ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
v.23, n.11, p.860-868, 2019
Campina Grande, PB, UAEA/UFCG – http://www.agriambi.com.br

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v23n11p860-868

Rooting of sweet potato seedlings submitted to supplemental calcium and phosphorus nutrition on substrate

Everton T. M. Ichikawa[1], Adalton M. Fernandes[2] & Lydia Helena da S. de O. Mota[1,3]

[1] Universidade Estadual Paulista/Faculdade de Ciências Agronômicas. Botucatu, SP, Brasil. E-mail: teruo-kun_ichikawa@hotmail.com - ORCID: 0000-0001-8664-8526
[2] Universidade Estadual Paulista/Centro de Raízes e Amidos Tropicais. Botucatu, SP, Brasil. E-mail: adalton.fernandes@unesp.br (Corresponding author) - ORCID: 0000-0002-6745-0175
[3] Instituto Federal de Educação, Ciência e Tecnologia do Acre. Cruzeiro do Sul, AC, Brasil. E-mail: lydia.mota@ifac.edu.br - ORCID: 0000-0003-4172-9204

ABSTRACT: The objective of this study was to evaluate the rooting and growth of sweet potato seedlings in trays in response to substrate supplementation with calcium (Ca) and phosphorus (P). Two greenhouse experiments were conducted in a randomized block design with a split plot scheme and eight repetitions. In the Ca experiment, the plots were the doses of 0, 100 and 200 mg kg^{-1} of Ca, and in the P experiment, by the doses of 0, 150 and 300 mg kg^{-1} of P. In both experiments, the subplots corresponded to the sampling time of seedlings (15, 30, 45, 60 and 75 days after planting). The Ca present in the substrate was sufficient to promote the proper rooting and growth of sweet potato seedlings in the trays. The Ca supply in excess (200 mg kg^{-1}) adversely affected the growth of seedlings that remained in the tray for more than 60 days. Although the seedlings supplied with P showed higher root growth rate after 45 days, the initial P available in the substrate was sufficient to promote the adequate growth of the seedlings in the trays until 60 days.

Key words: *Ipomoea batatas*, herbaceous cutting, clod integrity, root growing, permanence time in tray

Enraizamento de mudas de batata-doce submetidas a nutrição suplementar com cálcio e fósforo no substrato

RESUMO: O objetivo deste estudo foi avaliar o enraizamento e crescimento de mudas de batata-doce em bandejas em reposta à suplementação do substrato com cálcio (Ca) e fósforo (P). Foram conduzidos dois experimentos em casa de vegetação no delineamento de blocos casualizados em esquema de parcelas subdivididas com oito repetições. No experimento com Ca as parcelas foram as doses de 0, 100 e 200 mg kg^{-1} de Ca e no experimento com P as doses de 0, 150 e 300 mg kg^{-1} de P. Em ambos experimentos as subparcelas corresponderam às épocas de amostragem das mudas (15, 30, 45, 60 e 75 dias após o plantio). O Ca presente no substrato foi suficiente para promover o adequado enraizamento e crescimento das mudas de batata-doce nas bandejas. O fornecimento de Ca em excesso (200 mg kg^{-1}) afetou negativamente o crescimento de mudas que permanecem na bandeja por mais de 60 dias. Apesar das mudas adubadas com P apresentarem maior taxa de crescimento radicular após os 45 dias, o P inicialmente disponível no substrato foi suficiente para promover o crescimento adequado das mudas nas bandejas até os 60 dias.

Palavras-chave: *Ipomoea batatas*, estaca herbácea, integridade de torrão, crescimento radicular, tempo de permanência em bandeja

Ref. 209157 – Received 24 Jul, 2018 • Accepted 25 Sept, 2019 • Published 30 Sept, 2019

Introduction

The production of sweet potato (*Ipomoea batatas* (L.) Lam.) seedlings from mini cuttings in trays in a controlled environment is a viable technique (Rós et al., 2011) that allows a greater production of seedlings when there is a shortage of stems (Rós-Golla et al., 2010), facilitates the control of pests and diseases, and provides greater uniformity in the field (Reghin et al., 2007; Rós-Golla et al., 2010).

In the mini cutting system, the seedlings have better sanity (Montes, 2012) which results in greater yields in the field (Rós et al., 2012; Montes et al., 2015). However, as the nutritional status of seedlings plays an important role in the phases of induction and root formation (Cunha et al., 2009), crop nutritional management in this phase is very important. In this production system, it is necessary to provide supplemental fertilization of the substrate (Rós et al., 2011; 2013) because depending on the period of the seedlings' permanence in the greenhouse, the substrate cannot supply the nutritional needs of the seedlings (Rós et al., 2011; 2013) and the supplemental fertilization can reduce the permanence time of seedlings in the greenhouse (Rós et al., 2013). In other situations in which the seedlings need to stay for a longer period in the trays, the supplemental fertilization of the seedlings is also essential for the maintenance of their quality.

Thus, as the quality of the seedlings is indispensable to a greater percentage of their survival in the field and a greater crop yield (Camargo et al., 2011), it is necessary to use nutritional management that favors crop rooting. Supplemental fertilization of the substrate with the nutrients calcium (Ca) and phosphorus (P) may be an alternative for improving the rooting of sweet potato seedlings in the greenhouse, since several studies have demonstrated the effects of these nutrients on the root growth of crops (O'Sullivan et al., 1997; Caires et al., 2001; Sánchez-Calderon et al., 2005; Silva et al., 2011; Fernandes et al., 2014). However, the suitable amounts of Ca and P that should be applied to the substrate to increase the rooting and quality of sweet potato seedlings are not yet known. Thus, the objective of this study was to evaluate the rooting and growth of sweet potato seedlings in trays in response to substrate supplementation with Ca and P.

