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Research Article

Calcium particle film improves sweet potato growth and partitioning[1]

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ABSTRACT

High temperatures may affect the development and yield of the sweet potato crop. Technologies such as particle films can mitigate their effects. This study aimed to evaluate the effect of calcium oxide (CaO) particle film on sweet potato remobilization and accumulation of photoassimilates, as well as its impact on the crop yield. The experimental design was randomized blocks, with four replicates per treatment: control, 5, 10 and 15 % of CaO. In general, there was an increase for root volume; average weight per root; dry and fresh weight of roots, branches and leaves; and growth rates at 10 % of CaO. The highest yield and number of marketable roots were observed at 10 and 15 % of CaO. The use of 10 % of CaO caused an increase in the remobilization of photoassimilates and, consequently, an increase in the sweet potato yield.

KEYWORDS: *Ipomoea batatas* L., calcium oxide, artificial shading, photoassimilates distribution.

RESUMO

Filme de partículas de cálcio melhora o crescimento e partição de batata-doce

Altas temperaturas podem afetar o desenvolvimento e rendimento da cultura da batata-doce. Tecnologias como filmes de partículas podem mitigar seus efeitos. Objetivou-se avaliar o efeito de filme de partículas de óxido de cálcio (CaO) na remobilização e acúmulo de fotoassimilados em batata-doce, bem como seu impacto na produtividade da cultura. O delineamento experimental foi em blocos ao acaso, com quatro repetições por tratamento: controle; 5; 10; e 15 % de CaO. De maneira geral, houve aumento de volume radicular; peso médio por raiz; massa seca e fresca de raízes, ramos e folhas; e taxas de crescimento para 10 % de CaO. A maior produtividade e número de raízes comercializáveis foram observados para 10 e 15 % de CaO. A utilização de 10 % de CaO causou aumento na remobilização de fotoassimilados e, consequentemente, aumento na produtividade da batata-doce.

PALAVRAS-CHAVE: *Ipomoea batatas* L., óxido de cálcio, sombreamento artificial, distribuição de fotoassimilados.

INTRODUCTION

Sweet potato (*Ipomoea batatas* L.) is cultivated worldwide for human and animal feeding (Chandrasekara & Kumar 2016). Around 107 million tons are produced annually, making it one of the most cultivated tuberous roots (FAO 2017). In Brazil, it is the fourth most consumed tuberous root, with an annual production estimated at 600,000 tons (IBGE 2017). The Northeast region is the primary producer of sweet potato in Brazil, mainly by small farmers, as it requires less technology and has a low production cost (Figueiredo et al. 2012).

Dry and warm conditions seem to limit the cultivation of sweet potato in the Brazilian Northeast region due to water, thermal and luminous stress. The use of particle films is a promising technique that can improve the water consumption and increase the crop yield (Silva et al. 2019a), as observed for olive tree (*Olea europaea*) (Brito et al. 2018) and tomato (*Solanum lycopersicum*) (Silva et al. 2019b). Thus, particle films can mitigate unfavorable climate conditions on sweet potato crops in this region.

Quantitative analysis of plant growth consists of measuring the accumulation of dry mass and the size of the photosynthetic apparatus in regular intervals of time (Peixoto et al. 2011). For instance, there is a linear relationship between radiation intercepted by plants and dry matter production (Portes & Melo 2014). Thus, partition and remobilization

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are determining factors for plant yield (Gifford et al.1984). Changes in the distribution patterns of assimilates of the plant components by management practices, such as particle films, may help to increase the crop yield (Fahad et al. 2017). Thus, this study aimed to investigate if applying calcium oxide (CaO) particle film can remobilize the photoassimilates of sweet potato plants and increase their yield.

MATERIAL AND METHODS

The experiment was performed in São Cristovão, Sergipe state, Brazil (10º55'27''S, 37º12'01''W and 46 m of altitude), from April to September 2018. The climate is tropical rainy, with an average annual temperature of around 25.2 ºC, dry summer and average yearly rainfall of 1,300 mm, concentrated in April-September (Santos et al. 2009). During the experimental period, the weather conditions were monitored by a meteorological station installed in the experimental area (Figure 1).

