Communications in PLANT SCIENCES

http://cpsjournal.org
e-ISSN 2237-4027
Volume 12 (2022)

RESEARCH ARTICLE

Time of potato plant harvest in soilless cultivation for screening phosphorus use efficient genotypes

Darlene Sausen[1]*, **Ivan Ricardo Carvalho**[2], **Franciele Antônia Neis**[1], **Suzi Cerezer Uliana**[1], **Ritieli Baptista Mambrin**[3], **Raíssa Schwalbert**[3], **Miriam da Silva Tavares**[4] and **Fernando Teixeira Nisoloso**[3]

[1]Federal University of Santa Maria, Santa Maria, RS, Brazil.
[2]Regional University of Northwest of Rio Grande do Sul, Ijuí, RS, Brazil.
[3]Centro De Ensino Superior Riograndense, Marau, RS, Brazil.
[4]Goias State University, Posse, GO, Brazil.
Correspondence to: darlene_sn@yahoo.com.br

Submitted on March 08, 2021
Accepted on February 15, 2022
Early View on February 15, 2022
Final Publication on February 16, 2022

Authors declare no conflict of interest

KEYWORDS:
Mineral nutrition
Phosphorus use
Plantlets production
Soilless cultivation system
Solanum tuberosum L.

ABSTRACT

The shorter the duration of the selection process of potato genotypes more efficient in the use of P, the lower the casting time of a new plant variety in the market and its growing field, where effectively verify the reduction of use of phosphate fertilizers, which may help to increase the sustainability of the potato production chain. Therefore, the objective of this study was to determine the time of collection of potato plants grown in a closed system with sand as substrate and subjected to P restriction in nutrient solution aiming at the selection of more efficient genotypes on the P use. For this purpose, seven potato genotypes (SMIC 148-A, Dakota Rose, Sminia 793103-3, SMIB 106-7, 212-3 SMIF, SMIJ 319-1 and P 150), were grown in a closed soilless system with sand as substrate and nutrient solution containing two P levels (low: 2.32mg L^{-1}; and high: 23.2mg L^{-1}). The plants were harvested three sampling times (18, 39 and 62 days after transplanting (DAT)). The data showed that it is not advisable to use the plant growth assessment carried out until 18 DAT for screening of genotypes efficient in the use of phosphorus. However, at 39 DAT most potato genotypes already showed differences in all growth parameters evaluated between P levels, enabling the selection of the most efficient in P use and therefore not necessary cultivation by the end of the crop cycle.

Highlighted Conclusions

1. Selection of potato genotypes for P efficiency based on evaluations performed until 18 days after transplanting is not recommended.
2. At 39 days after transplanting, most potato genotypes already exhibit differences between the levels of P for all growth parameters evaluated, allowing the selection of the most efficient ones with respect to P, thus eliminating the need for cultivation until the end of the crop cycle.

INTRODUCTION

In the agricultural production there is a concern about sustainability and the environmental impact caused by the dependence on the use of inputs and mineral fertilizers, especially non-renewable ones, such as phosphate fertilizers (Cordell et al. 2012). Nonetheless, restricting the use of mineral fertilizers and pesticides may significantly reduce the yields of crops (Rempelos et al. 2013). The situation is even more complicated in the case of potato (*Solanum tuberosum* L.), which is less efficient in both uptake and utilization of phosphorus (P), compared to other major annual crops (Hopkins et al. 2014; Thornton et al. 2014), and for which there is a substantial difference of response between the cultivars planted in Brazil (Fernandes et al. 2017). As a result, high doses of phosphate fertilizers are employed for the adequate development of plants and to obtain high production of tubers (Balemi and Schenk 2009; Fernandes et al. 2016).

To make the potato production chain more sustainable, the current efforts in plant breeding include the search for genotypes that are more efficient in P use (Balemi 2011; Soratto et al. 2015; Leonel et al. 2016;). An efficient genotype in P use is that which produces greater biomass quantity with lower P consumption, under conditions of adequate supply or limitation of the nutrient (Moura et al. 2001). The response to its use, the increment in biomass

production per unit of P, is obtained by the difference between the biomass yields at both levels of the nutrient (low and high) divided by the difference between these levels (Fidelis et al. 2010). Developing potato genotypes with higher efficiency for P uptake and/or use is essential to obtain high production even in soils with low natural availability of P and, therefore, meet the demand of consumption by a global population in continuous growth, with little possibility to include new areas of production.