Material and Methods

Two independent experiments, one with Ca and another with P supplementation, were conducted using the cultivar Ligeirinha in polystyrene trays in the greenhouse of the Center of Tropical Roots and Starches (CERAT) in Botucatu, SP, Brazil. In both experiments, experimental design of randomized blocks was used in a split-plot scheme, with eight repetitions. In the Ca experiment, the plots were the doses of 0, 100 and 200 mg kg^{-1} Ca applied to the substrate and the subplots by the sampling time of seedlings (15, 30, 45, 60 and 75 days after planting - DAP). In the P experiment, the plots were the doses of 0, 150 and 300 mg kg^{-1} P applied to the substrate and the subplots by the sampling time of seedlings (15, 30, 45, 60 and 75 DAP). Each plot was constituted by a polystyrene tray of 72 cells (12 rows of 6 cells) and each subplot by four plants (4 cells) collected in the central part of the plot. The adjacent plants, which were considered boundary plants, were not sampled in the following times.

Sweet potato mini cuttings with two nodes were collected from the apical portion of the stem (until 0.6 m) of plants cultivated in the field, from which the leaves were removed without damaging the buds. Then, the mini cuttings were selected for sanity and uniformity (size and weight), immersed in carbendazim solution (5 mL L^{-1}) for 10 min and planted in the trays with substrate. The experiments were installed with commercial substrate Plantmax®, which had 46% moisture. The substrate was previously dried in an oven with forced-air circulation at 45 °C and the chemical characteristics of the dry substrate were obtained: pH ($CaCl_2$) = 5.7; P (resin) = 594 mg kg^{-1}; K^+ = 13.5 $mmol_c$ kg^{-1}; Ca^{2+} = 6.8 $mmol_c$ kg^{-1}; Mg^{2+} = 6.5 $mmol_c$ kg^{-1}; H+Al = 7.74 $mmol_c$ kg^{-1}; CTC = 34 $mmol_c$ kg^{-1}; and base saturation = 78%. For the treatments at the installation of each experiment, the proper amounts of Ca and P were weighed and added to the dry substrate. Calcium chloride ($CaCl_2$) and a dilute stock solution of orthophosphoric acid (H_3PO_4) were used as sources of Ca and P, respectively. The substrate of all treatments in both experiments also received supplemental fertilization with 1.0 g kg^{-1} N (urea) and 0.5 g kg^{-1} K_2O (potassium chloride).

The nutrients were mixed with the dried substrate inside the plastic bag to promote the adequate blend. Subsequently, the substrate was placed in the 72 cell polystyrene trays according to the treatments of each experiment. A single mini cutting was placed in each cell by burying the basal bud in the substrate. Samples of mini cuttings were also collected, weighed (fresh matter), dried in an oven with forced-air circulation at 65 °C, and weighed for determination of initial amounts of dry matter (DM) accumulated in the mini cutting. The initial mean weight of the mini cuttings was 2,374 and 270 mg of fresh matter and DM, respectively.

The trays were placed at a 0.90 m height and supported by a cast metal bench to allow natural root pruning. During the duration of the experiments, the substrate was maintained with moisture close to 80% of its maximum retention capacity. Each time seedling samples were collected, four seedlings were removed from useful areas of the subplots and submitted for the evaluations. The substrate clod stability was evaluated with the wet clods, the cohesion of the clod during the removal of the seedlings from the tray was considered, and the following notes were assigned: 1 = indicates that more than 50% of the clod was retained in the tray; 2 = indicates that the clod detached from the tray but did not remain cohesive; and 3 = indicates that the clod was detached from the tray and more than 90% of it remained cohesive. The number of roots and leaves per seedling were obtained by counting these structures in each seedling. To obtain the total number of roots per seedling, only those roots emitted directly from the mini cuttings were counted, i.e., without considering the ramifications of the root system. The number of leaves per seedling was obtained by counting all fully expanded leaves. The leaf/root ratio was obtained by dividing the leaf number by the root number. The root system of the seedlings was analyzed as the variable length, surface and mean diameter using WinRhizo software, which is based on the method proposed by Tennant (1975).

The root growth rate (cm of root seedling^{-1} d^{-1}) was calculated from the first derivative of the equations adjusted to root length results by a function of sampling time, while relative root growth rate (RRGR) was calculated considering the root length and sampling times according to Eq. 1:

$$RRGR\left(cm\ cm^{-1}\ d^{-1}\right) = \frac{\ln RL2 - \ln RL1}{t2 - t1} \quad (1)$$

where:

RL1 and RL2 - correspond to the root length at times t1 and t2, respectively.

After these evaluations, the root system, leaves and mini cuttings were dried in an oven with forced-air circulation at 65 °C for 96 h and weighed for the determination of accumulated dry matter (DM). The DM of the seedlings was calculated by the sum of the values obtained in all seedling parts. The rates of DM accumulated in roots and seedlings were calculated by using the first derivative of the respective equations adjusted.

The results of each experiment were submitted to ANOVA separately. The doses of Ca and P were compared by the LSD test ($p \leq 0.05$), while the effects of sampling times were submitted to regression analysis ($p \leq 0.05$).

Results and Discussion

Ca experiment

The variables substrate clod stability, root and leaf number per seedling and leaf/root ratio were influenced only by sampling time (Table 1) in the Ca experiment.