The Ourinho variety, collected from the Itabaiana farm (Sergipe state), was used. Each branch contained 4-8 knots, and 50 % were buried to implant the crop. Using the Penman-Monteith method, drip irrigation was used based on the evapotranspiration values (Allen et al. 1998). Fertilizers were applied at planting (20 kg ha^{-1} of N, 90 kg ha^{-1} of P_2O_5 and 90 kg ha^{-1} of K_2O) and 30 days after planting (DAP) (30 kg ha^{-1} of N, 40 kg ha^{-1} of P_2O_5 and 60 kg ha^{-1} of K_2O). Weeds were removed weekly, using a hoe. Before the planting and harvest periods, soil samples were collected (0-20 cm) in each row with the treatments or the control. Then, they were sent to the laboratory, to determine chemical parameters.

The experimental design was randomized blocks, with four replicates and four treatments (control, 5, 10 and 15 % of CaO). Each unit consisted of furrows with 18 m long x 0.6 m wide each, spaced 0.3 m between plants and 1.0 m between furrows. The particle film applications were performed every ten days, starting at 30 DAP up to harvest. A semi-analytical scale (UX-620H Shimadzu) was used to weigh the CaO (solubility at 25 ºC; 0.159 g 100 g^{-1} of the solution - 1.2 g L^{-1}), and distilled water was added to obtain the desired concentrations. The films were applied using a costal electric sprayer (Kawashima PEM-P20) with a flow rate of 2.9 L min^{-1} and pressure of 450 kPa. A total volume of 83.5 mL was sprayed on the leaves according to the CaO concentrations. One plant per unit was collected every 15 days, after each application, to evaluate its growth and partitioning. Border plants were disregarded to perform these evaluations.

Fresh plants were collected, identified, measured and weighed. An integrator (Li-Cor model LI 3000) was used to measure the leaf area. After that, they were put into paper bags and placed in a forced-air circulation oven at 65 ºC, for 72 hours. Finally, the dry mass was determined (g). According to Benincasa (2003), when the dry matter mass and the leaf area are obtained at regular pre-established intervals, the following parameters can be determined: absolute

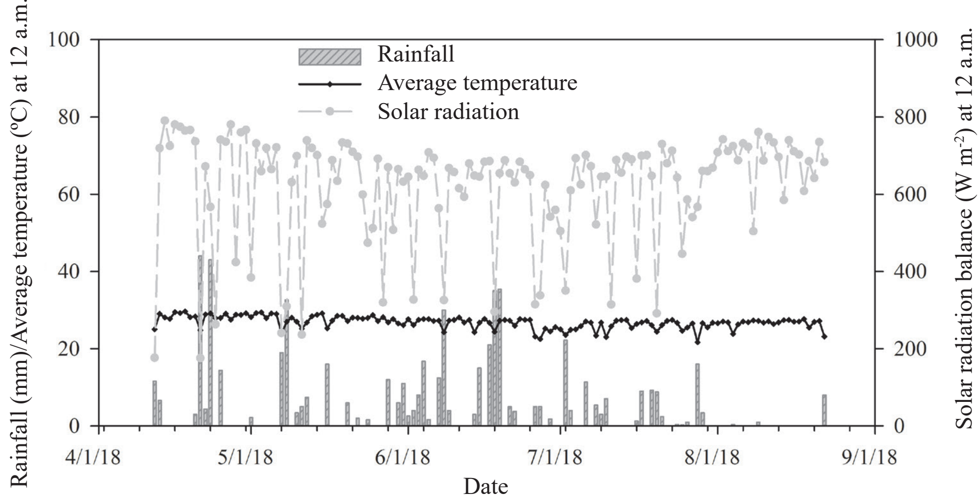

Figure 1. Average air temperature (ºC), accumulated solar radiation (Rn) (W m^{-2}) and daily cumulative rainfall (mm), from April to September 2018.

growth rate (g day^{-1}; variation or increase between two samples that indicate the plant growth rate); relative growth rate (g g^{-1} day^{-1}; increase in dry matter mass per unit of initial weight in a determined time interval); net assimilation rate (g m^{-2} day^{-1}; increase in dry matter mass accumulated in the plant per unit of leaf area available during a time range); leaf mass ratio (cm^2 cm^{-2}; balance between the leaf area and the area occupied by the plants); leaf area ratio (cm^2 g^{-1}; ratio between the leaf area and the dry plant mass); leaf area index (g g^{-1}; ratio of the leaf dry weight to the total dry mass); crop growth rate (g m^{-2} day^{-1}; total amount of dry matter accumulated per unit area of soil in a determined time); and crop index (quotient often used to measure the conversion efficiency of synthesized products into the material of economic importance) (Marafon 2012).

