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Optimal fertigation start time and frequency in cabbage seedlings

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Abstract

Although cabbage is one of the most important vegetables in Brazil, seedling production is carried out empirically by producers, given that there are no literature reports on the optimal start time and management strategy for seedling fertigation. The present study aimed to assess the influence of fertigation management on the development of cabbage seedlings, in order to determine the best start time and application intervals for nutrient supply. The study consisted of two experiments conducted in a randomized block design, with six repetitions each. The first involved six fertigation start times (0, 3, 6, 9, 12 and 15 days after emergence) and the second consisted of five treatments, that is, five fertigation application frequencies (every 3, 4, 5, 6 and 7 days after the first application). Biometric, physiological and nutrient characteristics were assessed when the seedlings reached the ideal (commercial) transplanting stage. Fertigation start times had a significant effect on the number of leaves, shoot and root dry weight, leaf area and macronutrient accumulation. The best results were obtained for a start time of 0 to 6 days after emergence (DAE). Application intervals had a significant effect only on calcium and sulfur accumulation. It was concluded that cabbage seedling fertigation should start three days after emergence, adopting a four-day application interval.

Keywords: *Brassica oleracea* L. var. *capitata,* fertilization, nutrients, nutrient solution

Introduction

Cabbage (*Brassica oleracea* L. var. *capitata*) is a widely consumed vegetable worldwide (Liu et al. 2020, Chrysargyris et al. 2019, Wu et al. 2020) and one of the most consumed leafy vegetables in Brazil (Röder et al. 2015, Reis et al. 2017).

Seedling production is one of the most relevant production phases, not only for cabbage, but all vegetables. Poorly formed seedlings may compromise plant development and prolong their cycle, causing production losses (Carmona et al. 2012, Röder et al. 2015, Lima et al. 2019, Chrysargyris et al. 2019). According to Fávaris et al. (2016), high-quality seedlings are free of pathogens, well developed and uniform, and less vulnerable to biotic and abiotic stress after transplantation.

Cabbage seedlings are produced in trays and factors that influence their development and quality include cell size; substrate type; temperature conditions; light and humidity in the nursery and, primarily, water and nutrient availability. Most of the studies that investigated cabbage seedling production assessed only the effect of the substrate used and alternative sources of materials that make up new substrates (Carter et al. 2013, Costa et al. 2014, Chrysargyris et al. 2019, Monaco et al. 2020). However, other factors that have been little studied may affect this production stage.

One of the challenges faced in vegetable seedling production is to guarantee adequate seedling development. The volume of cell trays is smaller, and as a result, lower amounts of water and nutrients are available to plants (Carmona et al. 2012, Chiomento et al. 2019). In addition, the substrates used are composed of inert materials, thereby requiring a supplemental nutrient supply. Supplementation can occur via mineral and/or organic fertilizers, provided in the substrate itself or through fertigation.

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Thus, fertigation can be applied as an alternative for adequate nutrient supply during the seedling phases. Fertigation involves the application of specific nutrient solutions that vary as a function of the crop. The optimal start time and application interval remain little discussed in scientific circles and require more attention. There are no studies in the literature that describe the best fertigation start time or frequency for adequate cabbage seedling formation. In practice, Brazilian producers have empirically adopted fertigation onset between 8 and 10 days after emergence (DAE), applied every 5 to 7 days.

As such, the hypothesis of the present study is that adequate nutrient supply, via fertigation, combined with correct management of the other production factors can improve seedling quality and reduce their production costs and time. Thus, the question is: When should fertigation be started and how often should cabbage seedlings be fertigated?

The present study aimed to determine the optimal fertigation start and frequency for cabbage seedling formation.

Material and Methods

The study consisted of two independent experiments conducted between December 8 and 28, 2019. The first assessed fertigation start times and the second, application intervals.

The experiments were conducted in an arch-shaped greenhouse covered with 150-micra light-diffusing plastic sheeting and 50% shade cloth on the sides, located at 19°45'26" S and 47°55'27" W, in the municipality of Uberaba, Minas Gerais state.

The climate of the region is characterized as Aw (tropical wet-dry), with cold dry winters and hot wet summers, according to Köppen's classification (Beck et al. 2018). Temperature and relative humidity data were collected inside the greenhouse, using a thermohygrometer installed 1.20 m above the ground, with average temperatures of 27.51°C and 61.16% relative humidity.