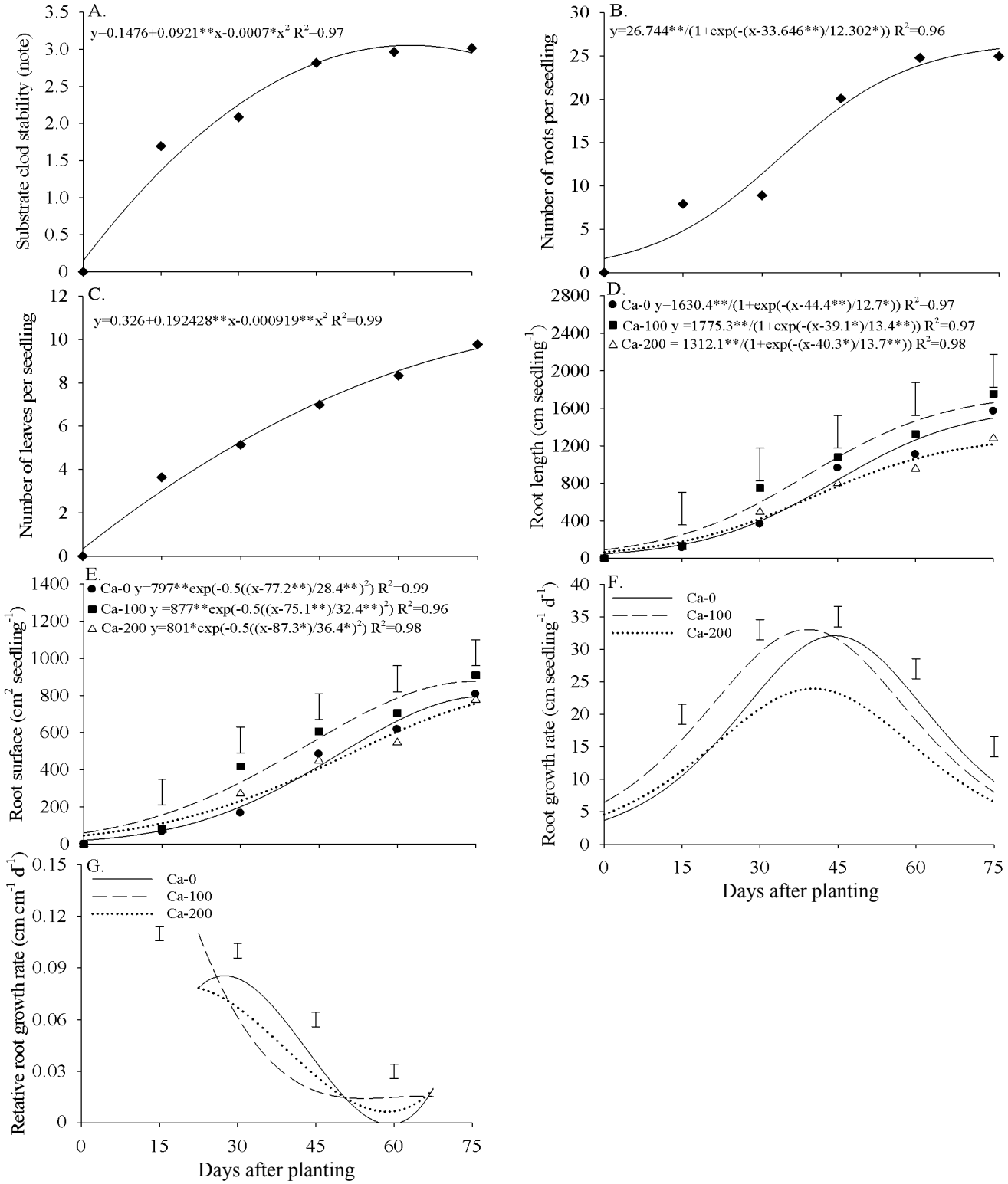
The fact that the supplemental Ca fertilization does not increase the substrate clod stability indicates that fertilization of the substrate cannot always decrease the permanence time of sweet potato seedlings in a greenhouse, as reported by Rós et al. (2013). In addition, these authors verified that the supplemental fertilization of the substrate with NPK fertilizer 19-06-10 did not increase the root number emitted by sweet potato seedlings; their results are similar to those obtained in the present study in which there was Ca supplementation to the substrate.

The substrate clod stability and the number of leaves and roots of the sweet potato seedlings increased until near the last permanence day of the seedlings in the trays (Figures 1A, B and C). After 45 days of seedlings' permanence in the trays, the increase in the substrate clod stability was small due to the lower emission of new roots. Rós et al. (2013) also verified that after the 42 days of seedling' permanence in the trays, sweet potato seedlings emitted few new roots, which is in agreement with the results of this study and shows that the emission of

Table 1. Plant variables of sweet potato seedlings grown in trays in response to supplementation of Ca and P during the growth period of the seedlings

Variables	Ca doses (mg kg^{-1})			ANOVA		
	0	100	200	Doses (D)	Time (T)	D x T
Substrate clod stability (note)	2.5 a	2.5 a	2.6 a	ns	<0.001	ns
Root number per seedling	16.7 a	18.1 a	17.19 a	ns	<0.001	ns
Leaf number per seedling	7.1 a	6.6 a	6.7 a	ns	<0.001	ns
Leaf/root ratio	0.5 a	0.4 a	0.4 a	ns	<0.001	ns
Root length (cm seedling^{-1})	824	1007	728	ns	<0.001	0.050
Root surface (cm^2 seedling^{-1})	428.5	544.2	423.8	0.023	<0.001	0.048
Root diameter (mm)	0.30 a	0.31 a	0.33 a	ns	ns	ns
Root growth rate (cm seedling^{-1} d^{-1})	25.8	29.4	18.9	<0.001	<0.001	<0.001
Relative root growth rate (cm cm^{-1} d^{-1})	0.043	0.043	0.039	ns	<0.001	<0.001
Root DM (mg seedling^{-1})	120.2 a	117.9 a	112.6 a	ns	<0.001	ns
Leaf DM (mg seedling^{-1})	433.5	435.3	389.7	0.047	<0.001	<0.001
Mini cutting DM (mg seedling^{-1})	464.7 a	461.2 a	464.9 a	ns	<0.001	ns
Whole seedling DM (mg seedling^{-1})	1018	1014	967	0.018	<0.001	0.002
Root DM accumulation rate (mg seedling^{-1} d^{-1})	3.2 a	3.3 a	3.0 a	ns	<0.001	ns
Seedling DM accumulation rate (mg seedling^{-1} d^{-1})	17.0	15.9	14.8	<0.001	<0.001	<0.001
	P doses (mg kg^{-1})			ANOVA		
	0	150	300	Doses (D)	Time (T)	D x T
Substrate clod stability (note)	2.6 a	2.6 a	2.7 a	ns	<0.001	ns
Root number per seedling	20.7 a	20.6 a	19.9 a	ns	<0.001	ns
Leaf number per seedling	6.3 a	6.9 a	6.7 a	ns	<0.001	ns
Leaf/root ratio	0.29 a	0.34 a	0.33 a	ns	0.003	ns
Root length (cm seedling^{-1})	864	1040	929	0.002	<0.001	<0.001
Root surface (cm^2 seedling^{-1})	80.7	98.8	87.0	0.006	<0.001	0.004
Root diameter (mm)	0.286 a	0.294 a	0.289 a	ns	ns	ns
Root growth rate (cm seedling^{-1} d^{-1})	18.2	28.6	27.7	<0.001	<0.001	<0.001
Relative root growth rate (cm cm^{-1} d^{-1})	0.021	0.021	0.026	<0.001	<0.001	<0.001
Root DM (mg seedling^{-1})	101.1	122.3	116.6	ns	<0.001	<0.001
Leaf DM (mg seedling^{-1})	359.5	418.9	419.0	ns	<0.001	0.002
Mini cutting DM (mg seedling^{-1})	452.9 a	444.7 a	445.3 a	ns	<0.001	ns
Whole seedling DM (mg seedling^{-1})	913.5	985.9	980.9	ns	<0.001	0.004
Root DM accumulation rate (mg seedling^{-1} d^{-1})	2.8	3.4	3.4	<0.001	<0.001	<0.001
Seedling DM accumulation rate (mg seedling^{-1} d^{-1})	13.9	17.9	17.5	<0.001	<0.001	<0.001