The shorter the time to select potato genotypes that are efficient with respect to P, the shorter the time to release a new cultivar in the market and its cultivation in the field, where the reduction in the use of phosphate fertilizers will effectively be observed. Knowing the traits and mechanisms involved in P nutritional efficiency may help differentiate genotypes with respect to uptake, translocation and use of P, including the tolerance to low and high levels of the mineral (Fritsche-Neto et al. 2010). Identifying these differences under specific nutritional conditions, especially under restriction of P, is the goal of most programs of mineral nutrition in the effort to incorporate such variability to the crop, expand its adaptability and increase its yield (Machado et al. 2004; Muller et al. 2007; Balemi and Schenk 2009; Fernandes et al. 2014; Soratto et al. 2015).

In this context, the use of closed cultivation systems out of the soil, with sand as substrate, is a feasible alternative to multiply plants which allows better control of mineral nutrition, facilitating the study on the interaction between nutrient and plant, besides being an excellent production system for seed potato (Mateus-Rodriguez et al. 2013; Muller et al. 2007; Muthoni et al. 2013; Souza et al. 2013; Bisognin et al. 2015). However, researchers do not know the moment from which potato plants in closed cultivation began to exhibit physiological alterations due to low P supply in the nutrient solution, in order to make possible their selection according to P use efficiency without compromising the responses of each genotype due to the different growth rates. These symptoms may occur for some genotypes already at the first stages of development, which would lead to early selection of the best genotypes and reduce the time and costs with cultivation until the end of the crop cycle.

Thus, this study aimed to determine the moment of harvest of potato plants grown in closed system with sand as substrate and subjected to P restriction in the nutrient solution, in order to select genotypes that are more efficient for P use.

MATERIAL AND METHODS

The experiment was carried out in greenhouse in the city of Santa Maria – RS, Brazil (29º 42’ 56’’S, 53º 43’ 13’’W and altitude of 95 m). The potato genotypes used in the present study came from the plants of Potato Breeding and Genetics Program of the Federal University of Santa Maria: SMIC 148-A, Dakota Rose, SMINIA 793103-3, SMIB 106-7, SMIF 212-3, SMIJ 319-1 and P 150.

The plants used came from plants that were micropropagated and inoculated in standard MS cultivation medium (Murashige and Skoog 1962), kept in growth room at temperature of 25 ± 2 °C and 16-h photoperiod for 14 days and then acclimated for 14 days in soilless cultivation system, under 60% shade cloth for 5 days. Then, they were transplanted to a system of cultivation in sand (Bandinelli et al. 2013) comprising a black polyethylene tray (55 x 34 x 15 cm), on which a 7-cm-thick layer of medium-size crushed stone was placed to drain the irrigation solution. This layer of crushed stone was covered by a thin polyethylene screen to separate the substrate, which was composed of an 8-cm-thick layer of medium sand.

Three irrigations with nutrient solution were performed every day, with duration of 15 min each, using a digital programmer and a low-flow rate pump, to saturate all the substrate with the solution. Excess solution was drained through a hole at the bottom of the tray. Each tray had twelve plants at spacing of 10 x 10 cm.

Treatments with P consisted of 5 and 50% of the standard concentration of P in the nutrient solution described by Bisognin et al. (2015), prepared with tap water, for potato soilless cultivation, referred to in the present study as low (2.32 mg P L^{-1}) and (23.2 mg P L^{-1}) levels of P. These levels of P have already been tested by the authors and led to limited plant growth (2.32 mg P L^{-1}) and normal plant growth (23.2 mg P L^{-1}). KCl was used to maintain the K concentration in the solution. Electrical conductivity (EC) was kept at 2 dS m^{-1}, using water to reduce the EC when necessary, whereas pH was kept at 5.7, adjusted every two days by the addition of HCl. The experiment was conducted in a 7 x 2 factorial scheme (seven genotypes and two P levels) in randomized blocks, with six replicates. The experimental unit consisted of three plants.

Samples were collected at three random times during the development of potato plants. At 18, 39 and 62 days after transplanting (DAT), 3 plants per replicate were collected, washed in tap water and divided into leaves, stems, tubers and roots. The effect of P levels in the nutrient solution was assessed on each plant for each genotype based on mean length of stems (cm), mean number of leaves and tubers, fresh weight of tubers (g), total dry weight of plants (g) and the harvest index (HI). Dry weight was determined after drying the material at 60 ºC.

