01' W, altitude: 420 m), where the environmental conditions were: minimum and maximum air temperatures of 22 and 36 ºC, respectively; mean air relative humidity ranged from 45–80%. Physic nut seeds, collected directly from the treetop of a plant population in Eldorado, Mato Grosso do Sul, Brazil, were placed for germinating in plastic trays (42 × 28 × 6 cm) containing washed sand and were daily irrigated with distillate water. Eight days after germination, the seedlings were withdrawn of sand and selected for homogeneity of root system length and shoot height. The seedlings presented with 150 ± 10 mm mean height and 60 ± 5 mm primary root length.

The seedlings were transferred to plastic pots (1.5 L) containing nutrient solution of Hoagland & Arnon (1950) modified with the following concentrations: macronutrients (mmol L^{-1}) NO_3 = 7.5; $H_2PO_4^-$ = 0.5; K = 3.0; Ca = 2.5; Mg = 1.0 and SO_4 = 1.0 and micronutrients (µmol L^{-1}): B = 23.0; Cu = 0.16; Fe-EDTA = 44.8; Mn = 6.3; Zn = 0.65 e Mo = 0.05. After seven days of adaptation, plants were submitted to Al concentrations of 0; 200; 400; 600; 800 and 1,000 µmol L^{-1}, corresponding to Al^{3+} activity solution, estimated by the software Visual MINTEQ 3.0 (GUSTAFSSON, 2011) of: 14.5, 21.4; 46.6; 75.6; 108.3 e 144.8 µmol L^{-1}, respectively. Aluminum was added in form of $AlCl_3.6H_2O$. The solution's pH (4.15 ± 0.05) was daily monitored and adjusted when necessary using 0.5 mol L^{-1} NaOH or 0.5 mol L^{-1} HCl solutions.