The yield was obtained by the root weight from each plot. The total weight was extrapolated to t ha^{-1}. The mean root diameter was obtained by the transversal measurement of the central part of the root, using a digital caliper, and expressed in mm. The displacement of water volume allowed to obtain the root volume by the graduated cylinder (mL) (Torres Netto et al. 2006).

The starch content was determined by the Lane-Eynon method. This method reduces a defined volume of an alkaline copper reagent (Fehling) to cuprous oxide. The endpoint is indicated by methylene blue and facilitated by a slight excess of reducing sugar (Zenebon et al. 2008).

The data were submitted to Anova ($\alpha = 0.05$) and regression analysis. All analyses were performed using the R software (Bhering 2017) and graphs designed using the SigmaPlot 12.5 software.

RESULTS AND DISCUSSION

According to the soil analysis, the pH was higher in the experimental plots where CaO films were applied, as well as Ca + Mg and Ca (Table 1), indicating that the particle film may cause a local indirect liming in the soil, increasing its pH and, therefore, the plant nutrient absorption.

The particle film caused artificial shading, and the application occurred on leaves. In case of rain (what happened in the experimental period), the leaves ended up being washed, and the Ca flowed into the soil. Thus, by applying the calcium-based particle film (CaO), it was possible to provide the soil with a higher Ca^{2+} content, consequently raising the pH, what caused an increase in the microbial activity and the release of nutrients from the soil (Silva et al. 2011).

The number of commercial roots (Figure 2A) and yield (Figure 2C) tended to increase as the CaO particle film also increased, while the percentage of commercial roots increased in CaO concentrations up to 10 %, decreasing thereafter (Figure 2B).

The root volume (Figure 3A), diameter (Figure 3B) and weight (Figure 3C) showed a linear relation between days after planting and calcium particle films concentrations. Plants treated with CaO at 10 and 15 % showed the highest root volume and weight values, being roughly similar for diameter (Figure 3).

At 10 % of CaO, a more significant sweet potato production potential was noted. It possibly occurred due to the particle film effect as a barrier to UV excess and IR radiation, causing a reduction in the luminous stress, allowing the active photosynthetically leaf area to absorb solar energy and dry mass conversion (Glenn 2012, Slattery et al. 2017).

The highest starch content values were observed at 120 DAP (Figure 4). The starch content was higher for the control, mostly at 120 and 135 DAP, for all treatments.

The beginning of root starch accumulation is a significant development stage of the sweet potato, as it marks the photoassimilates translocation to this reserve, modifying the source/drain ratio of the plant (Schons et al. 2007). In this study, the starch ended up being remobilized for the root growth in its final

Table 1. Soil chemical analysis after the particle film application.

Sample	pH	OM	Ca + Mg	Ca	Mg	Al
		%	cmol dm^{-3}			
Control	5.52	1.49	2.00	1.33	0.67	0.0
5 % of CaO	6.59	1.39	2.39	1.82	0.57	0.0
10 % of CaO	6.94	1.51	3.68	2.67	1.01	0.0
15 % of CaO	7.66	1.47	4.12	3.39	0.73	0.0

phase (120-135 DAP), as can be seen with the higher starch content in the control group, when compared to particle film treatments. At harvest (150 DAP), the particle film, mainly at 5 and 10 % of CaO, showed the highest starch content, when compared to the other treatments. The fact that there is a decrease in the starch content at harvest suggests that, instead of producing starch, the plant demanded root growth, filling and weight (Figure 2).