In the fertigation onset experiment, six start times were assessed, namely T1 = 0, T2 = 3, T3 = 6, T4 = 9, T5 = 12 and T6 = 15 DAE. In the application frequency experiment, the following five intervals were assessed: T1 = every 3 days, T2 = every 4 days, T3 = every 5 days, T4 = every 6 days and T5 = every 7 days. Both experiments were carried out in a randomized block design (RBD), with six repetitions. Each experimental unit (plot) consisted of 64 plants and the 40 central plants of each plot were assessed (study area). The experimental unit was represented by a polyethylene tray.

The nutrient solution used in the present study was that proposed by Furlani et al. (1999), which contains the following nutrient chemical composition: nitrogen (N) - (198.0 g 1000L^{-1}); phosphorous (P) - (39.0 g 1000L^{-1}); potassium (K) - (183.0 g 1000L^{-1}); calcium (Ca) - (142.0 g 1000L^{-1}); magnesium (Mg) - (38.0 g 1000L^{-1}); sulfur (S) (52.0 g 1000L^{-1}) in the form of S-SO_4; boron (B) - (300 mg 1000L^{-1}); copper (Cu) - (20 mg 1000L^{-1}); iron (Fe) (2000 mg 1000L^{-1}); manganese (Mn) - (400 mg 1000L^{-1}); molybdenum (Mo) - (60 mg 1000L^{-1}) and zinc (Zn) - (60 mg 1000L^{-1}).

It is important to underscore that the nutrient solution used was prepared by the authors for application in the experiments in question. The nutrient solution proposed by Furlani et al. (1999) is one of the most widely used in vegetable seedling production.

The cabbage hybrid used in seedling production was the Astrus Plus (SEMINIS®), which exhibits five average cycles of 90 to 100 days; healthy and vigorous medium-sized plants; dark green waxy leaves; semi-flat heads; small and very compact heart; with an average weight of 1.8 to 2.5 kg.

Sowing was performed on December 8, 2019, in polyethylene trays, with 200 22.0 cm³ cells, filled with Bioplant Plus® substrate, and one seed per cell, subsequently covered with a thin layer of substrate. According to manufacturer`s analyses, the substrate used is composed of *Sphagnum* moss (50%); coconut powder (20%); rice husk: (20%); vermiculite (10%); 3 kg m^{-3} of lime; 1.5 kg m^{-3} of PG Mix fertilizer (14-16-18 + micra) and 1.5 kg m^{-3} of monoammonium phosphate (MAP) (11-52-00). It also exhibit the following characteristics: 55% humidity; 100% water retention capacity (WRC); density of 160 kg m^{-3}; hydrogen ionic potential (pH) of 6.5 and electrical conductivity (CE) of 0.8 mS cm^{-1}. The experiment was conducted on wire benches 90 cm above the ground. During the experiment, the seedlings were irrigated four times a day (8:00 a.m.; 12:00 p.m.; 2:00 p.m. and 4:30 p.m.), using an automatic sprinkler irrigation system, in order to maintain the substrate at container capacity. From sowing to emergence (three days after sowing), all the treatments were irrigated only with water. Emergence was considered when at least 90% of the cells in each treatment exhibited emerged seedlings. Fertigation was started and repeated according to the treatments proposed in each of the experiments, applied only once a day at 8:00 am.

In the fertigation start times experiment, the first application varied as a function of the treatment. After the first application of each treatment, fertigation was repeated every five days. Thus, depending on the onset of fertigation, the number of applications differed in the various treatments, as follows: five applications in T1; four in T2; three in T3 and T4; two in T5 and only one in T6.

For the fertigation frequency experiment, all the treatments received the first application at 3 DAE. Next, based on the treatments, applications were repeated every 3, 4, 5, 6 or seven days. Thus, the number of fertigations in the treatments differed depending on application frequency, with five applications in T1; four in T2; three in T3 and T4 and only two in T5.

All the treatments received the same daily amount of water. However, for fertigation application, the volume of water in the first irrigation of the day (8:00 a.m.) was substituted with the same volume of nutrient solution. Fertigation was performed with a backpack sprayer. After fertigation, a small volume of water was sprayed on the seedlings to prevent nutrient solution accumulation on the leaves. The other irrigations (12:00 p.m.; 2:00 p.m. and 4:30 p.m.) were carried out only with water for all the treatments.

