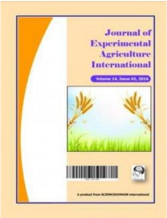

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Fluorescence and Growth of Eggplant under Irrigation Levels and Silicon Doses

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Authors' contributions

This work was carried out in collaboration among all authors. Authors RTF, JSN and DAC conducted and wrote the manuscript. Authors ACG and ASL consisted of job supervisors as well as those responsible for statistical analysis. Authors FRAF and MEBB contributed in the corrections and theoretical enrichment of the article. Author JTAF contributed in conducting the experiment and typing data. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The study was conducted to evaluate the fluorescence and growth of eggplant under influence of water deficit and silicon doses.
Study Design: The design was a randomized complete block design, in a 5 x 2 factorial

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arrangement, with four replications and one plant per plot, totaling 40 experimental units.
Length and Place of Study: The research was implemented between September and November 2016, in a greenhouse of the Center of Science and Technology Agrifood, at the Federal University of Campina Grande (UFCG / CCTA), Campus of Pombal-PB, Brazil.
Methods: Doses of 0, 75, 150, 225 and 300 mg L^{-1} of silicon and the irrigation slides of 50 and 100% of real evapotranspiration - ETr were used, which were obtained by weighing the pots daily in order to keep the weight close to the field capacity.
Results: The use of 50% level of the ETr provides reductions of 5.58; 7.92 and 6.84% of fluorescence in the initial, maximum and quantum yield of the photosystem. The fresh and dry mass of the stem presented the maximum productivity (140.8 and 48.1 g) in the plants irrigated with 100% Etr and treated with doses of 106 and 110 mg L^{-1} of Si.
Conclusion: The fluorescence and biomass of the eggplant plants is reduced with the decrease in irrigation level; while the application of silicon does not result in increment in the fluorescence and dry mass of the leaf. The 100% irrigation level of the ETr associated with the application of 108 mg L-1 of silicon resulted in the best results in stem mass accumulation.

Keywords: Solanum melongena; silicic fertilization; water deficit; abiotic stress.

1. INTRODUCTION

The eggplant (*Solanum melongena* L.) is a crop of high socioeconomic importance, producing worldwide approximately 52.3 million tons in an area of 1.85 million ha. China (32.9 million tons), India (12.5 million tons) and Egypt (1.3 million tons) are the largest producers [1]. In Brazil, recent data estimate that the production of this vegetable is around 90 thousand tons [2], being mainly cultivated by small and medium producers.

The cultivation of this oilseed crop has been gaining notoriety, mainly due to its nutritional and phytotherapeutic properties, being an important source of phenolic compounds, carotenoids and alkaloids [3]. Cultivation at temperatures between 20 and 35°C were observed in great conditions, especially by being a tropical climate crop and presenting itself as a good alternative to the semi-arid.

One of the main limitations imposed on agriculture in the semi-arid region is related to low water availability due to low rainfall and high annual evapotranspiration [4]. In the eggplant crop, water deficits can negatively affect characteristics such as mineral composition, leaf water potential, photosynthesis and fruit yield [5,6]. Thus, strategies that minimize the deleterious effects and/or increase the efficiency of water use is being studied [7,8].

Silicon (Si) is the second most abundant element of the earth. It is absorbed by plants as monostetic acid (H_4SiO_4), being reported in the literature as the beneficial element for some crops and essential for other species such as rice and sugar cane. Some of the benefits provided by Si include increased tolerance to biotic and abiotic stresses, thus Si deposition on the cell wall may decrease cuticular transpiration, thereby reducing plant water loss [9]. Benefits of Si application on the depletion of water stress was reported in potato [10], pepper [11], arugula [12] and tomato [13].

Therefore, the objective of this study was to evaluate the fluorescence and growth of the eggplant under influence of water deficit and silicon doses.

2. MATERIALS AND METHODS

The research was carried out between September and November 2016, in a greenhouse of the Center of Science and Technology Agrifood, at the Federal University of Campina Grande (UFCG / CCTA), Campus of Pombal-PB, Brazil, at geographical coordinates 6 ° 46 '16' 'of Latitude S and 37 ° 49' 15 '' longitude W, at an altitude of 144 m.