The data were subjected to analysis of variance and the means between genotypes and between P levels were compared by Scott-Knott test at 0.05 probability level (Scott and Knott 1974) using the software program Sisvar 5.6 (Ferreira 2014).

RESULTS AND DISCUSSION

Early selection is necessary in potato breeding programs. However, to initiate the selection of genotypes more efficient with respect to P (in either uptake or use) at the initial stages of development, the physiological symptoms cause by low P supply or the adaptive factors of the genotype to this condition of P restriction need to be expressed in the plant at this stage. In the present study, for all variables analyzed the differences between P levels and between potato genotypes at 18 days after transplanting (DAT) were very subtle in the few times they occurred (Table 1 and 2). Thus, we do not recommend growth evaluations of potato plants up to 18 DAT aiming at selection of genotypes for P use efficiency.

In the last two collections (39 and 62 DAT), the growth parameters were in general influenced by P levels in the substrate, and the greatest differences were found at 62 DAT (Table 1 and 2). The mean length of stems of all potato genotypes decreased in the presence of low P level at 39 and 62 DAT, and at 39 DAT the genotypes Dakota Rose and SMIJ 319-1 showed the highest values of mean length of stems compared with the others, at both low and high levels of P. At 62 DAT, the genotype SMIJ 319-1 showed the highest value of mean length of stems at both P levels, but without differing from the genotypes Dakota Rose and SMIC 148-A at the low level of P. SMINIA 793103-3 and SMIF 212-3 were the genotypes with lowest values of mean length of stems at high level of P at 39 and 62 DAT. Therefore, for this parameter, early selection (at 39 DAT) would be representative of the selection performed close to the end of crop cycle (62 DAT).

Table 1. Effect of P levels in the mean stem length, in the number of leaves and tubers, evaluated at 18, 39 and 62 days after transplanting grown on closed system with sand as substrate. Santa Maria, RS, 2018.

Days after transplanting	18				39				62			
P level	Low		High		Low		High		Low		High	
Genotype	Mean stem length (cm.pl^{-1})											
SMIC 148-A	7.23*	Aaγ	7.58	Aaγ	14.04	Bbβ	23.53	Abβ	20.82	Baα	44.36	Abα
Dakota Rose	7.54	Baγ	10.43	Aaβ	19.31	Baβ	30.46	Aaα	23.39	Baα	30.11	Adα
SMINIA 793103-3	6.96	Aaβ	8.84	Aaβ	12.67	Bbα	16.54	Acα	11.44	Bbα	17.20	Aeα
SMIB 106-7	5.74	Baγ	11.09	Aaγ	15.04	Bbα	24.18	Abβ	11.03	Bbβ	31.78	Adα
SMIF 212-3	7.93	Aaγ	9.65	Aaβ	11.58	Bbα	18.16	Acα	11.98	Bbα	18.70	Aeα
SMIJ 319-1	7.71	Aaγ	8.95	Aaγ	16.79	Baβ	31.07	Aaβ	22.28	Baα	53.91	Aaα
P 150	8.04	Aaβ	9.11	Aaγ	13.71	Bbα	25.43	Abβ	14.93	Bbα	34.86	Acα
Average	7.30		9.38		14.73		24.20		16.55		32.99	
CV (%)	12.78											
Genotypes	Leaves (nº.pl^{-1})											
SMIC 148-A	5.98	Aaγ	7.32	Aaγ	11.08	Bcβ	16.25	Acβ	14.83	Bcα	33.25	Acα
Dakota Rose	6.92	Aaβ	9.23	Aaγ	14.25	Abα	14.08	Acβ	14.24	Bcα	19.28	Adα
SMINIA 793103-3	6.05	Aaβ	6.43	Aaγ	10.82	Bcα	17.99	Acα	12.48	Acα	14.02	Aeβ
SMIB 106-7	6.42	Baβ	9.83	Aaγ	14.46	Bbα	17.61	Acβ	14.28	Bcα	33.72	Acα
SMIF 212-3	6.67	Aaα	9.33	Aaγ	10.75	Bcα	16.42	Acα	8.74	Bdα	12.72	Aeβ
SMIJ 319-1	7.17	Aaγ	8.08	Aaγ	17.00	Bbβ	21.08	Abβ	24.64	Bbα	62.68	Abα
P 150	7.07	Aaγ	8.48	Aaγ	28.29	Baβ	47.67	Aaβ	33.95	Baα	91.73	Aaα
Average	6.61		8.39		15.24		21.59		17.59		38.20	
CV (%)	15.17											
Genotypes	Tubers (nº.pl^{-1})											
SMIC 148-A	0.75	Abγ	0.83	Abγ	1.92	Abβ	2.00	Acβ	3.28	Bcα	4.94	Adα
Dakota Rose	0.68	Abγ	0.87	Abγ	3.08	Baβ	4.50	Aaβ	4.28	Bbα	6.17	Acα
SMINIA 793103-3	1.25	Aaβ	0.92	Abγ	3.08	Aaα	3.00	Abβ	3.67	Bcα	6.69	Acα
SMIB 106-7	0.75	Abβ	1.08	Abγ	2.33	Abα	2.58	Abβ	2.94	Bcα	5.44	Adα
SMIF 212-3	0.67	Abγ	1.17	Abβ	1.92	Bbβ	2.67	Abα	3.62	Acα	3.21	Aeα
SMIJ 319-1	0.75	Abγ	1.17	Abγ	2.92	Aaβ	2.75	Abβ	5.06	Baα	7.83	Abα
P 150	1.67	Aaγ	1.83	Aaγ	3.58	Aaβ	4.17	Abβ	5.17	Baα	12.44	Aaα
Average	0.93		1.12		2.69		3.10		4.00		6.68	
CV (%)	18.23											