The fresh (Figure 5A) and dry (Figure 5D) root matter showed a linear relationship that increased the DAP, mostly at 10 and 15 % of CaO. A non-linear association was observed for branches, where the fresh (Figure 5B) and dry (Figure 5E) matter increased up to 105 DAP, and after decreased chiefly in the control, 5 and 15 % of CaO. A non-linear relationship was found for leaf fresh (Figure 5C) and dry (Figure 5F) matter and, overall, it increased up

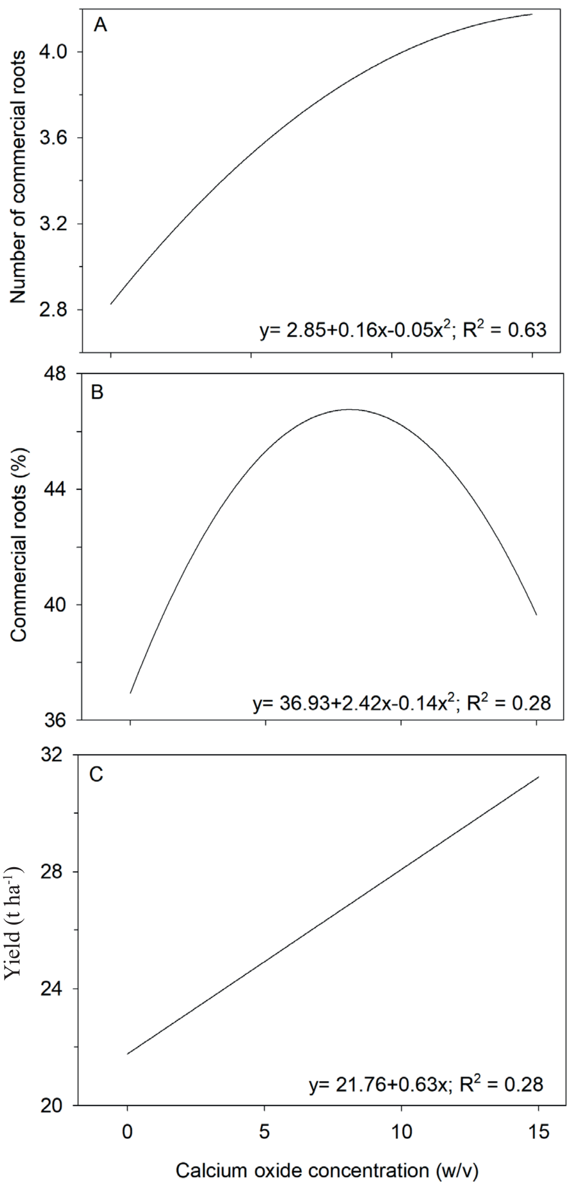

Figure 2. Number (A) and percentage (B) of commercial roots and estimated yield (t ha^{-1}) (C) of sweet potato (*Ipomoea batatas* L.), according to the application of three concentrations (5, 10 and 15 %) of calcium oxide particle film. The control (0) consisted of water application.

