(DOI): 10.5935/PAeT.V6.N3.02
This article is presented in English with abstracts in Spanish and Portuguese
Brazilian Journal of Applied Technology for Agricultural Science, Guarapuava-PR, v.6, n.3, p.17-25, 2013

Cientific Paper

Development and productivity of american lettuce (*Lactuca sativa* L.) Influenced by aluminum free in the soil

Clovis Pierozan Junior[1]
Paulo Sérgio Pavinato[2]
Marcelo Bridi[3]
Robson Kyoshi Ueno[4]
Bruno Vinícius Banhuk[5]

Abstract

The present study, was performed in Guarapuava, Paraná, with the objective of evaluating the development and productivity of lettuce plants (*Lactuca sativa* L.) cultivar Americana in soil with different Al^{3+} saturation, grown in greenhouse. The height of plants, main root length, circumference head, fresh matter of leaves and roots, dry matter of leaves and roots were evaluated, during the cycle of crop and at the harvest. In the harvest also was analyzed the number of leaves per plant. The used experiment design was completely randomized with four repetitions. The saturations of Al^{3+} used were 0, 20, 40 and 60%. The root system of the lettuce Americana is very susceptible to the toxic effects of aluminum, tolerating on maximum 6.0% of saturation so it does not present damage length loss and/or mass accumulation. The production of the aerial part of the Americana lettuce showed negative linear answer to the increase of saturation for Al^{+3}, not being tolerant to the presence of the free form of this element in the soil.

Keywords: Dry mass; fresh mass; saturation for Al^{3+}.

Desenvolvimento e produtividade de alface americana (*Lactuca sativa* L.) Influenciados por alumínio livre no solo

Resumo

O presente estudo foi realizado em Guarapuava, Paraná, com objetivo de avaliar o desenvolvimento e a produtividade de plantas de alface (*Lactuca sativa* L.) cultivar Americana em solo com diferentes saturações de Al^{3+}, cultivada em ambiente protegido. Foram avaliadas a altura de plantas, comprimento da raiz principal, circunferência da cabeça, massa fresca de folhas e de raiz, massa seca de folhas e de raiz, durante o ciclo da cultura e na colheita. Na colheita também foi analisado o número de folhas por planta. O delineamento experimental utilizado foi inteiramente casualizado com quatro repetições. As saturações de Al^{3+} utilizadas foram 0, 20, 40 e 60%. O sistema radicular da alface Americana é muito suscetível aos efeitos tóxicos do alumínio, tolerando no máximo 6,0% de saturação para que não apresente perda de comprimento e/ou acúmulo de massa. A produção da parte aérea da alface Americana mostrou resposta linear negativa ao aumento da saturação por Al^{+3}, não sendo tolerante à presença deste elemento na forma livre no solo.

Palavras-chave: Massa seca; massa fresca; saturação por Al^{3+}.

Desarrollo y productividad de la lechuga americana (*Lactuca sativa* L.) Influenciado por aluminio libre en el suelo

Resumen

Este estudio se realizó en Guarapuava, Paraná, para evaluar el crecimiento y rendimiento de las plantas de lechuga (*Lactuca sativa* L.) cultivar americana el suelo con diferentes saturaciones de Al^{3+}, cultivada en invernadero. Se evaluó la altura de las plantas, longitud de la raíz principal, el perímetro de la cabeza, masa fresca de hojas y de la raíz, masa seca de hojas

Received at: 03/03/2013 Accepted for publication at: 28/10/2013

1 MSc. in Agronomy by the Universidade Estadual do Centro-Oeste – UNICENTRO, Post graduate student by the ESALQ/USP. Avenida Pádua Dias., 11 Piracicaba, SP. CEP 13418-900 cp.9. Agriculture Pavilion. E-mail: clovispjunior@usp.br.

2 Doctor in Agronomy/Agriculture, Associate Professor, Department of Soil Science. ESALQ/USP. E-mail: pavinatto@usp.br.

3 MSc. in Agronomy, Universidade Estadual do Centro-Oeste – UNICENTRO. E-mail: bridi@unicentro.br

4 MSc. in Agronomy by the, Universidade Estadual do Centro-Oeste – UNICENTRO, Post graduation student in Animal Science by Universidade Federal do Rio Grande do Sui. E-mail: rkeno@ufrgs.br.