At 15 DAE, the number of leaves (NL) was assessed by counting the fully expanded leaves of 10 plants from the study area of each plot.

At 16 DAE, the physiological parameters of the seedlings were assessed by determining the OJIP chlorophyll-a fluorescence transient, using a FP100-Falker fluorometer, between 12:00 a.m, and 3:30 a.m. to enable the plants to adapt to the dark. Initial fluorescence (Fo), variable fluorescence (Fv), maximum fluorescence (Fm), maximum quantum efficiency (Fv/Fm), absorption flux per reaction center (ABS/RC) and trapped energy flux per reaction center (TRo/RC) were measured, using five readings per plot on the second true leaf of five plants from the study area. Chlorophyll-a content (CC) was determined by indirect measurement, applying the Falker chlorophyll index, measured by five readings per plot, on the second true leaf, between 11:00 a.m. and 3:00 p.m., using the Falker CFL1030 Chlorofilog.

The following were assessed at 17 DAE, that is, 20 days after sowing, when seedlings reached the commercial transplantation point: leaf area (LA) (cm^2 $plant^{-1}$); shoot dry weight (SDW) (g $plant^{-1}$); root dry weight (RDW) (g $plant^{-1}$) and shoot:root ratio (SRR). Also determined were N, P, K, Ca, Mg and S (g kg^{-1}) content, according to Embrapa methodology (2009). Next, N, P, K, Ca, Mg and S accumulation (mg $plant^{-1}$) in the seedling shoots was calculated by multiplying content by the shoot dry weight.

The data obtained were submitted to analysis of variance using the F-test. When a significant difference was observed, polynomial regression analysis was performed for the fertigation start times, where 1° and 2° models were selected as a function of the highest R^2 value. For the fertigation application intervals, the averages were clustered using the Scott-Knott method. A 5% significance level was used in all the analyses. The R Core Team program was used in data analysis and the SigmaPlot for graphic presentation.

Results and Discussion

Fertigation start time had a significant influence on all the biometric (Figures 1 A, 1B and 1C) and nutritional variables (Figures 2B, 2C and 2D), except for the shoot: root ratio (Figure 1B) and chlorophyll-a content (Figure 1C). There was no significant effect of start times for any of the physiological variables assessed (Figures 1D and 2A). In general, starting fertigation between 0 and 6 DAE produced better results in the cabbage seedlings (Figures 1 and 2).

Root dry weight (RDW) declined with later fertigation onset, exhibiting a decreasing linear response (Figure 1A). The highest RDW value (0.0209 g $plant^{-1}$) occurred at 0 DAE. Fertigation at 2 DAE resulted in greater Ca (2.8406 mg $plant^{-1}$, Figure 2C) and Mg accumulation (0.6853 mg $plant^{-1}$, Figure 2D). Application at 3 DAE produced the highest SDW (0.1435 g $plant^{-1}$, Figure 1A); NL15 (3.33 leaves per $plant^{-1}$, Figure 1B); and LA (23.35 cm^2 $plant^{-1}$, Figure 1C).

Fertigation onset at 5 DAE promoted greater P (1.7555 mg $plant^{-1}$, Figure 2C) and K accumulation (4.7267 mg $plant^{-1}$, Figure 2B). At 6 DAE there was higher N (2.2665 mg $plant^{-1}$, Figure 2B) and S accumulation (0.3708 mg $plant^{-1}$, Figure 2D).

With respect to fertigation frequency, there was a significant influence only for Ca and S accumulation (Figures 4C and 4D). The highest accumulations for Ca in cabbage seedlings were obtained with application every 3, 4 and 5 days (Figure 4C), and the highest for S every 3 or 4 days (Figure 4D). None of the remaining biometric (Figures 3A, 3B and 3C), physiological (Figures 3D and 4A) or nutritional variables (Figures 4B, 4C and 4D) were influenced by fertigation frequency. Thus, in general, the application intervals exerted little influence on cabbage seedling production.

Considering the results of the two experiments, early fertigation onset is more important than application frequency in the development of cabbage seedlings, given that 62.5% of the variables analyzed were influenced by start times, while only 12.5% were affected by application frequency. The results show that the earlier the fertigation onset, the better the seedling development.