Means followed by the same letters in the rows are not significantly different at $p \leq 0.05$ according to LSD test; DM – Dry matter



Ca–0, Ca–100 and Ca–200 – doses of 0, 100 and 200 mg kg^{-1} of Ca; ♦ - average of the three Ca doses; Vertical bars represent the least significant difference at $p \leq 0.05$ by LSD test; * and ** - Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively, by F test

Figure 1. Substrate clod stability (A), number of roots (B), number of leaves (C), root length (D), root surface (E), root growth rate (F) and relative root growth rate (G) of sweet potato seedlings in response to time of permanence in the trays and Ca supplementation

new roots by sweet potato seedlings grown in trays is reduced after approximately 40-45 days.

Before 54 days, the substrate clod stability was lower than 3.0, but after that time, it reached the highest note (3.0) (Figure 1A), demonstrating that the longer the permanence time of the seedlings in the substrate, the greater retention of substrate as a function of the roots occupying a larger portion of the tray cells (Rós et al., 2011). The lower stability of the substrate clods before 54 days indicates that the clods are still not cohesive and that transplanting of the seedlings at this stage may decrease the coherency of the seedlings in the field. The leaf/root ratio increased up to 45 DAP and decreased in the following periods ($y = 0.1054 + 0.018*x-0.0002*x^2$ $R^2 = 0.56$), indicating that the sweet potato mini cuttings planted on the substrate have

a greater production of leaves in relation to the roots until 45 days, and after this time, the production of leaves is reduced in relation to the roots. Thus, only after 54 days the clods had a cohesive structure (Figure 1A).

The mean root diameter was not influenced by the factors studied and was, on average, 0.31 mm (Table 1). The root length, root surface, root growth rate and relative root growth rate were affected by the Ca × Sampling time interaction (Table 1). In the first 15 DAP, the root length and the root surface of the sweet potato seedlings had a small and similar increase between Ca doses, with root growth rates that did not exceed 17 cm seedling^{-1} d^{-1} (Figures 1D, E and F). After 15 DAP, the root growth in length and surface increased intensively, and the root growth rates reached maximum values between 38 and 42 DAP (Figures 1D, E and F). In the treatment with supplemental fertilization of 100 mg kg^{-1} Ca, the root growth rate was higher than in the other treatments among 15 and 34 days. Ca is a nutrient with a preponderant role in plant root growth (Ritchey et al., 1982; Domingues et al., 2016), as it is involved in the process of cell division, differentiation and elongation (Fioreze et al., 2013). Thus, adequate Ca availability in contact with the root system is fundamental for plant survival, since this nutrient does not translocate from the shoot to the root tip (Caires et al., 2001).

Until 60 DAP, the root length did not differ significantly between Ca doses, although the relative root growth rate during the initial seedling development was higher in the treatment with 100 mg kg^{-1} Ca (Figures 1D and G). In the last evaluation (75 DAP), the root length of the plants treated with 100 mg kg^{-1} Ca was significantly higher than that of plants treated with 200 mg kg^{-1} Ca, but these values did not differ from those of the control without Ca (Figure 1D). These results show that Ca supplementation to the substrate increases root growth rates in the early stages of seedling growth, but this effect does not last until the end of the seedling growth period (Figure 1F). In the final stage of seedling formation, the high Ca supply reduced the root growth rate of the seedlings, possibly due to the increase in salinity caused by the $CaCl_2$ application (Figure 1F). The Ca deficiency inhibits the root growth of sweet potato and can cause death of the root tip (O'Sullivan et al., 1997); this did not occur in the treatment without Ca, indicating that the Ca already present in the commercial substrate was sufficient to promote the adequate root development of sweet potato seedlings.

The amounts of dry matter (DM) accumulated in the roots and mini cuttings were influenced only by the sampling time, and a linear increase in the amounts of DM accumulated in these structures of the seedlings was observed throughout the period of their permanence in the trays (Table 1, Figures 2A and D). The root DM accumulation rate increased until 52 DAP and reduced after this period, demonstrating that the maximum root growth of sweet potato seedlings in trays in terms of length and weight occurs from 38 to 52 DAP (Figures 1G and 2B).

In the leaves and seedlings, the amounts of DM accumulated were affected by Ca × Sampling time interaction (Table 1), increasing over the growth period of the seedlings without significant differences between the treatments without Ca and with 100 mg kg^{-1} Ca (Figures 2C and E). However, only in the last sampling (75 DAP) did the treatments without Ca and with 100 mg kg^{-1} Ca accumulate more DM in those seedling parts than the treatment with a larger Ca dose. This suggests that the excessive Ca supply, in the form of $CaCl_2$, may increase the salinity of the substrate and may decrease both root and shoot growth of sweet potato seedlings per decreased root growth rates and DM accumulation rates in the seedlings, mainly after 40 DAP (Figures 1G and 2F). Rós et al. (2011; 2013), using the same commercial substrate but also a supplemental fertilizer with mixed fertilizer (NPK 19-09-12 or 19-06-10), verified that the amounts of DM accumulated in the leaves and roots of the sweet potato seedlings grown in trays up to 70 days always increased expressively with the increase in the fertilizer rates applied to the substrate.