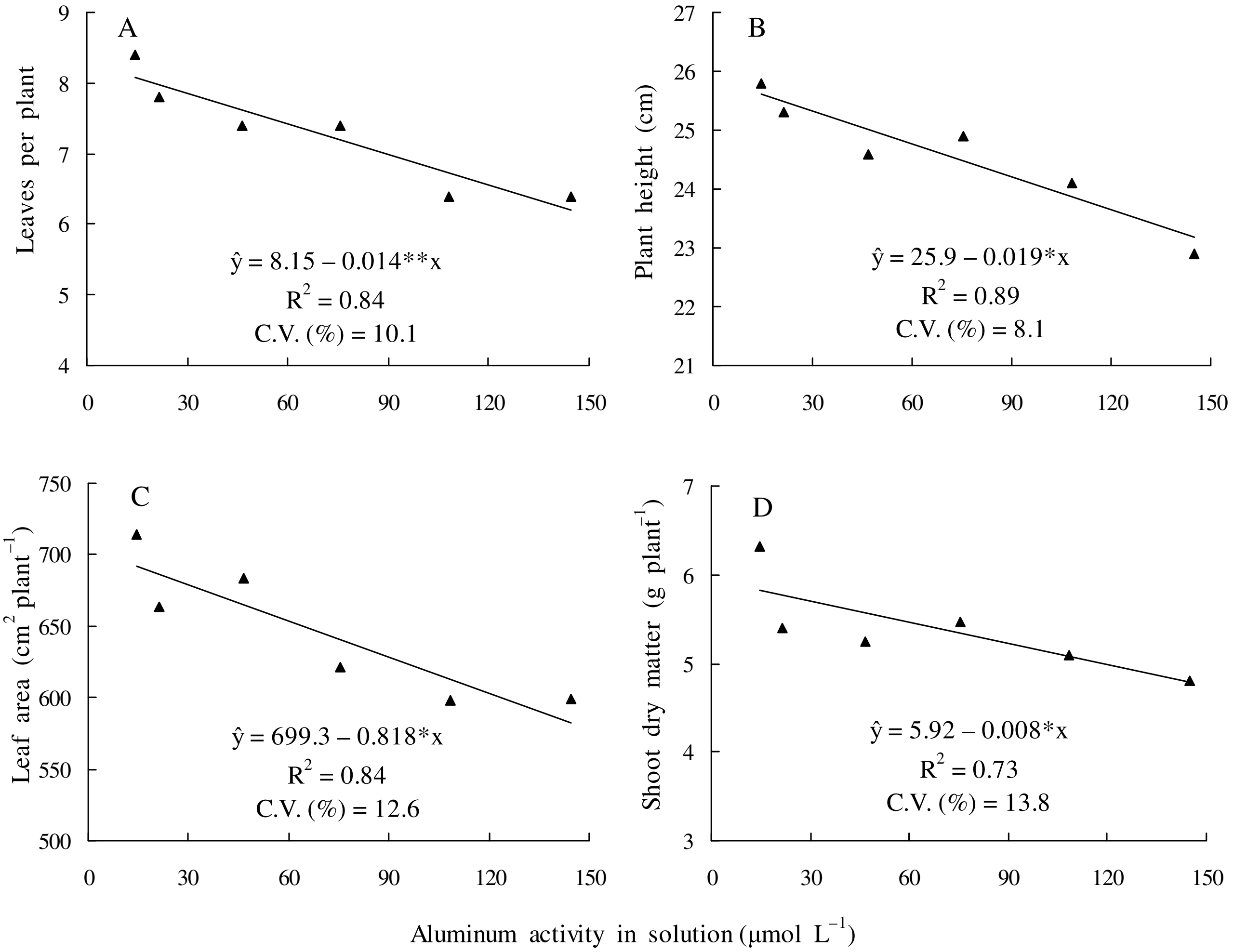
After 32 days of exposure to Al toxicity, the crop yield was evaluated in terms of dry matter production of shoots (SDM, g $plant^{-1}$) and roots (RDM, g $plant^{-1}$). Plants of all treatments were harvested separately, dried for four days at 65 ± 2 ºC, and then weighed. The leaf area (LA, cm^2 $plant^{-1}$) was determined using the following equation proposed by Severino et al. (2007): $LA = 0.84 (L \times W)^{0.99}$, where L and W are leaf length and width, respectively. The root lengths (mean of three longest roots in a plant) were measured (centimeter plant) for every Al treatment. Root volume (RV, cm^3 $plant^{-1}$) was determined by water displacement using a calibrated cylinder. The number of leaves per plant and plant height were also measured. The plant material from shoot and root were ground, digested in nitric-perchloric acid and the Al concentration was determined by spectrophotometry with eriochrome cyanine R as described by Miyazawa et al. (1999).

The study of relative importance of growth characteristics evaluated through the eight variables studied was expressed in decrease percentage caused by Al regarding to control plants without Al, according to the following equation: growth reduction (%) = [(growth without Al – growth with Al)/growth without Al] × 100.

The experiment was arranged in a completely randomized design with four replicates (an individual pot containing one plant represented one replicate). Data were submitted to analysis of variance (ANOVA); regression analysis was carried out by F test ($p < 0.05$) for variables that presented significant differences among treatments. The significant equations with the greatest determination coefficients were adjusted.

RESULTS AND DISCUSSION

The plant shoot growth of physic nut was negatively affected by Al activity in nutrient solution (Figure 1). It was verified linear decrease for all variables evaluated, with decreases of 14 leaf units (Figure 1a), 19 cm in height (Figure 1b), 818 cm^2 in leaf area and 8 g of shoot dry matter per plant for each increment of 1 mol L^{-1} of Al activity in nutrient solution, respectively. A number of studies have reported inhibited plant growth under Al toxicity (MATTIELLO et al., 2008; STOLF et al., 2008; NAING et al., 2009; STEINER et al., 2012). Similarly, in the present study, a sharp decrease in the leaf area, and growth of plants was noted, which is in agreement with the decrease in plant leaf area and root length reported in various other studies (LIMA et al., 2007). On the basis of these results, our findings suggested that an elevated Al activity in solution can inhibit the normal growth and development of physic nut young plants. However, it must be emphasized that in neither of Al activity used were verified symptoms of toxicity by Al in leaves that usually resemble to phosphorus deficiency (MALAVOLTA et al., 1997) as verified for coffee (BRACCINI et al., 1998) and apple tree (DANTAS et al., 2001).