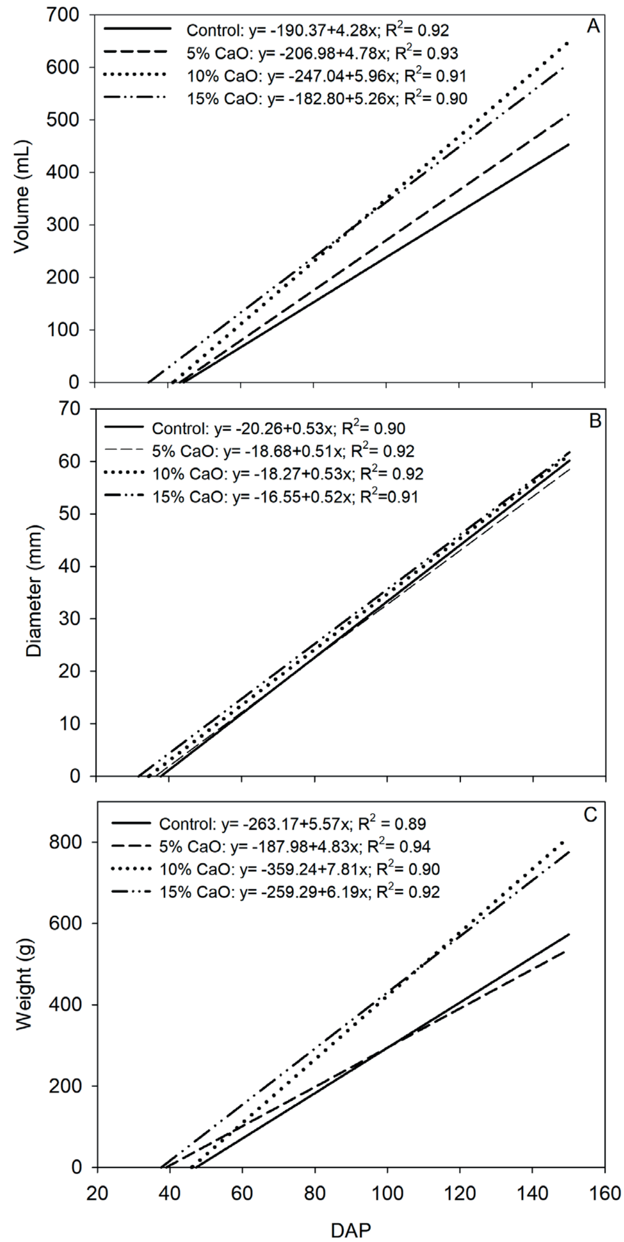

Figure 3. Root volume (A), diameter (B) and average weight per root (C) of sweet potato (*Ipomoea batatas* L.) submitted to concentrations of calcium-based particle film. DAP: days after planting.

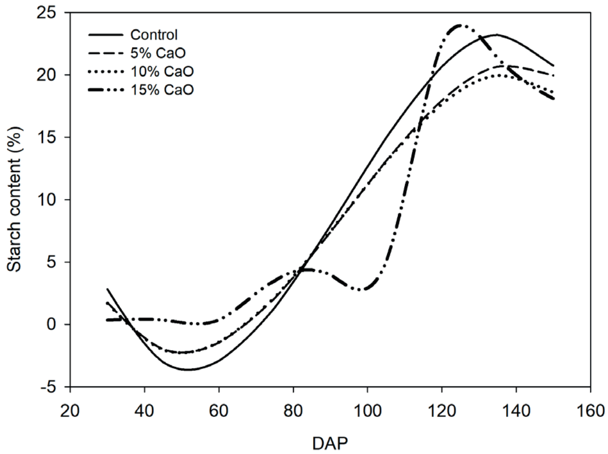

Figure 4. Starch content for sweet potato (*Ipomoea batatas* L.) submitted to particle film concentrations: control ($y = 39.68 - 1.91x + 0.02x^2 - 0.01x^3$; $R^2 = 0.76$); 5 % of CaO ($y = 27.24 - 1.33x + 0.01x^2 - 0.01x^3$; $R^2 = 0.80$); 10 % of CaO ($y = 27.43 - 1.35x + 0.02x^2 - 0.01x^3$; $R^2 = 0.79$); and 15 % of CaO ($y = 0.34 + 0.83x + 0.04x^2 - 0.01x^3$; $R^2 = 0.93$)]. DAP: days after planting.

to 105 DAP, and then decreased. An exception was observed at 15 % of CaO, peaking at 75 DAP and showing a slight reduction, when compared to the other treatments.

This biomass allocation between roots and leaves generates a balance in the plant growth, adaptation to environmental changes and possible stresses (water and light). Plants allocate more biomass in the stems/branches to facilitate the competition for light and carbon acquisition. Thus, a plant can distribute more biomass to the roots, allowing a higher nutrient absorption and biomass increase. Conversely, a plant can regulate its root morphology and physiology, instead of allocating more biomass to its roots, when there are abundant soil water and nutrients (Li et al. 2014).

The absolute growth rate showed a continuous trend for all treatments and, at 10 % of CaO, it reached 40 g day^{-1} at 150 DAP (Figure 6A). The relative growth rate reduced as the sweet potato developed (Figure 6B), and the net assimilation rate values varied (Figure 6C). For the control and 10 % of CaO, there was an increase in the middle of the sweet potato development and, in the end, it showed a sharp decrease (Figure 6C). However, at 5 and 15 % of CaO, the opposite was observed.