The experimental design was a randomized block design in a 5 x 2 factorial arrangement for five silicon doses (0, 75, 150, 225 and 300 mg L^{-1}) and two irrigation levels (50 and 100% of the actual evapotranspiration - ETr), with four replicates and one plant per plot, totaling 40 experimental units.

In order to determine the real evapotranspiration, the weighing lysimeter method in the treatments that received 100% of the ETr was used. For that, pots weight at field capacity (Wfc) was determined based on saturation by capillarity followed by drainage until constant weight, and each pots was daily weighed to obtain the current weight (Wc). With these data used the equation 1, in which the ETr was determined with the division of the subtraction of these numbers by the area (A) of the pot. Plants under 50% ETr received 50% of the water volume applied in plants under 100% ETr.

$$IS\ 100\%\mathrm{ETr} = \frac{\mathrm{Wfc} - \mathrm{Wc}}{\mathrm{A}} = \mathrm{mm} \qquad (1)$$

As an experimental unit, a 12.8 L pot was filled with the sample of a Fluvic Neosol collected in the 0-40 cm depth [14]. It was sieved and analyzed to obtain its physical and chemical characteristics, following the methodologies described by Embrapa [15], in the Laboratory of Soils and Plant Nutrition of CCTA / UFCG, as indicated in Table 1.

The eggplant (*Solanum melongena* L.) seedlings "Embu" cultivar were cultivated in 128-cell expanded polystyrene trays, using the Tropstrato® commercial mix as substrate, with two seeds per cell which was subsequent thinned to only one seedlings per cell. Transplanting was carried out at 40 days after sowing (DAS), when the plants had two true leaves and a height of approximately 15 cm.

Fertilization with macronutrients (except N) and micronutrients were performed according to the Malavolta [16] recommendation for potting. The following doses were applied, in mg dm-3: P = 100; K = 160; Ca = 230; Mg = 20; S = 155; B = 0.5; Cu = 1.5; Fe = 10; Mn = 4; Mo = 0.15 and Zn = 5.0 and the subsequent sources: simple superphosphate, KCl, $MgSO_4.7H_2O$ H_3BO_3, $CuSO_4$ $.5H_2O$, Fe-EDTA, $MnSO_4$ $.4H_2O$, ammonium molybdate and $ZnSO_4$ $.7H_2O$ respectively. In potassium (K) fertilization, the amounts of K supplied by potassium silicate were discounted to balance the nutrient doses between the treatments.

Silicon leaf fertilization was supplied by six sprays of the product Quimifol Silicio® (10% Si + 8.3% K, density = 1.31 kg L-1). Applications started seven days after transplanting (DAT) and the other applications were provided biweekly. The amount was applied respecting the vegetative development of the crop and increasing gradually in each application.

The solutions were prepared in one liter containers, each one representing a dose of silicon. As the product used to provide adequate amounts of the studied element (Quimifol) had potassium in its composition, it was necessary to use the potassium nitrate (KNO_3) to balance the nutrient concentrations at lower doses of Si. Urea was used to provide the concentrations of nitrogen applied along with KNO_3 in silicon treatment. In order to avoid possible problems, its application was separated in two days: on the first day, the doses for KNO_3 and the second, on Quimifol + Urea.

At 73 DAS, using a portable modulated fluorometer, the emission of chlorophyll, a fluorescence, was quantified and it was possible to determine the initial fluorescence (F0), the maxi-mum fluorescence (Fm), the variable fluorescence (Fv) and the maximum quantum yield of photosystem II (Fv / Fm) in each plant. At 114 DAS, through a destructive evaluation of the experiment, the biomass of the eggplants were determined. These were collected, fractionated and weighed for the determination of leaf fresh mass (LFM), stem fresh mass (SFM) and shoot fresh mass (SHFM). Then the material was packed in paper bags and placed in an air circulation oven at 65ºC for 72 hours for the determination of leaf dry mass (LDM), stem dry mass (SDM) and shoot dry mass (SHDM).