5 Environmental Sct. Faculdades Guarapuava. E-mail: banhuk@hotmail.com.

y raíces, durante el ciclo del cultivo y en la cosecha. En la cosecha también se analizó el número de hojas por planta. El diseño experimental fue completamente al azar con cuatro repeticiones. Las saturaciones de Al^{3+} utilizadas fueron 0, 20, 40 y 60 %. El sistema radicular de la lechuga americana es muy susceptible a los efectos tóxicos del aluminio, tolerando al máximo 6,0 % de saturación para que no presente una pérdida de longitud y / o acumulación de masa. La producción de la parte aérea de la lechuga americana mostró respuesta lineal negativa al aumento de la saturación por Al^{3+}, no siendo tolerante a la presencia de este elemento en forma libre en el suelo.

Palabras clave: masa seca; masa fresca; saturación por Al^{3+}.

Introduction

The lettuce (*Lactuca sativa* L.) is crop originally from Asia, belonging to the Asteraceae family, being the most consumed leafy vegetable in the world (KRAUSE-SAKATE, 2002) and in Brazil (SUTTON et al., 2006). The same can be cultivated during the whole year and in different regions of the country. (EMBRAPA, 2010).

The lettuce has as characteristics a short cycle and great quantity of leaves, and for this, it demands soils of sandy clayey texture, with elevated content of organic matter and nutrients, which need to be readily available, as well as a good supply of water in the soil (FILGUEIRA, 1982). According to RICCI et al. (1994), the lettuce crop is very demanding on the soil chemical characteristics, being that the fertilization constitutes in the most expensive management and which best corresponds in terms of yield and final quality of the product. In Brazil, the acid soils predominate, which present aluminum (Al) contents in toxic levels to the plants, and low contents of exchangeable magnesium and calcium, unfavorable characteristics to the development of most crops (NOLLA et al., 2007). The acid soils are found mainly in the regions of the Cerrado and in the South, occupying about 204 million hectares of the national territory (EMBRAPA, 1999).

The absorption and the accumulation of AL by the plant affect the cells and organelles in morphological, cytogenetic and physiological level, considerably hindering the establishment, development and final yield of the crop (CRESTANI et al., 2009). The initial and more pronounced symptom of aluminum toxicity is the inhibition of the cellular expansion of the roots (DELHAIZE and RYAN, 1995). This inhibition causes the reduction and thickening of the root system (NOLLA et al., 2007). Therefore, the most visible direct effect of the aluminum presence in the soil is the reduction of root growth of the plants, inducing to a possible water stress and nutritional deficiencies on the plants (DEGENHARDT et al., 1998).

Under these aspects, the current study has as objective to assess the effect of different Al^{3+} saturation on the soil, in the development of roots and aerial part of the lettuce, Americana variety.

Material and Methods

The experiment was conducted in greenhouse, in an experimental farm of the Universidade Estadual do Centro-Oeste – UNICENTRO, campus CEDETEG, Guarapuava-PR. It were tested three Al^{3+} saturations on the soil (m%= 20; 40; 60) besides of the control, where the soil did not present contents of Al^{3+} (m%=0). The used experimental design was entirely randomized, with four repetitions.

The used soil was homogenized to ensure uniformity, being then collected a sample and sent for chemical analysis of macronutrients (Table 1). The pH in $CaCl_2$ was relatively low, however, it was not performed any correction of the same to maintain the existing solubility of the Al^{3+} with the pH at this level. According to the analysis, the soil presented adequate contents of K^+ and Mg^{2+}, thus, it was not made correction for these nutrients, only fertilization of management. The soil presented deficiency of Ca^{2+} and of P, the first was not correct due to the effect of alkalinization of the soil which the liming would provoke, and of the neutralizer effect of Al^{3+} if the use of phosphogypsum was made.

The P was correct with Triple Super Phosphate (TSP) until it achieved a content of 10 mg dm^{-3} of soil. The soil was put in a cement mixer for obtainment of a good mixture of the soil with TSP, and with the treatments with Al^{3+} which were simultaneously applied. The used source of Al^{3+} was aluminum chloride hexahydrate with 11% of Al^{3+}, such source was the same used by PORTALUPPI et al. (2010) in hydroponic cultivation. In his experiment was verified that there is direct relation of the hydroponic cultivation with aluminum chloride hexahydrate and cultivation in the field with elevated natural content

Table 1. Chemical analysis of the soil before the application of the treatments with saturation by Al^{+3}.

pH	M.O.	P	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H^++Al^{3+}	SB
$CaCl_2$	gdm^{-3}	mehlich $mgdm^{-3}$	--------------------------- $cmol_c dm^{-3}$ ---------------------------					
5.0	44.3	2.6	0.44	2.1	2.1	0.0	5.09	4.64
CTC	**Bases**	**Al^{3+}**	**Ca^{2+}**		**Mg^{2+}**		**K^+**	
pH 7.0	**V%**	**m%**	--------------------%----------------------					
9.73	47.7	0.0	21.5		21.7		4.5	

of Al^{3+}. It were calculated the doses to elevate the saturation by Al^{3+} (m %) to 20, 40 and 60% of the effective CTC of the soil.

