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Sorbitol and lithovit-guano25 mitigates the adverse effects of salinity on eggplant grown in pot experiment

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Abstract. This trial aimed to study the separate effects of nano-fertilizers and sugar alcohols in mitigating salt-stress on eggplant (*Solanum melongena* L) crop. For this purpose, two different concentrations of lithovit®-guano25 (A1:0.5 g L^{-1} and A2:1 g L^{-1}) and sorbitol (B1:5 g L^{-1} and B2:10 g L^{-1}) were sprayed on eggplant irrigated by three NaCl solutions (EC1:1.5 dS m^{-1}, EC2:3 dS m^{-1} and EC3 6 dS m^{-1}). Control plants were salt-stressed without any product. Results revealed an inhibitory effect of increasing in salt-stress on vegetative traits (plant height, leaf number, weights of plant parts and root mass fraction), reproductive traits (fruit number, fruit weight, yield $plant^{-1}$, fruit diameter) and photosynthetic pigments. Control plants at EC6 had the highest cell electrolyte leakage (51.26%). Plant height and fruit number were maximized by A1 at all salinity levels. Additionally, A2 increased fruit weight by 89.98g, 85g and 92.3g compared to control respectively at 1.5, 3 and 6 dS m^{-1}. Yield $plant^{-1}$ increased by this treatment at all EC levels. At 3 and 6 dS m^{-1}, A2-treated plants had the highest chlorophyll a (respectively 1.67 and 1.4mg g^{-1} fresh weight), total chlorophyll (respectively 2.38 and 1.9mg g^{-1} fresh weight) and carotenoids (respectively 193 and 172µg g^{-1} fresh weight) contents. A2-treated plants had the lowest cell electrolyte leakage at 1.5 dS m^{-1} (14.27%), 3 dS m^{-1} (25.31%) and 6 dS m^{-1} (37.78%). Treating plants with B1 and B2 maximized respectively fruit diameter at 1.5 dS m^{-1} and water content in all plant parts at 3 dS m^{-1}. Both products helped plants reducing the adverse effects caused by salinity.

Key words: growth, nano-fertilizers, physiology, salinity, sugar alcohols, S. *melongena*.

INTRODUCTION

The degradation of soil due to salinization is a main constraint faced worldwide (Qadir et al., 2008). Salinity and drought are considered as major factors affecting crop productivity, undesirable in front of high food demand for growing human population (Arshadi et al., 2018; Martinez et al., 2018; Zargar et al., 2018). Based on the report of the United Nations' Food and Agriculture Organization (FAO & ITPS, 2015), soil salinization expanding in an accelerated rate is causing food insecurity in many countries. This abiotic stress inhibits crop growth by reducing water potential in roots and preventing water uptake, leading to physiological and nutritional disorders (Negrão et al., 2017). According to Pessarakli & Szabolcs, (2010) NaCl is the most dominant salt, adversely affecting morphology and physiology of cell and whole plant. Sodium cation accumulated under salt-stress prevent the accumulation of the remaining vital nutrient such as potassium, magnesium, iron etc, leading to a decrease in the ratio of K^+ over Na^+ (Keutgen & Pawelzik, 2009). This ratio is considered as an indicator of salt-tolerance (Munns & Tester, 2008).

Eggplant (*Solanum melongena* L.) crop is one of the solanaceous crop affected by salinity. It is cultivated in tropical, subtropical and Mediterranean areas. This crop is classified as moderately sensitive to sensitive to salinity based on conflictin g Literature (Bresler et al., 1982; Maas, 1984). It ranked among the top most important vegetable crop in Asia in general and the Mediterranean in specific (Frary et al., 2007). Lebanon ranked number 34 in the year 2017 for the production of eggplant among all countries, producing approximately 43,606 tons (FAOSTAT, 2017). Salinity caused previously, reductions in yields, an inhibition in vegetative growth, and a decrease in germination rate and seedling dry weights of stressed eggplants (Heuer et al., 1986; Akinci et al., 2004; Assaha et al., 2013).