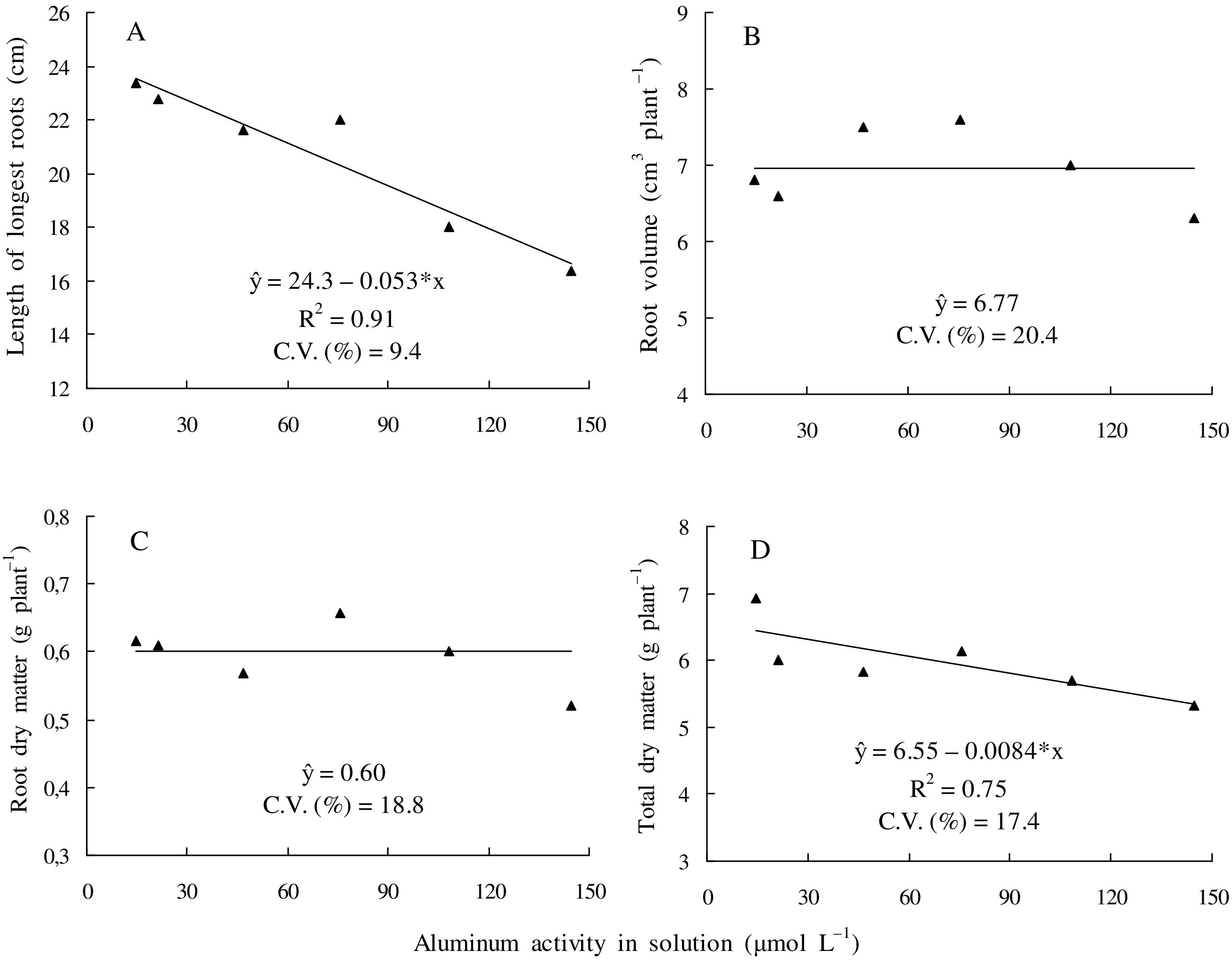
*, **: significant at 5 and 1 %, respectively, by F test (n = 5).