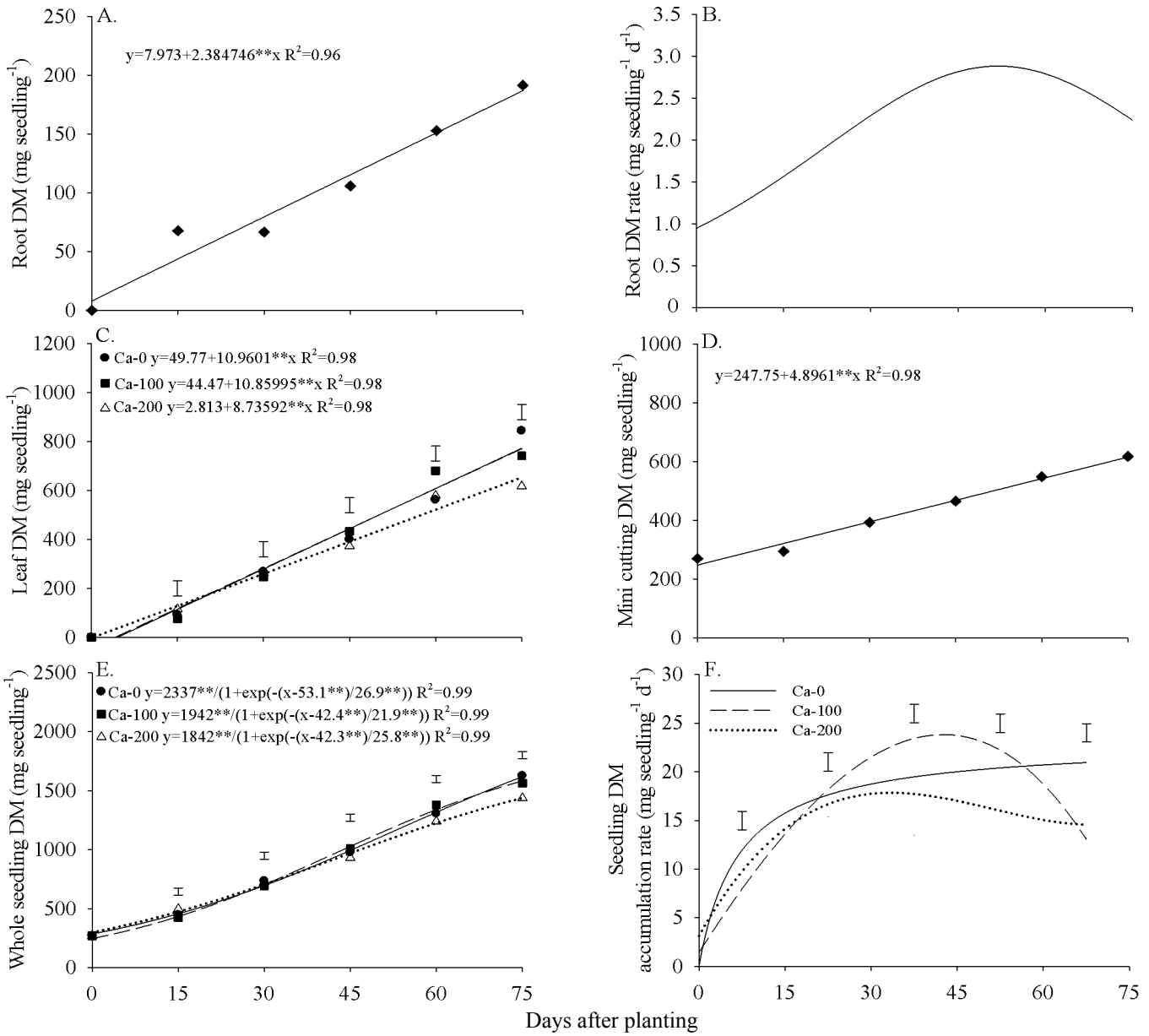
P experiment

Only the sampling time affected substrate clod stability, the number of roots and leaves per seedling, and the leaf/root ratio of the sweet potato seedling in the P experiment (Table 1). Although in this study the supplemental fertilization of the substrate with P did not alter the root number per seedlings, in other research, it was observed that fertilization of the commercial substrate with NPK fertilizer increased the root number formed by seedlings (Rós et al., 2011; 2013). These differences in the response to supplemental fertilization about seedling rooting probably are related to the initial fertility of the substrate and to the physiological stage of the stems used in the production of the mini-cuttings (stems harvested from young or older plants).

The substrate clod stability and the root number per seedlings increased up to 52 and 71 DAP, respectively (Figures 3A and B). Rós et al. (2013) also obtained increases in the root number of the sweet potato seedlings produced in trays up to 70 DAP, i.e., until a similar period to that observed in this study.

The increase in substrate clod stability up to 52 DAP indicates that transplanting the sweet potato seedlings to the field should be done by approximately 50 days, since after that period, the emission of new roots occurs in a smaller quantity and there is no improvement in the clod cohesion (Figures 3A and B). The number of leaves per seedling increased up to the last evaluation, indicating that there was a continuous increase in the emission of new leaves by the sweet potato seedlings throughout the permanence period in the trays (Figure 3C). In the present study, phosphate supplementation did not change the number of leaves per seedling, but in other studies, NPK fertilizer supplementation significantly increased the number of leaves of the seedlings (Rós et al., 2011; 2013).

The leaf/root ratio increased up to 58 DAP and reduced after this period, which indicates that during permanence in the trays, initially, the seedlings emitted a greater proportion of leaves than roots (Figure 3D). The mean root diameter of the sweet potato seedlings was not influenced by the factors studied and presented an average value of 0.289 mm (Table 1). However, root length, root surface, root growth rate and relative root growth rate were influenced by P doses, sampling times, and P doses × Sampling time interaction (Table 1).