The use of nano-fertilizers on salt-stressed crop has proved to be highly efficient method. Many manufactories are nowadays producing nano-fertilizers with different forms and combinations of nutrients. Lithovit® products are among nano-particles based on limestone and supplemented with diverse compounds (amino25, guano25, urea50 etc) (Bilal, 2010). In agriculture, these products were previously used under non-stressed and stressed conditions; lithovit®-standard was applied previously on salt-stressed tomato crop (Sajyan et al., 2018, 2019a, 2019b). In such trials, lithovit®-standard improved salt-stress of tomato due to, a better nutrient and water uptake, and a well-developed vegetative and reproductive growth. Lithovit-amino25 showed a stimulatory effect when sprayed on grapevines by improving quality and quantity of the targeted crop (Sassine et al.,2019). Moreover, the biological efficiency and production of *Pleurotus ostreatus* was also enhanced by the application of lithovit-urea on the substrate (Naim et al., 2020). Lithovit®-guano25 is another formulation of lithovit (28% CaO; 5% MgO; 4.5% SiO_2; 1.5% N; 0.6% P_2O_5; 0.6% K_2O; 0.5% Fe). Based on the presence of carbonate, this nano-fertilizer have the ability to increase atmospheric CO_2 concentrations. Thus, improving photosynthesis activity and slowing respiration in plants. The composition of this product seems to be highly efficient under salt-stress especially due to its richness in vital elements such as N, P, K, Si, Ca, Mg and Fe. In previous works, these elements which were applied in different forms and combinations on stressed vegetables, improved growth and production of the targeted crops (El-Fouly et al., 2002; Tuna et al., 2007; Tantawy et al., 2009; Siddiqui et al., 2014; Sadak et al., 2015).

On the other hand, Sorbitol is an alditol found in higher plants. It has been considered a non-metabolite, because it is metabolically more inert character than other saccharides (Lambers et al., 1981). Biosynthesis of sorbitol is restricted mainly to source leaves whereas metabolic utilization is restricted to sink tissues. In all cases, sorbitol accumulation is considered as an adaptative response of plants to drought, salinity or chilling stress. Endogenous accumulation of many solutes and compounds as a result of abiotic-stress has been studied intensively as being among the natural mechanisms of stress-tolerance in plants (Munns & Tester, 2008). Previous studies pointed out the exogenous application of these compounds such as melatonin and glycine-betaine on salt-stressed crops such as tomato or others (Sajyan et al., 2019c; Zhan et al., 2019). Accordingly, ameliorative effects following the application of these compounds were observed. Exogenous application of sorbitol was less tested on stressed or non-stressed vegetables. On maize, sorbitol induced accumulation in dry matter and inhibition in biochemical and photosynthetic traits (Jain et al., 2010). Under salt-stress, sorbitol promoted the tolerance of spinach crop by improving photosynthetic pigments, carbohydrates and proteins (Gul et al., 2017). Therefore, its exogenous application could be highly efficient as a method to counteract the adverse effects of salinity.

Accordingly, the current study aimed to test the effect of separate foliar spraying of lithovit-guano25 and sorbitol in different concentrations on salt-stressed eggplant crop irrigated by different NaCl solutions.

MATERIALS AND METHODS

Plant growth, treatments and experimental design

Seeds of eggplant (Var Black Knight) were sown in plastic trays in late April-2019 in a greenhouse located at 33°52'24.9"N 35°31'44.0"E / Lebanon. Thirty days after sowing, uniform plants of 3–4 leaves were transplanted into pots of 40 cm in diameter. Pots were filled by a mixture prepared on volume basis of 33% peat moss and 67% soil (Table 1). During the experiment, plants were kept under ambient light conditions, a day-night temperature of 20–25 ± 5 °C and a relative humidity of 60–70%. Based on substrate test, monopotassium phosphate (52% P_2O_5 and 34% K_2O) and NPK (20% N, 20% P2O5 and 20% K_2O) were added with a rate of respectively 5 g plant^{-1} and 3 g plant^{-1} at 5 days after transplantation (DAT).