The experimental unities were constituted of black plastic pots, with capacity of 14 dm^{-3}. Initially, the seeds of the cultivar of lettuce Americana Repolhuda were sowed in substrate for vegetables, in styrofoam trays of 128 cells. Eight days after the emergence of the plants, three seedlings were transplanted to the pots containing 12 dm^3 of soil with the previously applied treatments, being that each pot corresponded to a repetition. At the moment of the transplantation, the lettuce seedlings measured in average 7 cm of height. The fertilization of management was made a week after the seedlings transplantation, using 90 kg ha^{-1} of P_2O_5, 70 kg ha^{-1} of K_2O and 100 kg ha^{-1} of N.

It were assessed the plants height at the 7 and 19 days after the transplantation (DAT), the length of the main root at 19 and 70 DAT, head circumference at 51 and 70 DAT, fresh mass (FM) of the leaves, dry mass of the leaves (DM) at the 19, 49 and 70 DAT, FM and DM of the root at 19 and 70 DAT and the number of leaves per head at 70 DAT, being this moment when was done the harvest. In each destructive analysis (main root length, FM, DM and number of leaves) was used one of the plants of the pot, being left over only one for the moment of harvest.

The results were submitted to statistical analysis by the Sisvar® program, and when verified significant difference between the treatments ($p<0.05$). the results were submitted to regression analysis.

Results and Discussion

In all morphological assessments the analyzed characteristics presented significant differences between the treatments. The length of the main root was assessed twice, one at the beginning of the cycle (19 DAT), and one at the harvest (70 DAT), due to the fact that the plants were sowed in a single pot, making impossible an assessment of the roots in the middle of the cycle, due to the possibility of damaging other plants. For this characteristic was verified a smaller elongation of the main root according to increase of saturation by Al^{+3} (Figure 1).

At 70 DAT, the quadratic adjustment of the curve suggests that the lettuce does not tolerate saturation by Al^{+3}, because the growth of the crop root system is negatively affected with the increase of free aluminum on the soil. In the assessment done at 19 DAT, the average values for the main root length were of 5.25; 5.5; 4.5 and 4.5 cm for the treatments 0%, 20%, 40% and 60% of saturation of Al^{3+}, thus showing that, although little, there was expressive effect of the saturation by Al^{3+} in the initial development of the roots. STROBEL (1999), explains that the plants have a mechanism of tolerance to the Al^{3+} off the root, through a reaction of complexation with exudated organic acids, which are excreted by the plants root system, due to the biotic stress caused by exposition to the element. This liberated quantity of exudates would be proportional to the concentration of aluminum on the soil solution, and this root exudation would be greater in the beginning of the plants growth, explaining the plants behavior in this study.

In a study done by SILVA et al. (2007), where the author measured the resumption of the root growth in different oat cultivars submitted to aluminum concentrations in nutritive solution, the author concluded that the genotypes present different behavior between themselves, however in all of them was verified root system reduction at greater concentrations of the element.

The plants height, evaluated in the initial period of the crop cycle, showed negative linear correlation with increase of aluminum saturation on the soil for the both performed assessments (Figure 2).

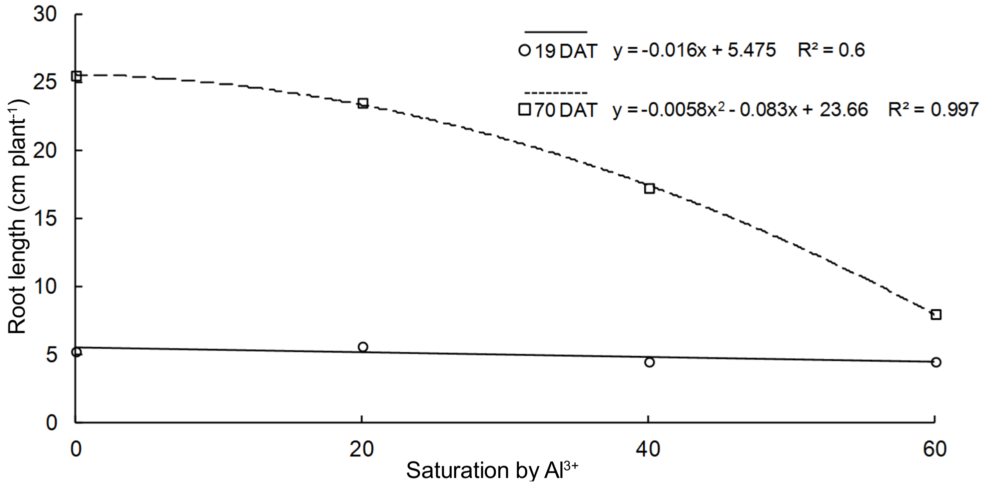

Figure 1. Length of main root of the lettuce at 19 and 70 DAT, under different saturation by Al^{3+} in the soil.