Table 1. Chemical and physical attributes of the soil used in the experiment

.... Chemical characteristics								
pH	**ECse**	**P**	**K^+**	**Na^+**	**Ca^{2+}**	**Mg^{2+}**	**Al^{3+}**	**$H + Al^{3+}$**
$CaCl_{2\ 1:2,5}$	**$dS\ m^{-1}$**	**$mg\ dm^{-3}$**	**..............................$cmol_c\ dm^{-3}$..............................**					
6.50	0.91	7.00	0.52	0.36	4.55	2.35	0.00	0.00

.... Physical characteristics						
Sand	**Silt**	**Clay**	**AD**	**DP**	**Total porosity**	**Textural class**
.... $g\ kg^{-1}$			**... $kg\ dm^{-3}$ ...**		**%**	
715	213	72	1.48	2.86	48	Sandy loam

pH – hydrogen potential, Ca^{2+} and Mg^{2+} extracted with 1 M L^{-1} KCl at pH 7.0; Na^+ and K^+ extracted using 1 M L^{-1} NH_4OAc at pH 7.0; Al^{3+}+ H^+ extracted using 0.5 M L^{-1} CaOAc pH 7.0; ECse – electrical conductivity of the saturation extract; AD - apparent density; DP –particle density

The data were analyzed using the analysis of variance by the F test ($p < 0.05$). The mean values of the irrigation levels were compared by F test ($p < 0.05$), which is conclusive for two factors from the same source of variation. Mean values for the silicon doses were analyzed by polynomial regression at 5% probability. Statistical software Sisvar version 5.6 was used for data analysis [17].

3. RESULTS AND DISCUSSION

According to the summary of the analysis of variance, there was a significant effect for interaction between irrigation levels and silicon doses for fresh leaf and stem masses, and for stem dry mass (Table 1). The irrigation levels provided significance for the initial and maximum fluorescence, quantum yield of photosystem II and the fresh and dry masses of the aerial part. The silicon doses promoted an isolated effect on the initial, variable and maximum fluorescence, quantum yield of photosystem II and on the dry and fresh masses of the shoot and dry leaves.

The 100% irrigation level provided higher efficiency of the photosynthetic apparatus, represented by the initial and variable fluorescence, presenting the largest increases of 161.05 and 530.7 quantum^{-1} electrons, respectively (Fig. 1A and 1B). The results obtained in the 50% Etr level shows a reduction of 5.58 and 7.92% regarding the level of 100%. Then, the greater availability of water to the plant provided, the greater absorption and translocation capacity of nutrients in the vegetal tissues. Thus, the higher availability of water results in lower transpiration losses, resulting in a greater nutritional contribution to the plant and improving the cooling of plant tissues through energy dissipation [18].

The quantum yield of photosynthetic II showed similarity to F0 and Fv, where the highest efficiency was obtained in the 100% Etr (0.78) level, presenting a superiority of 6.84% (Fig. 1C). This result shows that the plants irrigated with 50% of Etr promoted stress to the photosynthetic apparatus, since values below 0.75 quantum^{-1} electrons are considered stress conditions. The photosynthetic apparatus is intact when values vary between 0.75 and 0.85 quantum^{-1} electrons [19,20].

Results that validate those obtained by Magalhaes et al. [21], values of 0.78 for quantum efficiency of FSII in the level of 125% Etc found in common bean (*Phaseolus vulgaris* L.). Neves et al. [22] observed in sunflower (*Helianthus annuus*), values within the tolerable limits (0.75-0.85) of plants grown under ideal conditions of water regime.

The effect of the silicon doses on the initial fluorescence (F0) presented results that best fit the increasing linear effect of 164.81 quantum-1 electrons at the dose of 300 mg L^{-1} of Si (Fig. 2A). This increase in F0 rates can be considered destructive to the photosynthetic apparatus, since the uptake efficiency is reduced as F0 is raised, providing the FSII inactivation or the inhibition of excitation transfer between the antenna complex and the center of reaction [23].