Table 1. Soil physico-chemical characteristics

Soil characteristics	
Sand	75.55
Silt	4.07
Clay	20.38
Texture (USDA Texture Triangle)	Sandy Clay Loam
pH (1:5 soil water suspension)	6.89
Organic matter content (%)	5.09
Total $CaCO_3$ (%)	5.3
ECe (dS m^{-1}, soil paste extract)	0.264
Organic N (%)	0.31
Available P_2O_5 (ppm)	40.25
Exchangeable K_2O (ppm)	117.33
Exchangeable CaO (ppm)	7,019.15
Exchangeable MgO (ppm)	1,315.5
Exchangeable Na (ppm)	28.53

The experiment was arranged in a randomized completely design (CRD) based on NaCl irrigations considered as main factor and product-treatments as sub-factor. NaCl irrigations were divided on three levels of three concentrations namely 1.5 dS m^{-1}, 3 dS m^{-1} and 6 dS m^{-1}, while product treatments were divided into two products namely lithovit-guano25 (A) and sorbitol (B) applied separately in two concentrations at eachNaCl solution. Product concentrations were as follows: A1:0.5 g L^{-1}; A2: 1 g L^{-1}, B1:5 g L^{-1} and B2: 10 g L^{-1}. Control plants were salt-stressed eggplant crop irrigated by three NaCl solution with no product application. Spraying of different concentrations of both products was done four times during growth cycle starting at 15DAT with an interval of 2 weeks. Saline irrigation started at 21DAT with an interval of 2–3 days.

Vegetative and yielding traits

During growth cycle of eggplant (100DAT), vegetative traits were measured: plant height and leaf number. At the end of growth cycle, plants were removed carefully from pots, washed and separated into roots, stems and leaves. Fresh weights (FW) of different plant parts were recorded. For the determination of dry weights (DW), parts were oven dried at 100 °C until a constant weight was obtained. Afterwards, water content (WC) and root mass fraction were calculated as follows: WC = FW-DW/FW, RMF = DW of roots/ DW of total plant parts. In addition, fruits number was counted in all treatments. After fruit harvesting, diameter and weight were measured using a sliding caliper and a digital balance. Yield per plant was calculated by multiplying fruit number at harvesting by average weight of individual fruits of each treatment.

Cell electrolyte leakage

Leaves were sampled at 70DAT for the determination of cell electrolyte leakage as described by Lutt et al. (1996). Fresh leaves were excised into discs of $1cm^2$ and water bathed at ambient temperature. After 24 hours, conductivity (EC1) of distilled water was measured. Afterwards, tubed were autoclaved at 120 °C for 20 min and conductivity (EC2) of the solution was measured again. Cell electrolyte leakage was calculated as follows: CEL = (EC1/EC2) ×100.

Chlorophyll and carotenoids content

Fresh leaves were sampled at 75DAT for the determination of leaf chlorophyll and carotenoid content. Photosynthetic pigments were determined by spectrophotometry as described and quantified by Arnon (1949) and expressed as mg g^{-1} FW of leaves.

Statistical analysis

Data was subjected to analysis of variance by using Statistical Package for Social Sciences (SPSS) software version 25® software. Means were compared by Duncan's multiple range tests at $p \leq 0.05$. All graphs and were performed on Microsoft Excel Software. The correlation between yield and some growth attributes was tested by regression analysis which was done on SPSS software.