In this respect, nutrient supply immediately after cabbage seedling emergence increased the number of leaves, which contributed to the greater leaf area and shoot dry weight. In addition, root dry weight was also higher the earlier fertigation started, indicating that the root system also benefited from nutrient availability (Figure 1A).

These results corroborate those reported by Wu et al. (2020), who assessed the effect of fertigation on cabbage production in a greenhouse, observing that the greater the availability of water and nutrients, the higher the plant height, stem diameter, number of leaves and leaf area. According to Taiz et al. (2017), this occurred because nutrients are essential for plant growth and development, participating in several important metabolic processes. The early supply of these nutrients likely accelerated plant metabolism, which produced better biometric and nutritional results.

All nutrient accumulations were higher when fertigation started soon after plant emergence. Early nutrient supply maintained a larger amount available for absorption, which reflected in their accumulation. Thus, based on the findings obtained, it can be inferred that the greater the nutrient availability due to early application, the higher the accumulation (Figures 2B, 2C and 2D).

As previously stated, early fertigation promoted better results than later start times. The increase in values after fertigation on the day of emergence when compared to later onset (15 DAE) was 22.52% (NL15); 31.85% (SDW); 13.88% (RDW); 41.50% (LA); 21.02% (N); 7.15% (P); 42.67% (K); 36.63% (Ca); 25.58% (Mg) and 29.88% (S) (Figures 1 and 2).

Rasool et al. (2019) investigated the effect of straw, irrigation frequency and nutrient supply on cabbage production, finding that the highest biometric and physiological values occurred in the treatment with a larger amount of water and greater nutrient supply. However, when a slightly smaller amount of water and nutrients is available, plants developed less, but this did not cause economic loss. This demonstrates that in certain situations, nutrition and irrigation can be adjusted for more economic production, with yields approaching the highest values.

The greater nutrient accumulation for more frequent fertigation, that is, every 3 or 4 days, promoted higher Ca (Figure 4C) and S accumulation (Figure 4D). This may be due to the greater nutrient availability at shorter intervals, given that 5 applications were performed every 3 days and 4 applications every 4 days. In the other treatments, only 2 or 3 applications were carried out. Thus, increasing fertigation frequency also raises nutrient availability, which in turn results in higher nutrient accumulation.

Despite the effect of Ca and S accumulations, application frequency had no effect on seedling development, since the biometric variables were not influenced (Figures 3A, 3B and 3C). This may be due to the relatively early first application, which occurred at 3 DAE in all the treatments, when compared to the start time used by producers, at 8 to 10 DAE. Thus, early first application guaranteed adequate seedling development.

It is important to underscore that neither early fertigation (at plant emergence) nor greater frequency (every three or four days) compromised seedling physiology. In both experiments, the values obtained for all the physiological characteristics indicate that the seedling photosynthesis system was functioning adequately, and that the seedlings were not subjected to any stress (Figures 1D, 2A, 3D and 4A), given that these parameters can be used to assess stress in several plants (Bussotti et al. 2011a, Bussotti et al. 2011b, Desotgiu et al. 2012, Goltsev et al. 2012, Oukarroum et al. 2012, Krasteva et al. 2013, Kalaji et al. 2014).