It was observed for the variable and maximum fluorescence that the results fit the quadratic model, with the highest values in the plants submitted to the control treatment with 572.76 and 715.6 quantum^{-1} electrons, resulting in decreases of 9.6 and 4.9% in relation to the highest dose tested, respectively (Fig. 2B and 2C). The effect promoted by the Si on the fluorescence indices in this study differs from those obtained by Ferraz et al. [24] in cotton (*Gossipium hirsutun* L.), where they verified that the Si promoted increase in the maximum and variable fluorescence in the cultivars BRS Rubi and BRS Topázio. Maghsoud et al. [25] found that the application of 6 mM Si reduced the maximum fluorescence in wheat plants (*Triticum aestivum* L.).

The quantum yield of photosystem II behaved in a decreasing linear manner with the increasing doses of silicon at the maximum increment (0.795 quantum^{-1} electrons) in the control treatment, reaching a reduction of 7.5% at the maximum dose (300 mg L^{-1}) of Si tested (Fig. 2D). Thus, the application of Si promoted disturbances in the activity of FSII, reducing the photochemical efficiency and reducing the use and conversion of light energy. This effect is related to the increase of F0, promoting damage to the photosynthetic apparatus due to the decrease of FSII efficiency through the inactivation of reaction centers [26].

Al-Aghabary et al. [27] observed that the application of 2.5 mM Si increased the quantum yield of FSII in tomato plants (*Lycorpersicum esculenta* L.) under conditions of saline stress. Maghsoud et al. [25] verified that the application of 6 mM Si in wheat plants promoted an increase in the quantum efficiency of FSII.

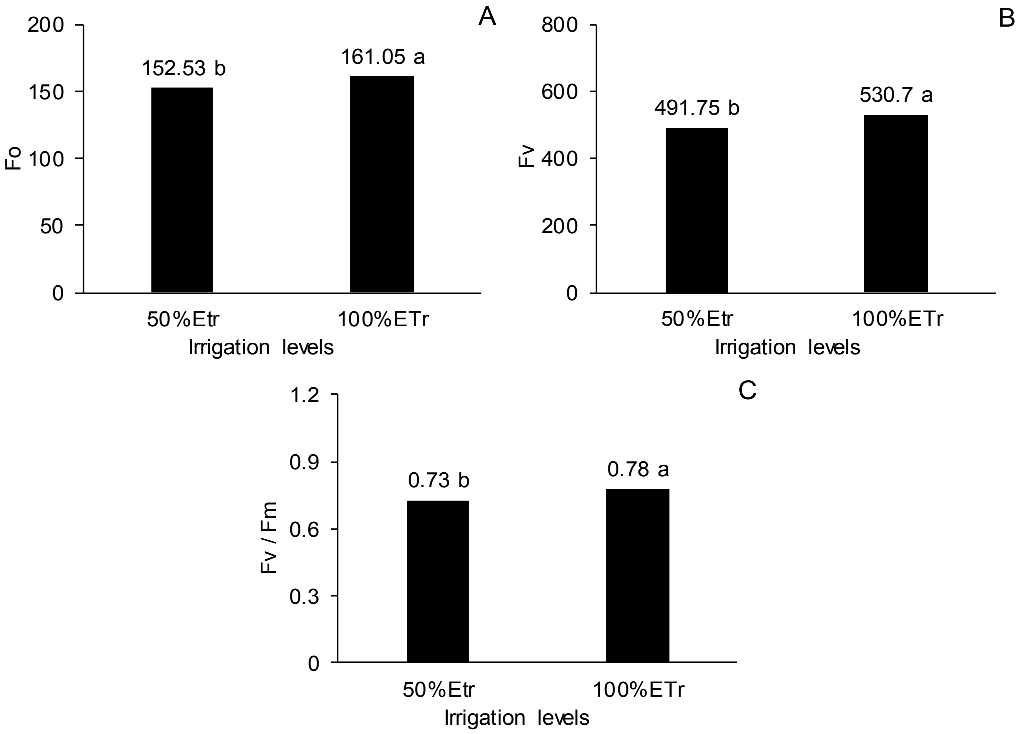

Fig. 1. Initial fluorescence - F0 (A), variable fluorescence - Fv (B) and quantum yield of photosystem II - Fv/Fm (C) treated with to different irrigation levels