Figure 1. Number of leaves (A), plant height (B), leaf area (C) and shoot dry matter (D) of physic nut young plants as affected by aluminum activity in nutrient solution.

In roots, symptoms of toxicity were quite evident manifesting through thickening and yellowing of root tips. Roots of control plants were long and clearer-color. Symptoms of Al toxicity in physic nut visually observed in this study agree with those reported by Braccini et al. (1998) in coffee.

Roots' growth was negatively affected by Al activity, reducing linearly with Al increase (Figure 2a). However, Al activity used did not affect the root volume and dry matter of root (Figure 2b and 2c, respectively). Macedo et al. (2011) found that the root length and fresh matter of physic nut plants were reduced in 25 and 38%, respectively, when exposed for seven days, the concentration of 220 µmol L^{-1} of Al in nutrient solution.

According to Epstein e Bloom (2006), nutritional factors often influence growth and morphology of particular organs of plants in specific ways. As the roots are organs in closer contact with nutritional environment of plant, they are especially prone to be affected by this environment. Behavior also observed in the present study. Aluminum effects in roots are well documented in literature and the reduction of root growth rate of sensible species has been considered the main effect of Al toxic influencing in elongation and cell division (FERREIRA et al., 2006). According to Samac e Tesfaye (2003), the primary site of Al toxic action is the distal part of transition zone in root tip, where cells are entering in elongation phase. The inhibition of root growth is the faster visible symptom of Al toxicity in plants.



*, **: significant at 5 and 1 %, respectively, by F test (n = 5).

Figure 2. Length of longest roots (A), root volume (B), root dry matter (C) and total dry matter (D) of physic nut young plants as affected by aluminum activity in nutrient solution.