Between the assessments, the plants presented height increase in relation to the first assessment, except for the saturation at 60% in which the plants presented a small reduction of height, caused by the fact of the tissues in the leaf tips were rotting. SOUZA et al. (2000), evaluating the height of two maize hybrids in several phenological stages in soils with and without aluminum presence, verified a smaller plant height in all assessed stages of both hybrids on the soils where the Al^{3+} had not been corrected.

It was done two assessments of head circumference, being that, both at 49 DAT as at the harvest (70 DAT) there was negative correlation between circumference and saturation by Al^{3+} on the soil (Figure 3), which means that, in the saturation of 20% of Al^{3+} there was expressive reduction in the head circumference. At the harvest, even when using the quadratic adjustment, the point of maximum efficiency is found in the saturation of 0%, being that, there was an average reduction around 12% between the saturation 0% and 20%, showing that for this characteristic, the presence of Al^{3+} in the soil is harmful to the plants, getting worst in saturations superior to 20%.

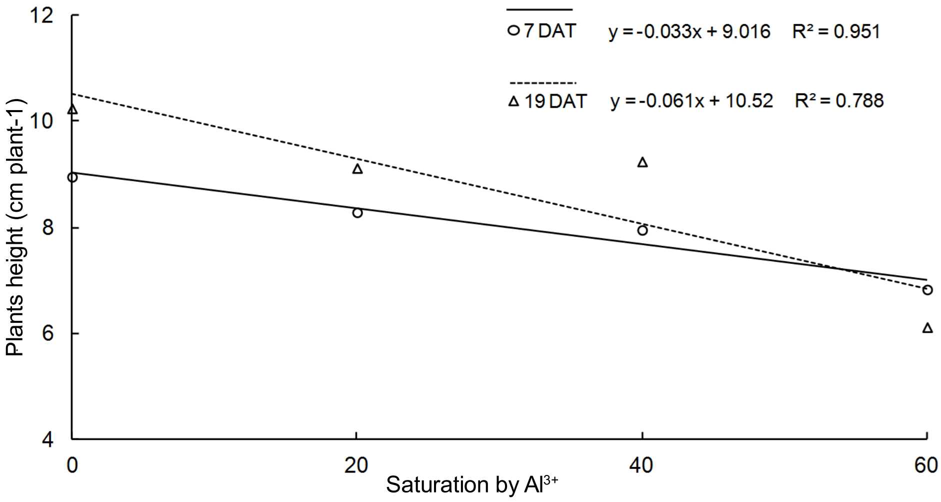

Figure 2. Height of the Americana lettuce plants at 7 and 19 DAT, cultivated under different saturations by Al^{3+} in the soil.

In an experiment done by MOTA et al. (2001) with potassium in americana lettuce, the authors discovered that smaller doses can be more efficient in relation to greater head circumferences, and that higher doses appear to be less efficient even in relation to the control, this result, according to the authors, is due to the fact of higher doses proportionate a nutritional imbalance, in which the excess of potassium impaired the absorption of other elements, such as calcium and magnesium, resulting in a smaller plants development. LANA et al. (2004), in an experiment done with sources of phosphorus, obtained the greatest results for lettuce diameter with the sources which provided a greater concentration of phosphorus in the leaves and in the soil. With this in sight, it is noted that an adequate balance of nutrients on the soil contributes for a greater root growth, capable of absorbing more nutrients, causing a higher growth of the aerial part. Following this, the high presence of free Al^{3+} interferes in the availability of other cationic nutrients, such as K, Ca and Mg, exerting deleterious effect on the plants grown in this soil.

The number of leaves per head (Figure 4) also decreases according to the increase of Al^{3+} saturation on the soil. The quadratic adjustment was the model specified, however, according to the equation, the greater number of leaves is found in the saturation 0%, meaning that the presence of toxic aluminum on the soil contributes for the reduction of number of leaves per plant. In the saturations of 20%, 40% and 60% the reduction of the number of leaves is respectively 9%, 35% and 71% in relation to the saturation 0%, indicating a sharper drop from the saturation of 20%, which explains the quadratic adjustment.