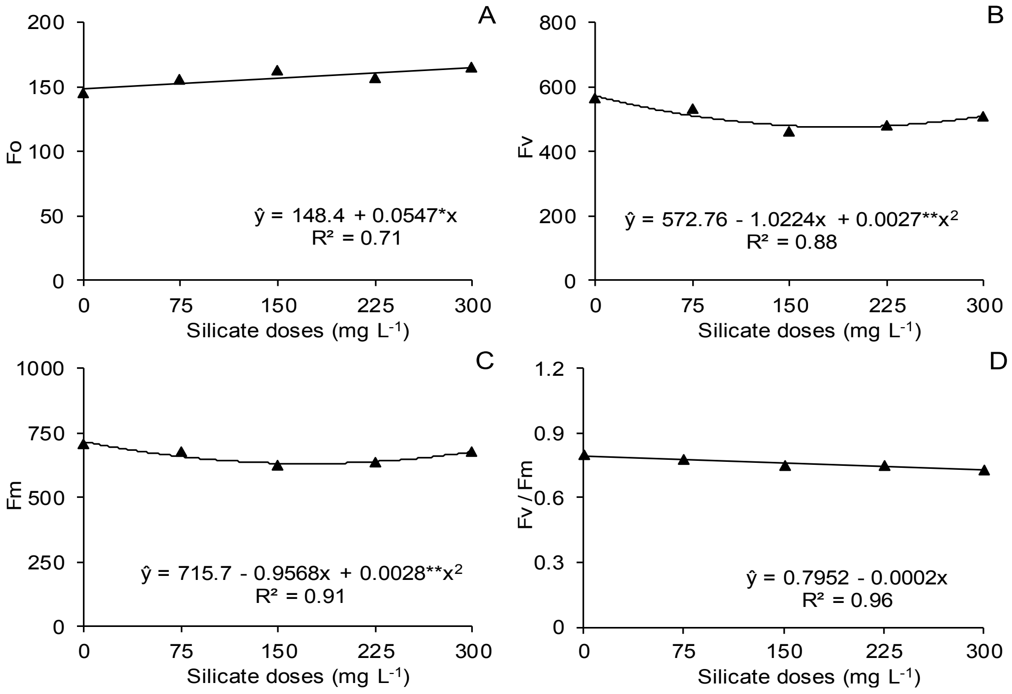

Fig. 2. Initial fluorescence - F0 (A), variable fluorescence - Fv (B), maximum fluorescence (C) and quantum yield of photosystem II - Fv/Fm (D) treated with to different irrigation levels

*** $P<0.01$; * $P<0.05$*

Table 2. Analysis of variance, by the mean square values for the initial fluorescence (F0), maximum fluorescence (Fm), variable fluorescence (Fv), quantum yield of photosystem II (Fv / Fm), stem fresh mass (SFM) and stem dry mass (SDM), leaf fresh mass (LFM) and leaf dry mass (LDM), shoot fresh mass (SHFM) and shoot dry mass (SHDM) of the eggplant treated with to silicate fertilization and irrigation levels

Source of variation	DF	Mean squares									
		F0	**Fm**	**Fv**	**FvFm**	**SFM**	**SDM**	**LFM**	**LDM**	**SHFM**	**SHDM**
Blocks	3	64^{ns}	28140^{**}	26026^{**}	0.0006^{ns}	783^{*}	117^{*}	80^{ns}	3.6^{ns}	798^{ns}	228^{**}
Irrigation levels (IL)	1	725^{*}	9517^{ns}	15171^{*}	0.0135^{**}	12179^{**}	3417^{**}	40^{ns}	1.1^{ns}	3023^{**}	2799^{**}
Doses Silicon (DS)	4	252^{*}	10674^{*}	10758^{*}	0.0016^{*}	1108^{**}	161^{**}	158^{ns}	9.7^{*}	841^{*}	168^{*}
Interaction (IL* DS)	4	34^{ns}	2213^{ns}	1530^{ns}	0.0005^{ns}	641^{*}	91.8^{*}	194^{*}	3.6^{ns}	141^{ns}	57.0^{ns}
Residue	40	100	4065	3336	0.0005	239	25.8	70	3.6	342	43.8
Averages		156.8	668.5	511.2	0.760	105.5	33.7	44.18	9.9	141.2	42.6
CV (%)		6.46	9.54	11.30	3.00	14.65	15.09	18.93	19.31	13.29	15.51