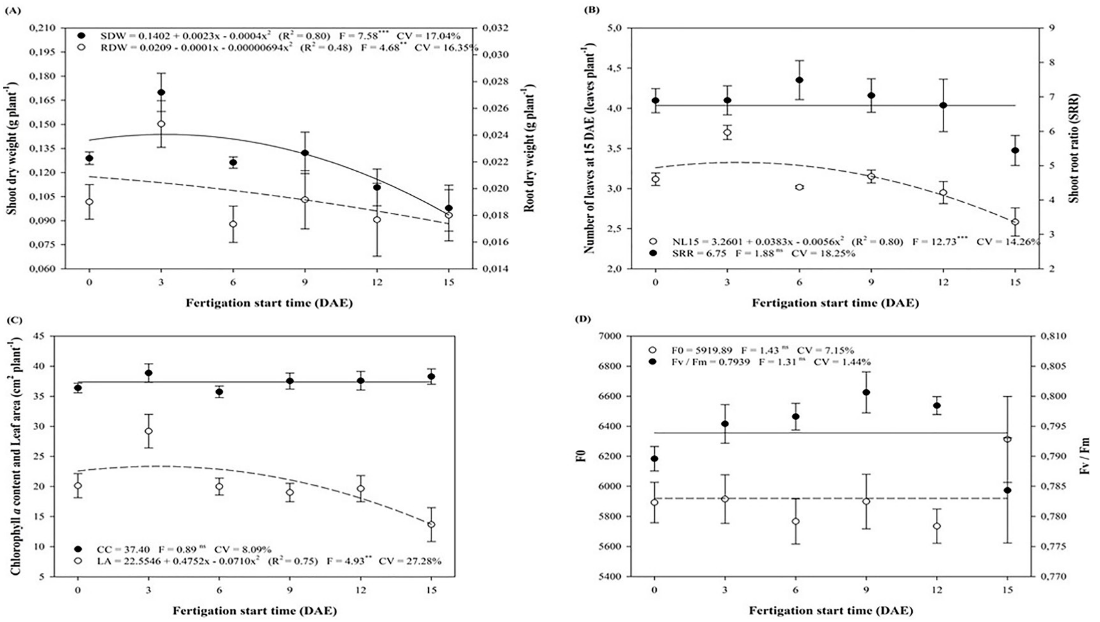

Figure 1. Regressions adjusted for shoot dry weight, root dry weight, number of leaves, shoot:root ratio (SRR), chlorophyll content, leaf area, initial fluorescence (F0) and maximum quantum efficiency (Fv/Fm) as a function of fertigation start times in cabbage seedlings. Bars indicate the standard error of the mean (n=6). ns = non-significant; "*" significant at 5%; "**" significant at 1%; "***" significant at 0.1% probability using the F-test; C.V. = coefficient of variation.

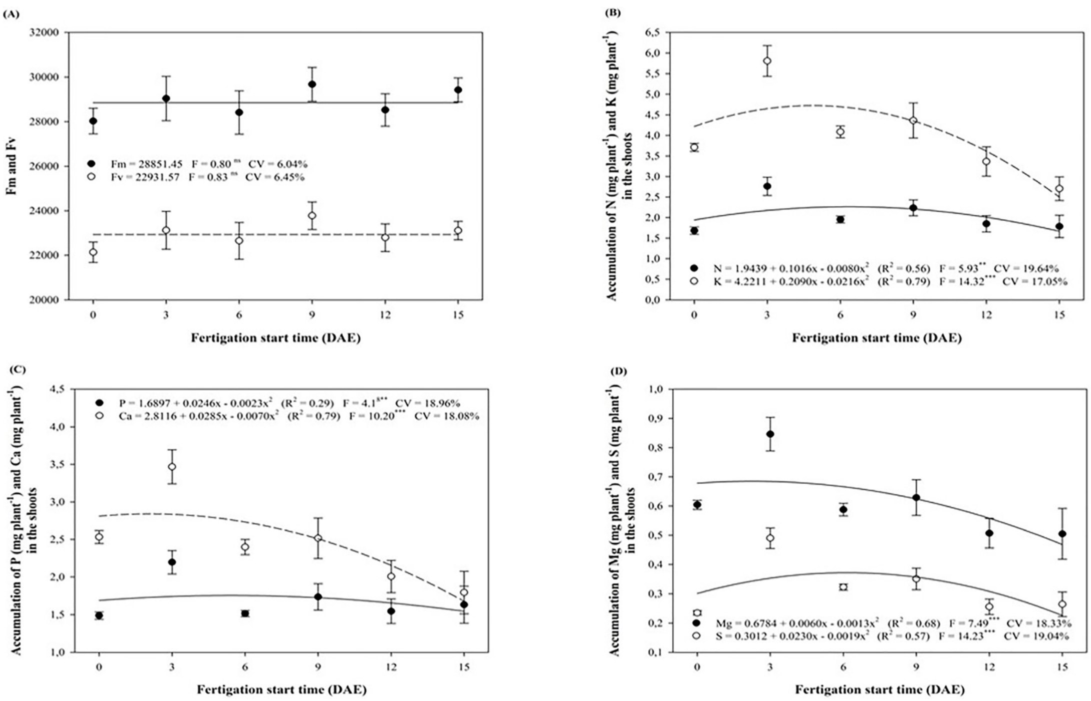

Figure 2. Regressions adjusted for maximum fluorescence (Fm), variable fluorescence (Fv) and shoot nitrogen, phosphorous, potassium, calcium, magnesium and sulfur accumulation as a function of cabbage seedling fertigation start times. Bars indicate the standard error of the mean (n=6). ns = non-significant; "*" significant at 5%; "**" significant at 1%; "***" significant at 0.1% probability using the F-test; C.V. = coefficient of variation.