In the same manner as the other factors, the FM and DM of the root (Figures 5a and 5b), in the two performed analysis, decreased with the increase of Al^{3+} concentration in the soil, having the quadratic model as adjustment of the tendency curve. Both characteristics present a similar curve, whereas at 70 DAT the FM of the lettuce roots presented tolerance up to 6.0% of Al^{3+} saturation in the soil, from this moment it started to lose production of FM. Now for the DM of the roots, the tolerance to Al^{3+} saturation was up to 29%, reducing the production with greater saturation. This behavior of the DM of roots is similar to the one of main root length (Figure 1). This means that in the saturations close to 0%, the roots present greater proportion of earliest tissues, in relation to greater saturations, which allows a greater elongation of roots, greater quantity of early tissues, favoring the absorption of water and nutrients. It is also noted that for the root length, the tolerance to Al^{3+} was smaller than for the accumulation of DM, suggesting that there was root thickening with the increase of saturation. PEREIRA et al. (2003), in an

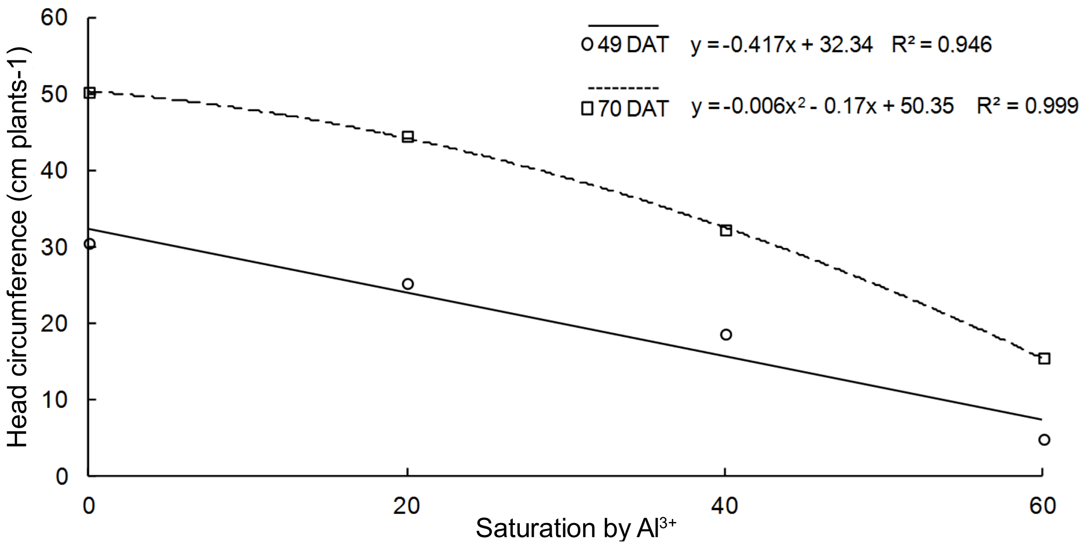

Figure 3. Head circumference of the Americana lettuce at 49 and 70 DAT, cultivated under different saturations by Al^{3+} on the soil.

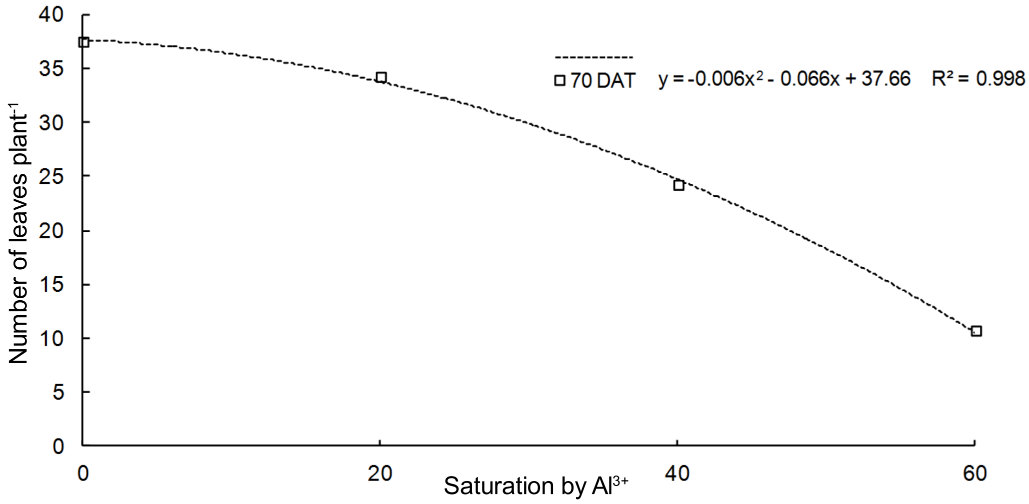

Figure 4. Number of leaves per americana lettuce head at 70 DAT, cultivated under different saturations by Al^{3+} on the soil.