*Averages followed by the same capital letter on the line within each variable, averages followed by the same lowercase letter in the column within each variable and averages followed by the same greek letter at the same phosphorus level between times collection do not differ from each other by the Scott-Knott test at 0.05 probability.

Table 2. Effect of P levels in the fresh mass of tubers, in the total dry mass of the plant and in the harvest índex evaluated at 18, 39 and 62 days after transplanting grown on closed system with sand as substrate. Santa Maria, RS, 2018.

Days after transplanting	18				39				62			
P level	Low		High		Low		High		Low		High	
Genotypes	Fresh mass of tubers (g.pl^{-1})											
SMIC 148-A	0.56*	Aaγ	0.64	Aaγ	6.02	Acβ	8.06	Acβ	23.76	Bdα	64.61	Acα
Dakota Rose	0.78	Aaγ	0.70	Aaγ	13.29	Baβ	24.45	Aaβ	53.59	Baα	82.06	Abα
SMINIA 793103-3	1.26	Aaγ	0.71	Aaγ	5.84	Acβ	6.77	Acβ	18.80	Beα	39.81	Adα
SMIB 106-7	0.38	Aaγ	0.54	Aaγ	9.69	Bbβ	14.89	Abβ	28.59	Bcα	80.55	Abα
SMIF 212-3	0.64	Aaγ	0.86	Aaγ	5.54	Bcβ	9.36	Acβ	19.44	Beα	34.62	Aeα
SMIJ 319-1	0.98	Aaγ	0.88	Aaγ	8.70	Abβ	9.60	Acβ	51.78	Baα	81.44	Abα
P 150	1.60	Aaγ	1.64	Aaγ	10.98	Bbβ	15.13	Abβ	35.35	Bbα	87.75	Aaα
Average	0.89		0.85		8.58		12.61		33.04		67.26	
CV (%)	12.56											
Genotypes	Total dry mass of the plant (g.pl^{-1})											
SMIC 148-A	0.24	Aaγ	0.23	Aaγ	2.05	Bbβ	3.14	Adβ	14.49	Bdα	42.44	Acα
Dakota Rose	0.23	Aaγ	0.33	Aaγ	3.29	Baβ	5.85	Aaβ	21.39	Bbα	32.04	Aeα
SMINIA 793103-3	0.37	Aaγ	0.21	Aaγ	1.69	Abβ	2.35	Adβ	10.15	Bfα	19.62	Afα
SMIB 106-7	0.10	Aaγ	0.15	Aaγ	2.61	Baβ	3.85	Acβ	11.21	Beα	33.36	Adα
SMIF 212-3	0.21	Aaγ	0.28	Aaγ	1.76	Bbβ	2.89	Adβ	10.26	Bfα	15.95	Agα
SMIJ 319-1	0.28	Aaγ	0.36	Aaγ	3.34	Baβ	4.52	Abβ	29.74	Baα	73.62	Aaα
P 150	0.41	Aaγ	0.47	Aaγ	2.94	Baβ	5.51	Aaβ	16.08	Bcα	46.05	Abα
Average	0.26		0.29		2.53		4.02		16.19		37.58	
CV (%)	7.26											
Genotypes	Harvest índex											
SMIC 148-A	0.32	Beγ	0.45	Abα	0.39	Adα	0.34	Beβ	0.35	Aeβ	0.29	Bcγ
Dakota Rose	0.31	Aeγ	0.10	Beγ	0.52	Aaα	0.50	Aaα	0.42	Acβ	0.42	Aaβ
SMINIA 793103-3	0.42	Bcβ	0.46	Abα	0.50	Abα	0.40	Bcβ	0.37	Adγ	0.41	Baβ
SMIB 106-7	0.25	Bfγ	0.31	Adγ	0.52	Aaα	0.47	Bbα	0.47	Abβ	0.37	Bbβ
SMIF 212-3	0.45	Bbβ	0.49	Aaα	0.49	Abα	0.48	Abα	0.51	Aaα	0.40	Baβ
SMIJ 319-1	0.35	Adβ	0.32	Bdα	0.44	Acα	0.26	Bfβ	0.35	Aeβ	0.20	Bdγ
P 150	0.50	Aaα	0.38	Bcα	0.48	Abα	0.37	Bdα	0.41	Acβ	0.37	Bbα
Average	0.37		0.36		0.48		0.40		0.41		0.35	
CV (%)	4.82											