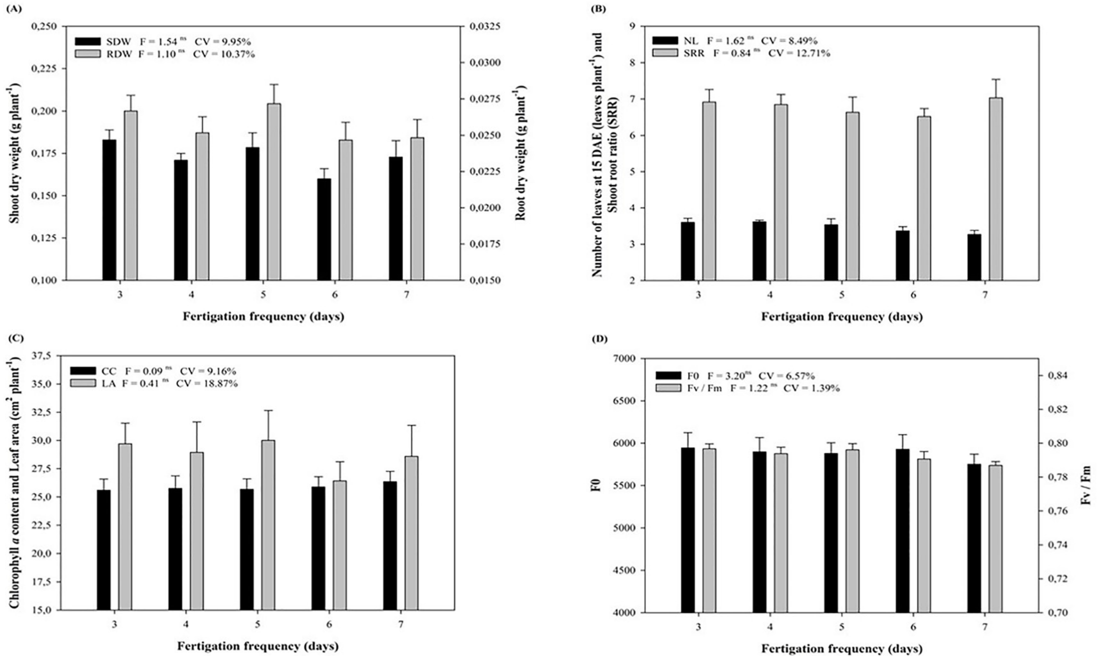

Figure 3. Average shoot dry weight, root dry weight, number of leaves, shoot:root ratio (SRR), number of leaves, chlorophyll a content, leaf area, initial fluorescence (F0) and maximum quantum efficiency (Fv/Fm) of cabbage seedlings, as a function of fertigation application intervals (fertigation frequency). Different lower case letters indicate differences between fertigation intervals. 5% significance according to the Scott-Knott clustering algorithm. Bars indicate the standard error of the mean (n=6).