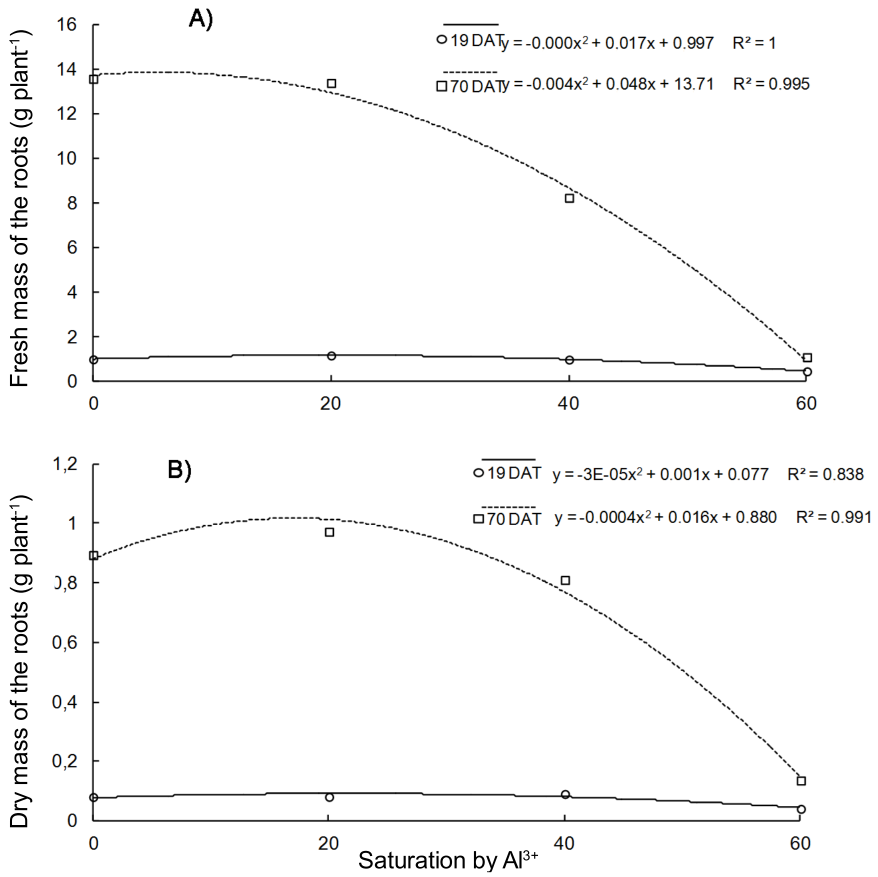

Figure 5. Fresh mass (a) and dry mass (b) of the root of Americana lettuce at 19 and 70 DAT, cultivated under different saturations by Al^{3+} in the soil.

experiment done with rootstocks of citrus, observed that in concentrations of aluminum in solution of up to 50 µmol L^{-1}, there was an increase in the DM of roots in relation to the control, however in the other studied concentrations (100, 200 and 400 µmol L^{-1}) there was DM decrease, agreeing with the data of DM of the roots of this study.

In the figure 6 (a and b) are represented respectively the FM and DM of the aerial part of the Americana lettuce. It is evident that both factors are disadvantaged by the increase of Al^{3+} saturation in the soil, because the linear adjustment of the tendency curve points to a greater production in the saturations of 0%, especially if it concerns the DM of the leaves, a fact which probably is caused by the greater FM of the roots in the lowest saturations, thus favoring the root absorption of water, as already reported.

The linear curves indicating the drop of DM and FM in the leaves (Figures 6a and 6b, respectively), and quadratic of the drop of DM and FM in the roots (Figures 5a and 5b, respectively), according to PEREIRA et al. (2003), are due to the fact that, in conditions of stress, the plants tend to translocate great quantities of photoassimilates to the roots, in detriment to the aerial part. MARSCHNER et al. (1996), in an experiment performed with partitioning of photoassimilates root/aerial part, report that the deficiency of nutrients can result in a greater translocation of photoassimilates of the leaves sources for disabled bodies.