*Averages followed by the same capital letter on the line within each variable, averages followed by the same lowercase letter in the column within each variable and averages followed by the same greek letter at the same phosphorus level between times collection do not differ from each other by the Scott-Knott test at 0.05 probability.

One of the first visual symptoms observed in plants grown at low P level was the reduction or delay in leaf production and expansion. The mean reductions in the number of leaves were equal to 29.4% at 39 DAT and to 53.9% at 62 DAT (Table 1). Such reduction in the number of leaves can be responsible for the lower growth and development of the plants, observed under conditions of low P level, which may be related to the reduction in the synthesis of cytokinins, a hormone responsible for cell division, induced by P deficiency (Martin et al. 2000). Initially, under P deficiency, plants respond by reducing the formation of new leaves but maintaining the growth of the existing ones. However, if P scarcity continues, leaf fresh weight may also decrease (Mollier and Pellerin 1999). For this parameter, the genotype P 150 was the most efficient at both high and low levels of P, at 39 and at 62 DAT, with mean production of 31 leaves per plant at low P level and 70 leaves per plant at high P level (Table 1). Conversely, the genotypes SMIF 212-3 and SMINIA 793101-3 are among those with the lowest number of leaves at both levels of P and collections, with mean production ranging from 10 to 18 leaves per plant (Table 1). These genotypes would be eliminated from a breeding program because they have lower potential for shoot growth and development compared with other genotypes under conditions of restriction or adequate supply of P.

The end product commercially desired in potato cultivation is the tubers, in both number and size, which vary according to cultivar and growing conditions (Fernandes et al. 2015). For the number of tubers at 39 DAT, only the genotypes Dakota Rose and SMIF 212-3 showed significant reduction when grown at low P level (Table 1). At 62 DAT, the reduction in the number of tubers occurred for all genotypes except SMIF 212-3 (Table 1). At low P level, the highest number of tubers is produced at 62 DAT, except for the genotype SMIB 106-7, which did not show difference between the collections. The same occurred at high P level, since all genotypes produced higher number of tubers as the cultivation time progressed, except the genotype SMIF 212-3, which did not show difference between the collections. In potato cultivation, aiming at production of mini-tubers, the number of tubers produced early by the mother plant is more important than the weight, since the latter can be managed by the duration of the potato cycle until harvest (Muller et al. 2007). The genotypes Dakota Rose, SMIJ 319-1 and P 150 are among the most efficient ones in P use for the production of tubers in number, whereas SMIC 148-A, SMIB 106-7 and SMIF 212-3 are the least efficient ones (Table 1). This demonstrates that early harvest, carried out before 62 DAT, is a negative factor for yield because it results in losses of tuber yield, besides possible losses in the concentration of mineral nutrients. However, it does not hamper the selection of the most efficient genotypes with respect to P use for tuber production, since it is already possible to observe differences between the genotypes at 39 DAT.