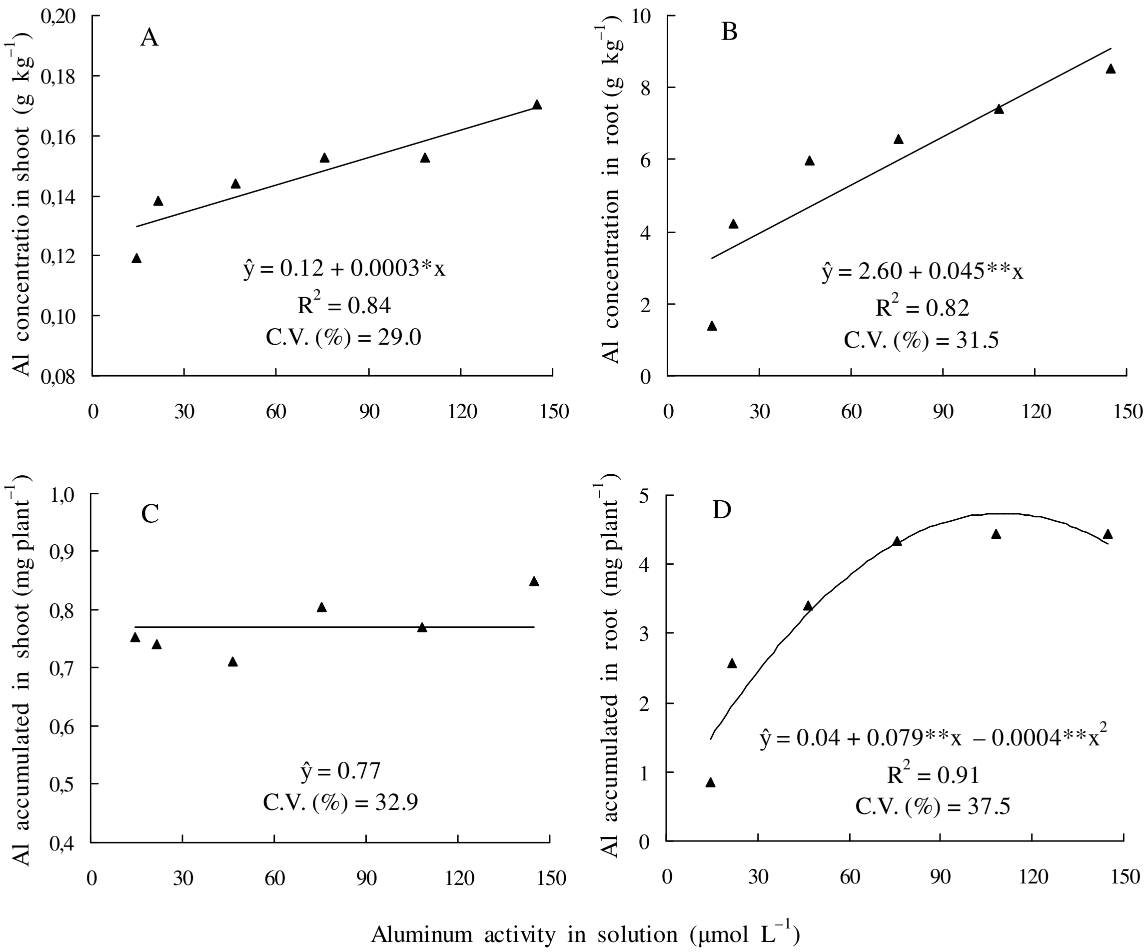
The damage in root structure formation, thickening and permeability decrease of root cells, contributes to accentuate the deleterious effects of Al in root system (BARCELÓ; POSCHENRIEDER, 2002; ILLÉS et al., 2006). Baligar et al. (1993) consider the root growth inhibition as a major Al effect, becoming it short and thick. This feature, incidentally, serves as a best indicator when evaluating the Al tolerance level in nutrient solution for species.

The decrease or increase percentage the effect of Al activity in regarding the control is shown in Table 1. The root length, number of leaves, shoot dry matter and total dry matter were variables more affected by Al activity in solution (Table 1), and can be used to discriminate the Al levels tolerance in physic nut plants. The main effect of Al toxicity in the plant shoots is the shortening of internodes, resulting in plants of smaller height (DANTAS et al., 2001). In physic nut young plants was verified that plant height was the less affected shoot variable, with 11.2% decrease compared to plant height in presence of 14.5 and 144.8 μmol L^{-1} Al activity in nutrient solution (Table 1). For the shoot dry matter, number leaves and leaf area such decrease was about 23.9; 23.8 and 16.1%, respectively, if compared to plant in presence of 14.5 and 144.8 μmol L^{-1} Al activity.

Table 1. Percentages of reduction or increase the effect of aluminum activity in nutrient solution on number of leaves (NL), plant height (PH), leaf area (LA), shoot dry matter (SDM), root length (RL), root volume (RV), root dry matter (RDM), and total dry matter (TDM)

Aluminum activity	NL	PH	LA	SDM	RL	RV	RDM	TDM
μmol L^{-1} of Al^{3+}	%							
21.4	–11.9	–1.9	–6.2	–14.5	–2.6	–8.3	–1.0	–13.3
46.6	–11.9	–4.6	–8.0	–16.9	–7.7	–2.8	–7.7	–16.1
75.6	–9.5	–3.5	–12.9	–14.9	–6.0	0.0	+6.7	–13.0
108.3	–23.8	–6.6	–16.3	–19.5	–23.1	–8.3	–2.5	–18.0
144.8	–23.8	–11.2	–16.1	–23.9	–29.9	–16.7	–15.6	–23.2