The leaf mass ratio also presented trends according to the CaO concentrations (Figure 6D). There was an increase during the plant development at 10 and 15 % of CaO, while, for 5 % of CaO and control, the leaf mass ratio remained similar. The leaf area ratio (Figure 6E) presented a continuous growth with a high increase in crop harvest at 10 and 15 % of CaO. The control and 5 % of CaO tended to increase at 120 DAP, followed by a reduction, while 5 % had high values.

The leaf area index values were higher at 120 DAP at 5 % and 15 % of CaO and control, respectively, while, for 10 %, 150 DAP were observed (Figure 6F). The crop growth rate values were higher for 5 % of CaO and control at 120 DAP, respectively (Figure 6G). At 10 %, the peak occurred at 90 DAP and, at 15 %, it varied during the crop development, with an increase at 45 DAP. Finally, the crop index increased for the control and 10 % of CaO (Figure 6H). The concentrations of 5 and 15 % of CaO increased gradually up to 135 DAP, without variation at 150 DAP.

Based on the decrease in the leaf fresh and dry mass (with an increase in the roots at 90 DAP), an inverse relationship was verified as photoassimilates translocated to the roots. Such behavior is corroborated by the initial crop establishment curves (Figure 4) that coincide with root growth, with a subsequent reduction in development, up to the maturation and filling of the tuberous roots and senescence of the leaves (Câmara et al. 2017).

As the effect of particle film application, the decrease in the relative growth rate may be explained by an increase in the respiratory activity, the promoted artificial shading and improvements in non-assimilating tissues (Barreiro et al. 2006). Thus, the highest relative growth at 10 % of CaO may be explained by the initial investment in leaf area formation and its photosynthetic capacity (Câmara et al. 2017). The net assimilation rate is a physiological indicator strongly related to photosynthetic efficiency, and this index must be evaluated with the leaf area ratio that explained the relative growth rate.

The leaf area ratio indicates the leaf area used to produce 1 g of dry mass (Benincasa 2003). Thus, it is possible that, in control plots, an increase in the interference of the upper leaves on the lower ones (self-shading) decreased the functional leaf area (Ford 2014, Niinemets 2016). This interference is supported in plots that received 10 and 15 % of CaO, where such a relationship increased in the final stage of the crop cycle, as it is necessary for the growth of tuberous roots that become drains (Singh et al. 1998).