RESULTS AND DISCUSSION

Vegetative and yielding traits

Data of vegetative and reproductive growth (Table 2) showed that increasing in salt-stress caused reductions in plant height, leaf number, fruit number, yield $plant^{-1}$ and fruit diameter. In fact, in non-treated plants, plant height, leaf number and fruit weight were reduced from 38.89 cm, 20.78 leaves and 25.02 g at 1.5 dS m^{-1} to reach a minimum of 24.44 cm, 5.44 leaves and 18 g respectively at 6 dS m^{-1}. Plant height and fruit number were significantly enhanced the most by A1 at all salinity levels. The remaining indicators were also significantly improved under all EC levels by different products. In specific, spraying of A2 increased fruit weight by 89.98 g, 85 g and 92.3 g compared to control respectively at 1.5, 3 and 6 dS m^{-1}. Accordingly, yield $plant^{-1}$ was maximized by A2 spraying at all EC levels. Moreover, treating plant with B1 enhanced significantly fruit diameter with the best effect observed at 1.5 dS m^{-1} compared to the remaining treatments. When comparing between both products, it was observed that product A was better mainly at higher EC levels compared to product B. Similarly, to previous indicators, salinity caused reductions in weights of plant parts (Table 3) peaking at 6 dS m^{-1}. Foliar spraying of various products with both concentrations enhanced significantly all indicators. Among all treatments, it was observed that foliar spraying of A2 at EC1.5, EC3 and EC6 dS m^{-1} maximized fresh weight of roots (respectively of 8.97 g, 7.16 g and 4.83 g), stems (respectively 24.72 g, 18.72 g and 15.38 g) and leaves (respectively 29.95 g, 30.45 g and 23.12 g) compared to all the remaining treatments including control at all EC levels. Accordingly, dry weights of A2-treated plants were also the highest among all treatments. On the contrary, it was observed that the application of sorbitol improved water content in roots, stems and leaves better that lithovit-guano25 with the best effect observed following B2 application.

Table 2. Effects of lithovit®-guano25 and sorbitol on vegetative and yielding traits of salt-stressed eggplant

Treatments	Plant Height (cm)	Leaf number	Fruit number	Fruit weight (g)	Yield plant^{-1} (g)	Fruit diameter (cm)
EC1.5/Control	38.89cde	20.78bc	1.00e	25.02j	25.02i	2.00j
EC1.5 / A1	46.78ab	25.56bc	6.00a	79.33e	476.00b	3.68hi
EC1.5 / A2	44.56bc	26.89ab	6.00a	115.24c	691.44a	6.44b
EC1.5 / B1	41.11bcd	27.44ab	3.00c	154.45a	463.35b	7.22a
EC1.5 / B2	43.89bcd	34.67a	2.00d	149.03b	298.07cd	6.61b
EC3 / Control	27.11f	11.33de	1.00e	20.00kl	20.00i	2.00j
EC3 / A1	50.67a	25.56bc	4.00b	70.13f	280.52d	5.01d
EC3 / A2	43.00bcd	26.89ab	3.00c	105.00d	315.00c	4.52ef
EC3 / B1	41.11bcd	27.44ab	4.00b	64.15g	256.59e	4.46f
EC3 / B2	37.22de	23.00bc	2.00d	79.25e	158.50f	5.21c
EC6 / Control	24.44f	5.44e	1.00e	18.00l	18.00i	1.50k
EC6 / A1	38.44cde	20.44bc	3.00c	23.47jk	70.40h	3.82gh
EC6 / A2	38.00cde	17.44cd	2.00d	55.15h	110.30g	4.70e
EC6 / B1	33.44e	11.67de	3.00c	20.06kl	60.17h	3.60i
EC6 /B2	38.33cde	17.44cd	2.00d	32.19i	64.39h	3.92g

A1 and A2 respectively 0.5 g L^{-1} and 1 g L^{-1} of lithovit®-guano25, B1 and B2 respectively 5 g L^{-1} and 10 g L^{-1} of sorbitol. Means *(n = 10)* followed by different letter within each column are significantly different according to Duncan's multiple range tests.

Table 3. Effects of lithovit®-guano25 and sorbitol on weights and water content of plant parts of salt-stressed eggplant