The increase of Al activity in nutrient solution provided linear increase in Al concentration, both in shoot and root of physic nut plants, with maximum activity (144.8 μmol L^{-1}) concentrations about 0.16 g kg^{-1} of Al in shoot (Figure 3a) and of 9.12 g kg^{-1} of Al in root (Figure 3b). Concerning the Al accumulation in shoot of physic nut plants were not affected ($p > 0.05$) by Al activity in nutrient solution, with average values about 0.77 mg $plant^{-1}$ (Figure 3c). The aluminum accumulation in root was adjusted to a quadratic model (Figure 3d), presenting maximum Al accumulation of 4.31 mg $plant^{-1}$ at 100 μmol L^{-1} Al activity. The Al accumulation value found in control plants, both in shoot and roots is due to the high levels of this element in physic nut plants before experiment deployment which was 0.48 mg $plant^{-1}$ in shoot and 4.05 mg $plant^{-1}$ in root system.



*, **: significant at 5 and 1 %, respectively, by F test (n = 5).

Figure 3. Aluminum concentration in shoot (A) and root (B), aluminum accumulated in shoot (C) and root (C) of physic nut young plants as affected by of aluminum activity in nutrient solution.

The Al was preferably accumulated in the root of physic nut plants, being small the amount translocated to the shoot (Figure 3). Results also observed and documented in the literature by several authors (BARCELÓ; POSCHENRIEDER, 2002). This fact justified the remarkable effect of this ion on the root development as observed in this study. Aluminum complexation in the roots, preventing its transport to the shoots of the plant, can be an important factor for Al tolerance in plants, because the permanence of the ion in the root can prevent the deleterious effects of this metal in other organs.

CONCLUSIONS

Physic nut young plants are sensitive to high aluminum activity in solution.

The root length, number of leaves, shoot dry matter and total dry matter were variables more affected by Al activity in solution, and can be used to discriminate the tolerance levels to aluminum in physic nut plants.

Aluminum accumulates, preferentially, in root of physic nut plants, being small the amount translocated to the shoot.

RESUMO: As plantas apresentam diferentes níveis de tolerância aos efeitos fitotóxicos do alumínio e a exploração dessa característica torna-se de relevante importância para a utilização dos solos ácidos. Objetivou-se com este trabalho avaliar o efeito da atividade de alumínio, em solução nutritiva, no crescimento inicial de plantas de pinhão-manso (*Jatropha curcas* L). As plantas foram cultivadas em vasos com capacidade para 1,5 L, contendo solução nutritiva. Após sete dias de adaptação, as plantas foram submetidas a concentrações de Al de 0, 200, 400, 600, 800 e 1.000 μmol L^{-1}, que corresponderam a atividades de Al^{3+} em solução de: 14,5; 21,4; 46,6; 75,6; 108,3 e 144,8 μmol L^{-1}, respectivamente. O aumento da atividade de Al^{3+} reduziu o número de folhas por planta, altura da planta, área foliar, matéria seca da parte aérea e comprimento da raiz principal das plantas de pinhão-manso. Plantas de pinhão-manso são sensíveis a elevada atividade de Al em solução. O comprimento da raiz, número de folhas e a produção de matéria seca da parte aérea e total foram as características mais afetadas pela atividade de Al em solução, e podem ser utilizadas para discriminar os níveis de tolerância ao alumínio em plantas de pinhão-manso. O acúmulo de alumínio aumentou de uma maneira dependente da atividade; no entanto, sua translocação das raízes para a parte aérea foi baixa.

PALAVRAS-CHAVE: *Jatropha curcas* L Acidez trocável. Toxicidade de alumínio. Absorção de alumínio.

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