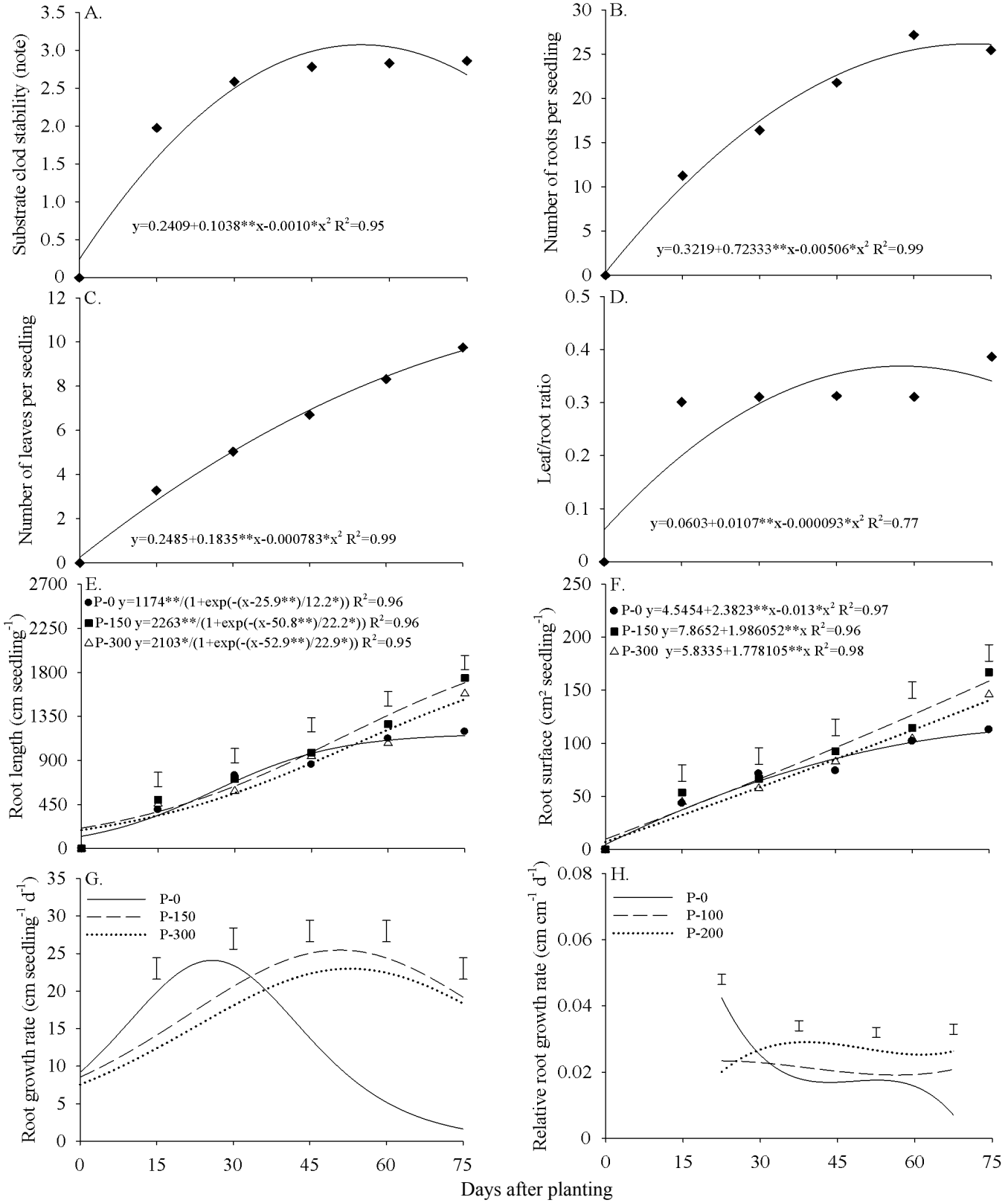


Ca–0, Ca–100 and Ca–200 – doses of 0, 100 and 200 mg kg^{-1} of Ca; ♦ - average of the three Ca doses; Vertical bars represent the least significant difference at $p \leq 0.05$ by LSD test. ** - Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively, by F test

Figure 2. Root dry matter (DM) accumulation (A), root DM accumulation rates (B), DM accumulation in leaves (C), mini cutting - DM (D), whole seedling - DM (E) and rates of DM accumulation in seedlings (F) of sweet potato in response to time of permanence in the trays and Ca supplementation

The root length and root surface in the two treatments with P supply increased similarly and did not differ until the last evaluation period (Figures 3E and F). However, the root growth rates increased up to 26 DAP in the control and among 51 and 53 DAP in the treatments with P supply to decrease in the following periods (Figure 3G). In the control, the root length and root surface increased up to 60 DAP without differing from the treatments with P supply, but in the last 15 days of seedling permanence in the tray, the root growth in the control treatment was lower due to a significant reduction in root growth rate and relative root growth rate during this period (Figures 3E, F, G and H). These results indicate that the P application to the substrate assists in the maintenance of root growth and prolongs the root growth rate when the time of seedling permanence in the tray is greater than 37 days; after this period, the root growth rate of the control becomes lower than that in the treatments provided with P (Figure 3G). This shows that if the substrate fails to supply all the P that sweet potato seedlings need, there may be significant losses in seedling rooting due to P deficiency. In sweet potato, P deficiency can reduce plant growth by half without presenting visual symptoms of P deficiency (O'Sullivan et al., 1997).

In the first 25 DAP the root growth rates and the relative root growth rate of the treatment without P were higher than those in the treatments with P, but after that period, they reduced significantly until the last evaluation (Figures 3G and H). This indicates that although in the treatment without P the roots reached their maximum growth earlier, the lower P availability in the substrate of this treatment limited root growth to the point of drastically reducing their growth rates. These results, as well as those of other studies, show that depending on the time of seedling permanence in the