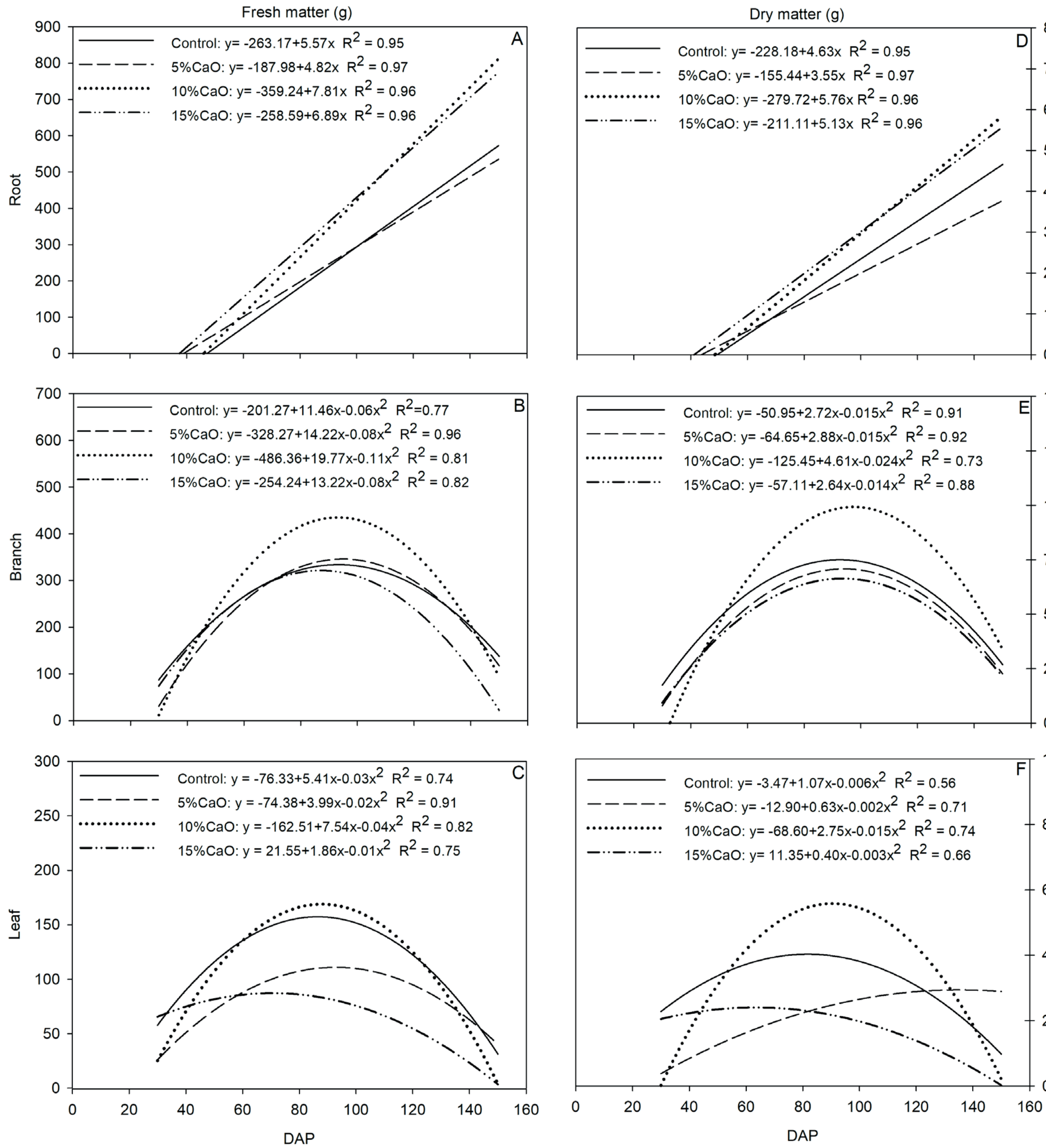

Figure 5. Fresh matter of roots (A), branches (B) and leaves (C), and dry matter of roots (D), branches (E) and leaves (F) of sweet potato (*Ipomoea batatas* L.), according to the application of calcium oxide particle film (5, 10 and 15 % of CaO).

The leaf area index describes the size of the photosynthetic device. Thus, the reduction of leaf area index in the control and 5 % of CaO at the final crop stage may be attributed to senescence and leaf abscission. This reduction is well recognized as a characteristic of sweet potato, due to its habits of determined growth (Conceição et al. 2005). However, at 10 and 15 % of CaO, it changed, and the leaf area index increased to prioritize the partitioning of photoassimilates to roots (Zheng & Moskal 2009, Portes & Melo 2014).

Tubers become priority drains in the assimilate partition from the beginning of their development, what indicates that the available photoassimilates were allocated to the root growth (Singh et al. 1998, Fernandes et al. 2010).

Plants with a high leaf area development had a better capacity to intercept solar radiation