Fresh weight of tubers was higher for all genotypes tested at 62 DAT than at 39 DAT at both levels of P (Table 2). Only the genotypes SMIC 148-A, SMINIA 793101-3 and SMIJ 319-1 did not differ between the tested levels of P at 39 DAT; in this collection, the genotype Dakota Rose was the most efficient in tuber fresh weight production at low (13.3 g pl^{-1}) and high (24.4 g pl^{-1}) levels of P, whereas the genotypes SMIC 148-A, SMINIA 793101-3 and SMIF 212-3 were the least efficient ones at both P levels, but without differing from the genotype SMIJ 319-1 at high level of P (Table 2). At 62 DAT, at low level of P, the genotypes SMIJ 319-1 (51.2 g pl^{-1}) and Dakota Rose (53.3 g pl^{-1}) are the most efficient ones for tuber fresh weight production and, at high level of P, the most efficient is P 150 (87.7 g pl^{-1}), in contrast to SMINIA 793101-3 and SMIF 212-3, which are the least efficient ones for tuber fresh weight production regardless of P level (Table 2). If the researcher intends to eliminate from the breeding program the least efficient genotypes regarding P use based on tuber fresh weight production at 69 DAT, his/her choice would probably include the genotypes SMINIA 793103-3 and SMIF 212-3, which were also the least efficient ones among the potato genotypes tested already at 39 DAT.

The total dry weight of the plant was also higher for all genotypes in the present study at 62 DAT than at 39 DAT at both levels of P (Table 2). Only the genotype SMINA 793101-3 showed no difference between both P levels at 39 DAT, which indicates that it may be less sensitive to P deficiency or less responsive to P increment in the nutrient solution. The genotypes SMIC 148-A, SMINIA 793103-3 and SMIF 212-3 are the least efficient ones in P use for total dry weight production, at both levels of P at 39 DAT (Table 2). Likewise, at 62 DAT, the least efficient genotypes in P use for total dry weight production were again SMINIA 793103-3 and SMIF 212-3 at both levels of P. On the other hand, the genotypes Dakota Rose, SMIB 106-7, SMIJ 319-1 and P 150 were the most efficient ones in P use for total dry weight production at 39 DAT, whereas at 62 DAT the most efficient was SMIJ 319-1, at both levels of P. These results show that there is no need for conducting experiments until the end of the plant cycle and that it is possible to select the most efficient genotypes in P use earlier, therefore saving financial resources and time (Machado et al. 2004).

The harvest index (HI) refers to the fraction of tubers produced in relation to the total dry weight of the plant. Therefore, the HI is a measure of the efficiency in the transport of photoassimilates to the tubers, which theoretically indicates that the genotype has higher efficiency of conversion of photosynthesized products into material of economic importance. Thus, genotypes with earlier tubering are expected to have higher HI than those with later tubering. However, for a specific genotype within the same collection, the level of P can affect tuber formation because P acts in potato plants by stimulating the formation of larger tubers and accelerating maturation (Luz et al. 2013; Rosen et al. 2014; Fernandes et al. 2015a,b; Fernandes et al. 2016). In the present study, it was possible to observe that, both at 39 and at 62 DAT, the genotypes exhibited higher HI at low level of P (Table 2). For this reason, it is necessary to calculate the P use efficiency (PUE) for fresh tuber yield. Under conditions of higher P availability some genotypes may produce more shoot dry weight, but not necessarily more fresh tubers or tuber dry weight (Soratto et al. 2015). As some potato genotypes exhibit differences in the HI between the levels of P at 39 DAT, it would be possible to select the most efficient or early ones, such as Dakota Rose and SMIB 106-7, and discard the less efficient or later, such as SMIJ 319-1 and SMIC 148-A (Table 2).

To confirm the similarity of response of the plants in nutrient solution and in soil, so as to eliminate the advantage of the ready availability of P in nutrient solutions and the fact that this system is artificial compared with the field conditions under which plants normally grow and develop, a new experiment should be carried out using soil as substrate.

Acknowledgements

The authors are grateful to CNPq for financial support and the Potato Genetic Improvement Program of the UFSM for the granting of genotypes.

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