Treatments	FWR (g)	DWR (g)	WaR (%)	FWS (g)	DWS (g)	WaS (%)	FWL (g)	DWL (g)	WaL (%)
EC1.5/Control	5.2gh	3.9b	25.5j	16.6e	5.0b	69.7h	10.1j	4.7h	53.3k
EC1.5 / A1	7.4b	3.8b	48.5c	20.0c	5.5a	72.5g	27.9b	7.9c	71.8ef
EC1.5 / A2	9a	4.6a	49.2c	24.7a	5.4a	78.1c	30a	10a	66.8j
EC1.5 / B1	6.1e	2.6f	57.3a	21.0b	5.4a	74.1f	25.9c	6.9e	73.2d
EC1.5 / B2	6.6d	3.3d	50.6b	17.1e	2.9g	82.8a	20.3f	4.8h	76.6b
EC3 / Control	3.0j	2.4g	20.0k	12.0h	3g	75.3e	10.3j	5.0gh	51.5l
EC3 / A1	5.4gh	3.2de	40.7e	15.5f	3.8e	75.2e	19.5g	5.9f	70h
EC3 / A2	7.2c	3.9b	45.9d	18.8d	4.7c	74.7ef	30.5a	8.8b	71.2fg

Table 3 (continued)

EC3 / B1	5.6f	3.6c	36.6g	16.4e	4.4d	73.1g	25d	7.2d	70.8g
EC3 / B2	5.0hi	2.6f	48.6c	14.4g	3.6f	75.3e	15.8i	4i	74.9c
EC6 / Control	1.8l	1.5i	17.9l	9.2j	3.4f	63.1i	3.5k	2.4j	32.5m
EC6 / A1	3.1j	1.9h	39.9e	13.7g	2.9g	79.1b	18.5h	5.2g	72.2e
EC6 / A2	4.8i	3.1e	35.6h	15.4f	3.5f	77.3c	23.1e	7.3d	68.2i
EC6 / B1	2.3k	1.5i	34.4i	14.0g	3.3f	76.3d	15.1i	4.2i	72.5de
EC6 /B2	3.1j	1.9h	39.0f	11.1i	2.9g	74.1f	10.3j	2.1j	79.7a

FWR: fresh weight of roots; DWR: dry weight of roots; WaR: water in roots; FWS: fresh weight of stems; DWS: dry weight of stems; WaS: water in stems; FWL: fresh weight of leaves; DWL: dry weight of leaves; WaL: water in leaves. A1 and A2 respectively 0.5 g L^{-1} and 1 g L^{-1} of lithovit®-guano25, B1 and B2 respectively 5 g L^{-1} and 10 g L^{-1} of sorbitol. Means (n = *10*) followed by different letter within each column are significantly different according to Duncan's multiple range tests.

Root mass fraction (Fig. 1) decreased by 0.08 g g^{-1} with increasing in salt-stress from 1.5 dS m^{-1} to 6 dS m^{-1} in non-treated plants. However, treated plants despite the product and concentration of application had lower root mass fraction as compared to control at all EC levels.

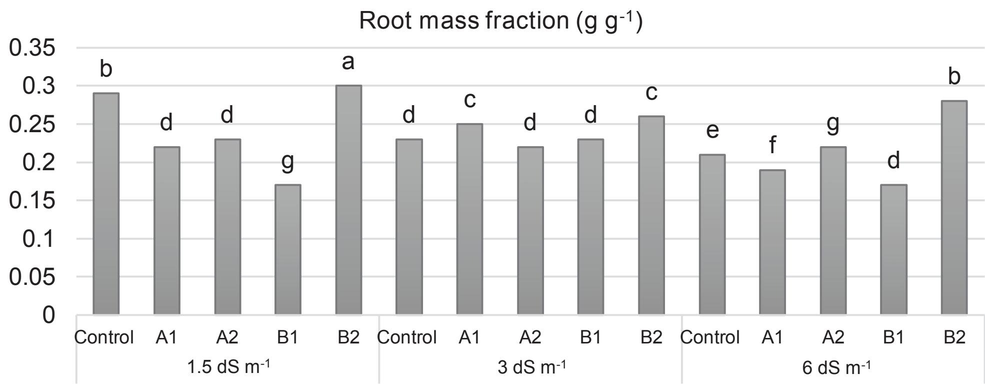

Figure 1. Effects of lithovit®-guano25 and sorbitol on root mass fraction of salt-stressed eggplant. A1 and A2 respectively 0.5 g L^{-1} and 1 g L^{-1} of lithovit®-guano25, B1 and B2 respectively 5 g L^{-1} and 10 g L^{-1} of sorbitol. Means (n = *10*) followed by different letter are significantly different according to Duncan's multiple range tests.