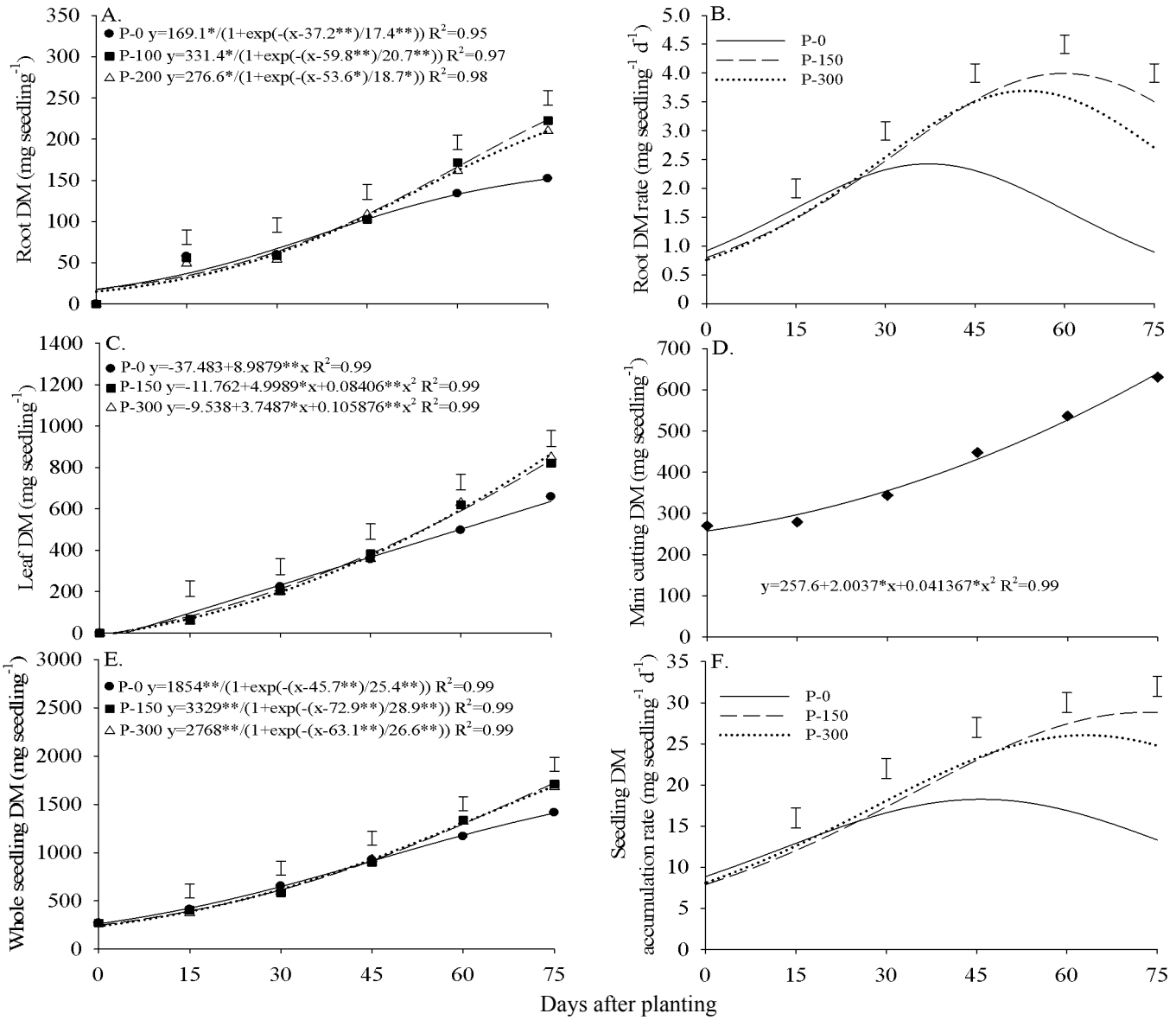


P–0, P–150 and P–300 – Doses of 0, 150 and 300 mg kg^{-1} of P; ♦ - average of the three P doses; Vertical bars represent the least significant difference at $p \leq 0.05$ by LSD test. * and **Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively; by F test

Figure 3. Substrate clod stability (A), number of roots (B), number of leaves (C), leaf/root ratio (D), root length (E), root surface (F), root growth rate (G) and relative root growth rate (H) of sweet potato seedlings in response to time of permanence in the trays and P supplementation

greenhouse, the substrate cannot meet the nutritional needs of the seedlings (Rós et al., 2011; 2013) and that P deficiency reduces plant root growth by severely reducing cell division in the root tissues (Sánchez-Calderon et al., 2005) since P acts in the process of energy transfer in the cells (Cruz et al., 2016).

The amounts of DM accumulated in the mini cuttings were influenced only by sampling times, but the DM accumulated in the roots, leaves and seedlings, as well as the rates of DM accumulated in the roots and seedlings, were influenced by P doses × Sampling times interaction (Table 1). In the mini



P–0, P–150 and P–300 – Doses of 0, 150 and 300 mg kg^{-1} of P; ♦ - average of the three P doses. Vertical bars represent the least significant difference at p ≤ 0.05 by LSD test. * and ** - Significant at p ≤ 0.05 and p ≤ 0.01, respectively by F test

Figure 4. Root dry matter (DM) accumulation (A), root DM accumulation rates (B), DM accumulation in leaves (C), mini cuttings - DM (D), whole seedlings - DM (E) and rates of DM accumulation in seedlings (F) of sweet potato in response to time of permanence in the trays and P supplementation

cuttings, there was an increase in the DM accumulation up to the last evaluation period, regardless of the P supplementation (Figure 4D).

In the roots, leaves and seedlings, the amounts of DM accumulated increased up to the last evaluation at all P doses. However, in the control treatment, the root and leaf DM in the last two evaluations and the whole seedling' DM in the last evaluation were significantly smaller than those values in the treatments supplied with P (Figures 4A, C and E), demonstrating that sweet potato responds positively to P fertilization (Cruz et al., 2016). This higher growth of seedlings supplied with P occurred because in these treatments the rates of DM accumulated in the roots and seedlings were higher than those in the treatment without P from 45 days until the end of the permanence of the seedlings in the trays (Figures 4B and F).

These results indicate that P supplementation benefits the growth of sweet potato seedlings that remain for more than 60 days in trays. Increases in the amount of DM accumulated in the roots and leaves of sweet potato seedlings submitted to applications of NPK fertilizer to the commercial substrate were also observed by other authors (Rós et al., 2011; 2013). However, in the case of seedlings transplanted up to 45 days, the P addition did not bring greater benefits for root development, although at that stage, the seedlings would stand out from the trays, but the clods would not remain fully cohesive.