The harmful effect of aluminum on the crops is not new information, because there is several

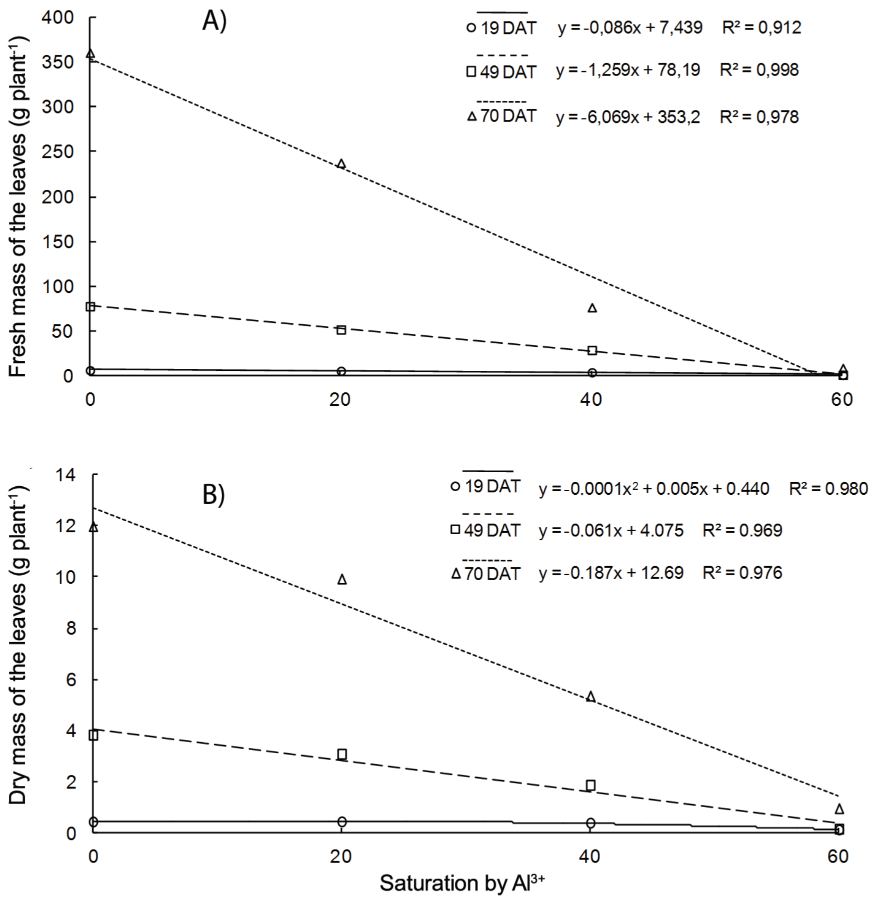

Figure 6. Fresh mass (a) and dry mass (b) of the aerial part of the Americana lettuce at 19, 49 and 70 DAT, cultivated under different saturations by Al^{3+} in the soil.

information of literature mentioning the loss in the plants development with the presence of this toxic element. According to CAMARGO (1984), the negative influence of aluminum depends on the pH and the toxicity of certain concentration of this element decreases with the pH elevation, when close to 7.0, decreasing consequently the solubility of this element. However, this study was of great importance to be aware of the tolerance of lettuce to this element, being a crop little adapted to environments of low fertility.

Conclusions

The root system of the Americana lettuce is very susceptible to the toxic effects of aluminum, tolerating in the maximum 6.0% of saturation so it does not present loss of length and/or accumulation of mass.

The production of the aerial part of the Americana lettuce showed negative linear response to the increase of saturation by Al^{+3}, not being tolerant to presence of this element in the free form in the soil.

References

CAMARGO, C.E. O pH das Soluções Nutritivas no Comportamento de Cultivares de Trigo à Toxicidade de Alumínio. **Bragantia**, v.43, n.2, p.327-335, 1984.

CRESTANI, M.; CARVALHO, F.I.; OLIVEIRA, A.C.; SILVA, J.A.G. DA; SOUZA, V.Q. DE; PARACHU, E.A.M; SILVEIRA, G. DA; RIBEIRO, G.; LUCHE, H.S. Aluminum stress in black oat cultivars under hydroponic conditions. **Bragantia**, v.68, n.3, p.639–649, 2009.

DEGENHARDT, J.; LARSEN, P.B.; HOWELL, S.H. Aluminum resistance in the *Arabidopsis* mutant *alr*-104 is caused by an aluminum-induced increase in rhizosphere pH. **Plant Physiology**, v.117, n.1, p.19-27, 1998.

DELHAIZE, E.; RYAN, P.R. Aluminum toxicity and tolerance in plants. **Plant Physiology**, v.107, n.2, p.315–322, 1995.

EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária. **Sistema brasileiro de classificação de solos**. Brasília: EMBRAPA-CNPS, 1999, 412p.

EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária. **Alface**. Embrapa Hortaliças. Disponível em: <http://www.cnph.embrapa.br/paginas/dicas_ao_consumidor/alface.htm> Acesso em: 10 de junho de 2011.

FILGUEIRA, F. A. R. **Manual de Olericultura**: Cultura e Comercialização de Hortaliças. São Paulo: Agronômica Ceres, 2 ed, 1982. 357p.

KRAUSE-SAKATE, R.; LE GALL, O.; FAKHFAKH, H.; PEYPELUT, M.; MARRAKCHI, M.; VARVERI, C.; PAVAN, M.A.; SOUCHE, S.; LOT, H.; ZERBINI, F.M.; CANDRESSE, T. Molecular characterization of Lettuce mosaic virus field isolates reveals a distinct and widespread type of resistance breaking isolate: LMV-Most. **Phytopathology**, v.92, n.5, p.563-572, 2002.

LANA, R.M.Q.; ZANÃO JÚNIOR, L.A.; LUZ, J.M.Q.; SILVA, J.C. Produção da alface em função do uso de diferentes fontes de fósforo em solo de Cerrado. **Horticultura Brasileira**, v.22, n.3, p.525-528, 2004.

MARSCHNER, H.; KIRBBY, E.A.; CAKMAK, I. Effect of mineral nutritional status on shoot-root partitioning of photoassimilates and cycling of mineral nutrients. **Journal of Experimental Botany,** v.47, Special Issue, p.1255-1263, 1996.

MOTA, J.H.; ERNANI, R.J. de S.;SILVA, C. da; CARVALHO, J. G. de; YURI, J.E. Efeito do cloreto de potássio via fertirrigação na produção de alface-americana em cultivo protegido. **Ciência agrotecnológica**, Lavras, v.25, n.3, p.542-549, 2001.

NOLLA, A.; SCHLINDWEIN, J.A.; ANGHINONI, I. Crescimento, morfologia radicular e liberação de compostos orgânicos por plântulas de soja em função da atividade de alumínio na solução do solo de campo natural. **Ciência Rural**, v.37, n.1, 2007.

PEREIRA, W.E.; de SIQUEIRA, D.L.; PUIATTI, M.; MARTÍNEZ, C.A.; SALOMÃO, L.C.C.; CECON, P.R. Growth of citrus rootstocks under aluminium stress in hydroponics. **Scientia Agricola**, v.60, n.1, p.31-41, 2003.

PORTALUPPI, R.; BRAMMER, S.P.; de MAGALHÃES, J.V.; da COSTA, C.T.; CAIERÃO, E.; do NASCIMENTO JUNIOR, A.; SILVA JUNIOR, J.P. Tolerância de genótipos de cereais de inverno ao alumínio em cultivo hidropônico e em campo. **Pesquisa aAgropecuária Brasileira**, v.45, n.1, p.178-185, 2010.

RICCI, M.S.F.; CASALI, D.W.V.; CARDOSO, A.A.; RUIZ, H.A. Produção de alfaces adubadas com composto orgânico. **Revista de Horticultura Brasileira**, v.12, n.1, p.56-58, 1994.

SILVA, J.A.G. da; de CARVALHO, F.I.F.; COIMBRA, J.L.M.; VIEIRA, E.A.; BENIN, G.; de OLIVEIRA, A.C.; FINATTO, T.; BERTAN, I.; da SILVA, G.O.; CORREA, M.R. Tolerância ao alumínio em cultivares de aveia branca sob cultivo hidropônico. **Bragantia**, v.66, n.4, p.587-593, 2007.

SOUZA, J.R.P.; GUIMARÃES, M.F.; MÜLLER, M.M.L.; SANTOS, C.H. Morphological alterations of corn (Zea mays L.) plants in response to aluminium toxicity in the soil. **Arquivos de Biologia e Tecnologia**, Curitiba, 2000. n.pag.

STROBEL, B.J; BERNHOFT, I.; BORGGAARD, O.K. Low molecular weight aliphatic acids in soil solution under different vegetations determined by capillary zone electrophoresis. **Plant and Soil**, v.212, p.115-121, 1999.

SUTTON J. C.; LIU, W.; MA, J.; BROWN, W.G.; STEWART, J.F.; WALKER, G.D. Evaluation of the fungal endophyte Clonostachys rosea as an inoculant to enhance growth, fitness and productivity of crop plants. **Acta Horticulturae**, v.782, p.279-286, 2006.