*** $P<0.01$; * $P<0.05$; $^{ns}P>0.05$*

It was verified for the fresh and dry masses of the stem the effect of the interaction between the irrigation levels and Si doses, with the maximum increments (140.8 and 48.1 g) in the plants irrigated with 100% Etr and submitted to the doses of 106 and 110 mg L^{-1} of SI, respectively (Fig. 3A and 3B). The plants irrigated with 50% ETr presented average values of 88.1 and 24.4 g plant^{-1} for the fresh and dry mass of the stem, reaching reductions of 59.8 and 97.1%. These results indicate that the application of Si promotes the development in plants under water deficit in function of promoting improvements in nutritional balance, providing a greater accumulation of Si in the cell wall and favoring the accumulation of biomass [28,12].

The accumulation of fresh leaf mass was superior in the 100% level ETr with 51.44 g in plants without silicate fertilization (Fig. 3C). While the application of 135 mg L^{-1} of Si promoted the increase (49.6 g) in leaf mass content in plants irrigated with 50% ETr. This effect suggests that decreasing water availability reduces leaf emission and mass production. Thus, the Si applied to plants with low water availability promotes improvements due to the deposition of Si in the roots, leaves and stem, reducing water loss through transpiration [12].

The silicon application linearly reduced the accumulation of dry matter, promoting losses of 21.2% when comparing the values of the lowest and highest dose applied (Fig. 3D). The absorption and translocation did not occur efficiently due to the low root and xylem activity of the transporter, since the increase of the applied dose does not guarantee that it is absorbed by the plant [28].

The fresh shoot mass behaved similar to the dry mass of the leaves, reducing the accumulation as a function of Si doses with losses of 15.6% when comparing the values of the lowest and highest dose applied (Fig. 4A). This response may be due to the cellular wall stiffness as a result of Si accumulation in the tissues, resulting in reduced leaf water potential [29] causing a low translocation capacity of photo-assimilates in the plant.

The effect of the 100% ETr irrigation level promoted the highest increases in fresh and dry shoot mass, increasing 13.1 and 48.7% compared to the values obtained in plants irrigated with 50% ETr (Fig. 4B). The water supply under reduced conditions may promote limitations to the stomatal activity and to the photosynthetic apparatus, resulting in the decline of the partitioning and accumulation of biomass by the plant [30].

The benefit of silicon fertilization on the accumulation of biomass in plants is still controversial, as in *Corymbia citriodora*, where the fertilization with Si did not have an effect on the fresh and dry masses of the roots and shoot [31]. The application of Si via irrigation water in melon (*Cuccumis melo* L.) did not have an effect on the accumulation of dry shoot matter and in total plant dry mass [28]. The leaf fertilization of 150 mg L-1 of Si in okra (*Abelmoschus esculentus* L.) plants under salt stress promoted increases of 40% and 36% in fresh and dry shoot mass and 32% and 25% in fresh and dry root mass, respectively [32].