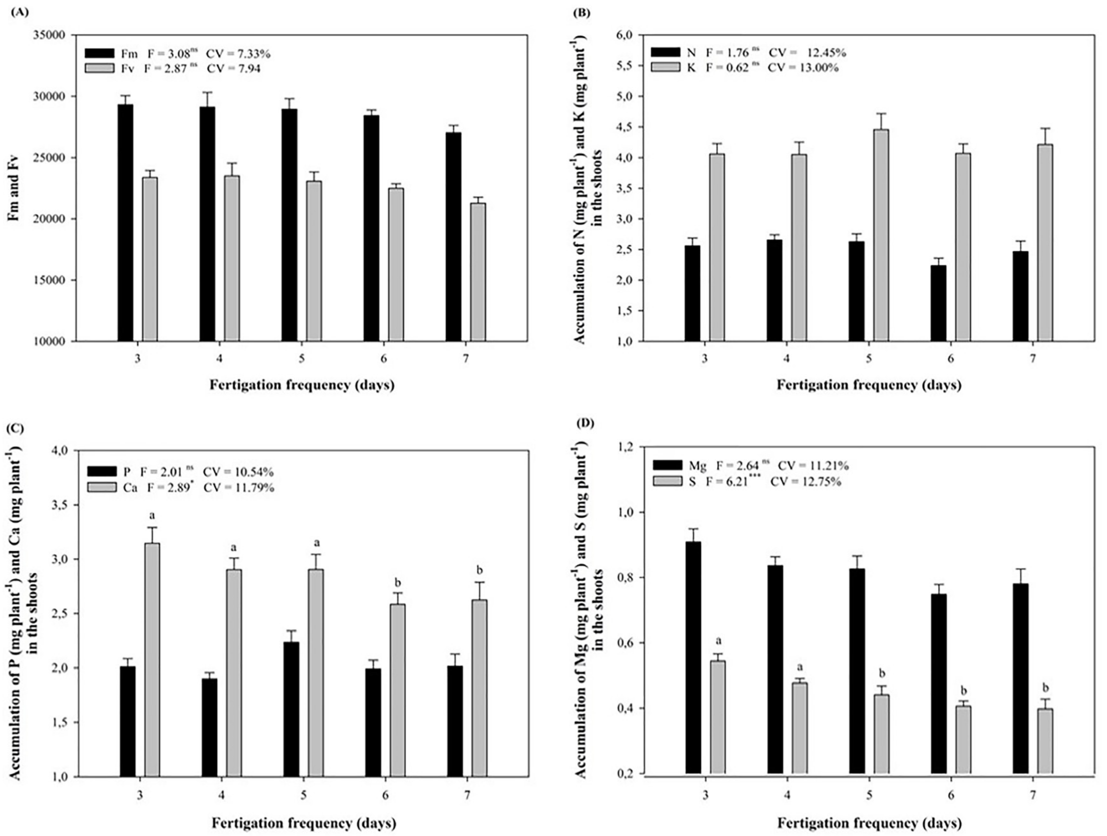

Figure 4. Average maximum fluorescence (Fm), variable fluorescence (Fv) and shoot nitrogen, phosphorous, potassium, calcium, magnesium and sulfur accumulation, as a function of fertigation application intervals (fertigation frequency). Different lower case letters indicate differences between fertigation intervals. 5% significance according to the Scott-Knott clustering algorithm. Bars indicate the standard error of the mean (n=6).

Producers generally wait 8 to 10 days to perform the first fertigation in vegetable seedlings, to allow the root system to develop and be able to absorb the fertilizers applied. In addition, there is a concern about the saline or phytotoxicity effects on young seedling tissues. However, the results of the present study indicate that even with early and frequent applications, there was no photoinhibition stress on the plants, given that the Fv/Fm values were always above the minimum value of 0.75. According to Reis & Campostrini (2011), Fv/Fm values between 0.75 and 0.85 quantum^{-1} electrons indicate that plants have an intact photosynthetic apparatus. Values below the minimum limit of 0.75 quantum^{-1} electrons reduce the photosynthetic potential of plants.

With respect to the economic aspect, the cabbage seedlings produced in both studies, where fertigation started at 0, 3 and 6 DAE, reaching the transplant point (commercial standard) 20 days after sowing (DAS). For the seedlings that were fertigated from 9 DAE onwards, more time was needed in the greenhouse to reach this standard. Since early seedling production was also the study object, we did not wait for all the seedlings to reach the transplant point to start the assessments. Current commercial cabbage seedling production lasts an average of 30 days (from sowing to transplantation). This 10 day decrease in the production stage guarantees lower seedling production costs and total production expenses. The seedlings produced in the studies were ready 33.3% faster than the commercial standard used. Thus, several production factors also declined, such as time the seedlings remained in the nursery; fertilizer, irrigation and pest and disease control costs, among others.

In summary, based on the results obtained in the present study, fertigation start times interfere more in cabbage seedling production than application intervals. In both experiments, the physiological parameters assessed indicate that there was no stress on the plants, regardless of the treatment, indicating only a positive treatment effect. Fertigation onset at plant emergence favors root dry weight production and at 3 DAE, shoot dry weight production. More frequent applications every 3 or 4 days increase Ca and S accumulation. Proper management can decrease seedling formation time.

Conclusions

During cabbage seedling production fertigation should be started 3 DAE and applied every 4 days.

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