Conclusions

1. The Ca present in the substrate was sufficient to promote the proper rooting and growth of sweet potato seedlings in the trays. However, the higher Ca supply (200 mg kg^{-1}), in the form of $CaCl_2$, adversely affected the development of seedlings that remained in the tray for more than 60 days.

2. Although the seedlings supplied with P showed a higher root growth rate after 45 days, the initial P available on the

substrate was sufficient to promote the adequate growth of the seedlings in the trays until 60 days.

Acknowledgements

We thank the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) for providing a scholarship to the first author (Fapesp Process n. 2014/25122-4), and we are grateful to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for providing a grant for excellence in research to the second author (Proc. 301827/2017-6).

Literature Cited

Caires, E. F.; Fonseca, A. F.; Feldhaus, I. C.; Blum, J. Crescimento radicular e nutrição da soja cultivada no sistema plantio direto em resposta ao calcário e gesso na superfície. Revista Brasileira de Ciência do Solo, v.25, p.1029-1040, 2001. https://doi.org/10.1590/S0100-06832001000400025

Camargo, R.; Pires, S. C.; Maldonado, A. C.; Carvalho, H. P.; Costa, T. R. Avaliação de substratos para a produção de mudas de pinhão-manso em sacolas plásticas. Revista Trópica – Ciências Agrárias e Biológicas, v.5, p.32, 2011.

Cruz, S. M. C.; Cecílio Filho, A. B.; Nascimento, A. S.; Vargas, P. F. Mineral nutrition and yield of sweet potato according to phosphorus doses. Comunicata Scientiae, v.7, p.183-191, 2016. https://doi.org/10.14295/cs.v7i2.958

Cunha, A. C. M. C. M. da; Paiva, H. N. de; Leite, H. G.; Barros, N. F. de; Leite, F. P. Influência do estado nutricional de mini cepas no enraizamento de mini estacas de eucalipto. Revista Árvore, v.33, p.607-615, 2009. https://doi.org/10.1590/S0100-67622009000400003

Domingues, L. S.; Ribeiro, N. D.; Andriolo, J. L.; Possobom, M. T. D. F.; Zemolin, A. E. M. Crescimento, produtividade de grãos e acumulação de cálcio, potássio e magnésio em plantas de feijão relacionadas à nutrição com cálcio. Acta Scientiarum Agronomy, v.38, p.207-217, 2016.

Fernandes, A. M.; Soratto, R. P.; Gonsales, J. R. Root morphology and phosphorus uptake by potato cultivars grown under deficient and sufficient phosphorus supply. Scientia Horticulturae, v.180, p.190-198, 2014. https://doi.org/10.1016/j.scienta.2014.10.035

Fioreze, S. L.; Rodrigues, J. D.; Carneiro, J. P. C.; Silva, A. A.; Lima, M. B. Fisiologia e produção da soja tratada com cinetina e cálcio sob deficit hídrico e sombreamento. Pesquisa Agropecuária Brasileira, v.48, p.1432-1439, 2013. https://doi.org/10.1590/S0100-204X2013001100003

Montes, S. M. N. M. Utilização de mudas isentas de vírus como material de propagação para a cultura da batata doce. Pesquisa & Tecnologia, v.1, p.1-5, 2012.

Montes, S. M. N. M.; Paulo, E. M.; Montes, R. M. Avaliação da ação de uma virose na produção e qualidade de tubérculos de batata-doce. Arquivos do Instituto Biológico, v.82, p.1-3, 2015. https://doi.org/10.1590/1808-1657000492013

O'Sullivan, J. N.; Asher, C. J.; Blarney, F. P. C. Nutrient disorders of sweet potato. Canberra: ACIAR, 1997. 136p.

Reghin, M. Y.; Otto, R. F.; Olinik, J. R.; Jacoby, C. F. S. Viabilidade do sistema de produção de mudas em bandejas em três cultivares de cebola. Ciência e Agrotecnologia, v.31, p.1075-1084, 2007. https://doi.org/10.1590/S1413-70542007000400020

Ritchey, K. D.; Silva, J. E.; Costa, U. F. Calcium deficiency in clayey B horizon of savannah Oxisols. Soil Science, v.133, p.378-382, 1982. https://doi.org/10.1097/00010694-198206000-00007

Rós, A. B.; Araújo, H. S.; Narita, N. Uso de fertilizante de liberação lenta na produção de mudas de batata-doce em bandeja. Semina: Ciências Agrárias, v.34, p.2667-2674, 2013. https://doi.org/10.5433/1679-0359.2013v34n6p2667

Rós, A. B.; Araújo, H. S.; Narita, N.; Tavares Filho, J. Uso de fertilizante e tempo de permanência de mudas de batata-doce produzidas em bandejas. Pesquisa Agropecuária Brasileira, v.46, p.845-851, 2011. https://doi.org/10.1590/s0100-204x2011000800009

Rós, A. B.; Hirata, A. C. S.; Santos, H. S. Avaliação da produtividade de plantas de batata-doce oriundas de matrizes livres de vírus. Revista Brasileira de Ciências Agrárias, v.7, p.434-439, 2012. https://doi.org/10.5039/agraria.v7i3a1716

Rós-Golla, A.; Hirata, A. C. S.; Araújo, H. S.; Santos, V. B.; Narita, N. Multiplicação de material vegetativo de batata-doce em diferentes bandejas e produção de raízes. Pesquisa & Tecnologia, v.7, p.1-7, 2010.

Sánchez-Calderón, L.; López-Bucio, J.; Chacón-López, A.; Cruz-Ramírez, A.; Nieto-Jacobo, F.; Dubrovsky, J. G.; Herrera-Estrella, L. Phosphate starvation induces a determinate developmental program in the roots of *Arabidopsis thaliana*. Plant and Cell Physiology, v.46, p.81-104, 2005. https://doi.org/10.1093/pcp/pci011

Silva, A. S.; Moraes, W. B.; Souza, G. S. Doses de cálcio no crescimento do feijoeiro cultivado em solução nutritiva, na presença de alumínio. Idesia (Arica), v.29, p.53-58, 2011. https://doi.org/10.4067/S0718-34292011000300008

Tennant, D. A Test of a modified line intersect method of estimating root length. Journal of Ecology, v.63, p.995-1001, 1975. https://doi.org/10.2307/2258617