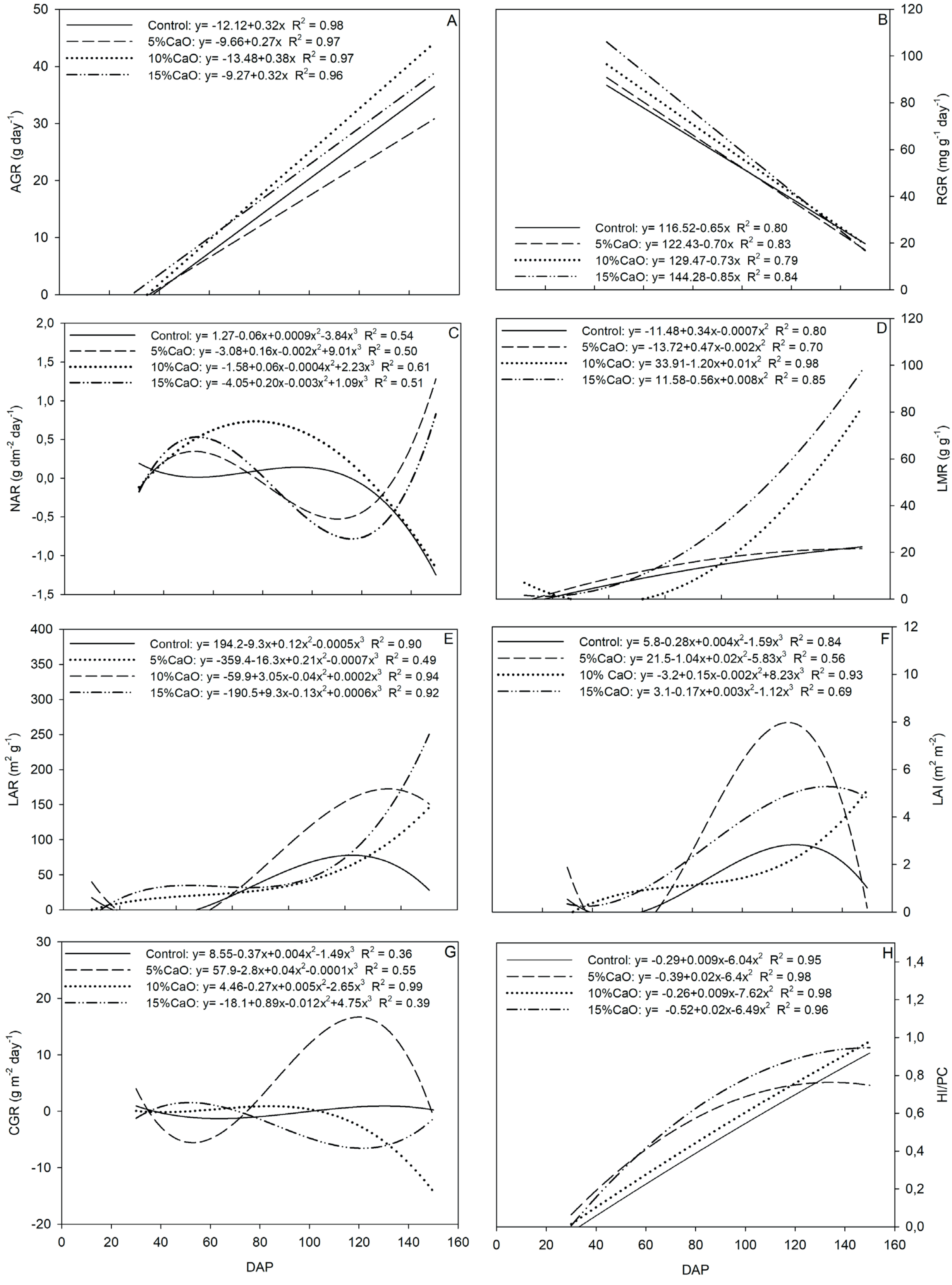

Figure 6. Growth rates of sweet potato (*Ipomoea batatas* L.) submitted to concentrations of calcium-based particle film (CaO). AGR: absolute growth rate; RGR: relative growth rate; NAR: net assimilation rate; LMR: leaf mass ratio; LAR: leaf area ratio; LAI: leaf area index; CGR: crop growth rate; HI/PC: harvest index or partition coefficient.

and, consequently, a higher dry mass production. However, the crop yield depends on the partition of assimilates produced in photosynthesis into roots, and the "strength" of roots as drains in the allocation of assimilates is the primary factor in determining the sweet potato yield (Oliveira et al. 2016).

The highest yield occurred at 150 DAP, at 10 % (34.98 t ha^{-1}) and 15 % (30.8 t ha^{-1}) of CaO. Such values are a result of the particle film application on sweet potato partitioning, and, taken together, increased the number of commercial roots, average weight per root and root volume.

CONCLUSIONS

1. The application of calcium oxide particle films improves the morpho-agronomic aspects, growth and yield of sweet potato, due to the artificial shading provided by them;
2. The concentration of 10 % of CaO increases the remobilization of photoassimilates and, consequently, the sweet potato yield.

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