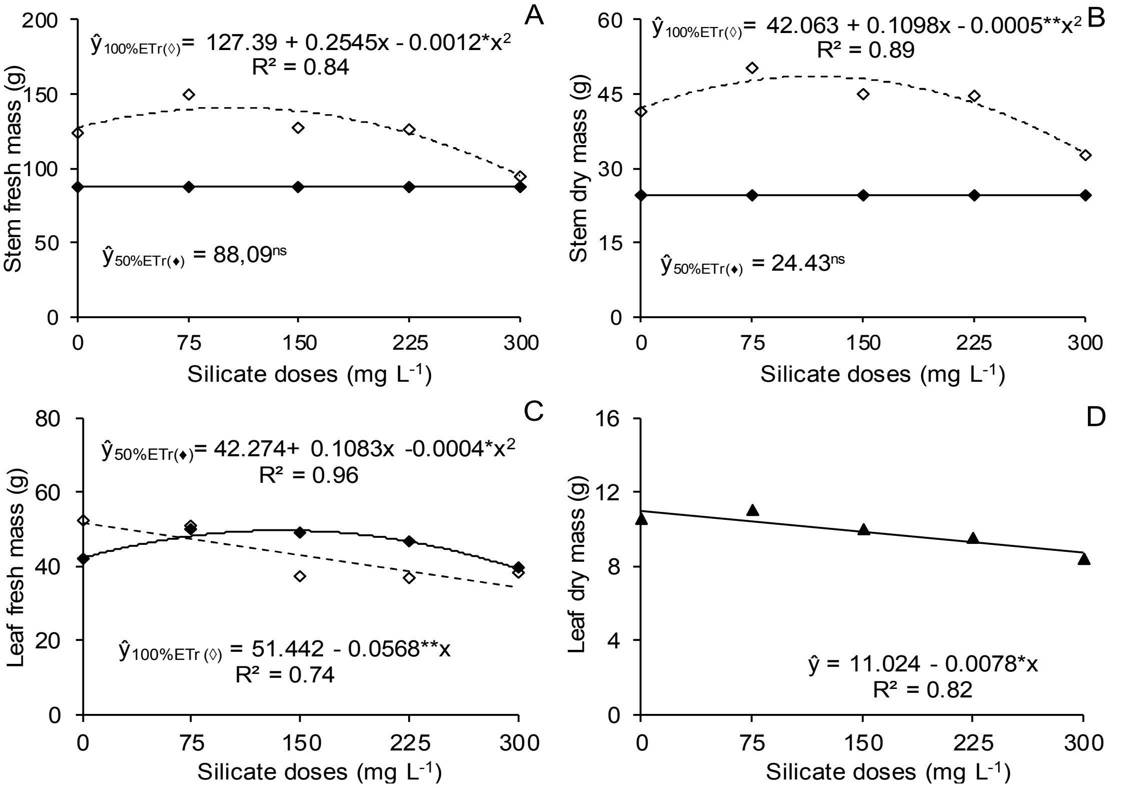

Fig. 3. Fresh (A) and dry matter of the stem (B), leaf fresh mass (C) and leaf dry mass (D) of eggplant treated with different irrigation levels and silicate fertilization

*** P<0.01; * P<0.05*

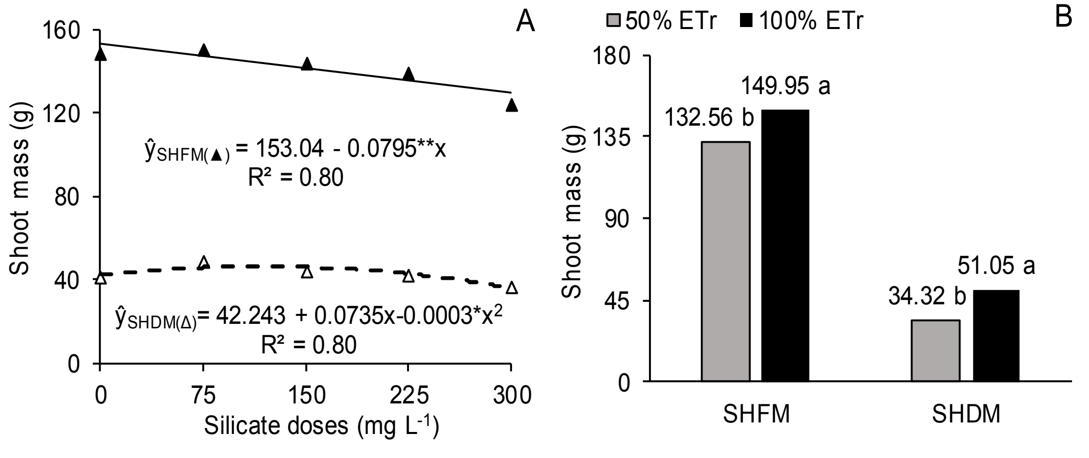

Fig. 4. Shoot mass (A) in function of doses of silicon and irrigation levels (B)

*** P<0.01; * P<0.05*

4. CONCLUSION

The fluorescence and biomass of the eggplant plants is reduced with the decrease in irrigation level; while the application of silicon does not result in increment in the fluorescence and dry mass of the leaf.

The 100% irrigation level of the ETr associated with the application of 108 mg L^{-1} of silicon resulted in the best results in stem mass accumulation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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