Cell electrolyte leakage

Cell electrolyte leakage (Fig. 2) was increased drastically with increasing in salt-stress from 1.5 dS m^{-1} (21.18%) to 6 dS m^{-1} (51.26%) reflecting a low membrane stability in stressed plants. All treatments reduced significantly cell electrolyte leakage from leaves. A2-treated plants had the lowest cell electrolyte leakage at 1.5 dS m^{-1}, 3 dS m^{-1} and 6 dS m^{-1} with respectively 14.27%, 25.31% and 37.78%. When comparing between both products, it was observed that spraying of lithovit-guano25 reduced cell electrolyte leakage more than sorbitol. Depending on the concentration, the application of the former reduced this indicator by a range of 3 to 10% compared to the application of the latter.

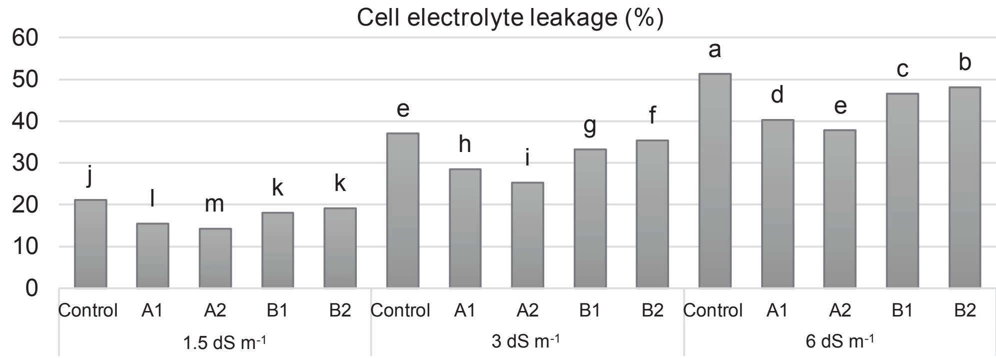

Figure 2. Effects of lithovit®-guano25 and sorbitol on cell electrolyte leakage of salt-stressed eggplant. A1 and A2 respectively 0.5 g L^{-1} and 1 g L^{-1} of lithovit®-guano25, B1 and B2 respectively 5 g L^{-1} and 10 g L^{-1} of sorbitol. Means (*n=10*) followed by different letter are significantly different according to Duncan's multiple range tests.

Chlorophyll and carotenoids content

Photosynthetic pigments including chlorophyll a, b and carotenoids were reduced with increasing in salt-stress with the lowest values obtained at non-treated plants at 6 dS m^{-1}. Chlorophyll a (Fig. 3) was enhanced by all treatments at EC1.5, EC3 and EC6 except B2 treatments. It was maximized by treatments includin g Lithovit-guano25 especially in high concentration (A2: 1 g L^{-1}). A2-treated plants had significantly the highest chlorophyll a content at EC3 and EC6 with respectively 1.67 and 1.4 mg g^{-1} fresh weight. Chlorophyll b and consequently total chlorophyll content were similarly affected by salinity and various treatments. In fact, A1-treated plants caused maximization of chlorophyll contents only at EC1.5. Consequently, the application of lithovit-guano25 seemed to be positively affected by increasing in the applied concentration. On the contrary, the application of sorbitol in lower concentration seemed to be better in enhancing chlorophyll contents more than its application in high concentrations. Carotenoids content (Fig. 4) was also improved the most by lithovit-guano25-treated plants and optimized by A2 application. This latter treatment improved carotenoids

Table 4. Effects of lithovit®-guano25 and sorbitol on the ratio of chlorophyll a over b and total chlorophyll over carotenoids

Treatments	Chlorophyll a/b	Total chlorophyll/ carotenoids
EC1.5/Control	2.57de	11.52b
EC1.5 / A1	2.33e	12.45a
EC1.5 / A2	2.41efg	11.37b
EC1.5 / B1	2.75bc	11.46b
EC1.5 / B2	2.60cd	11.26bc
EC3 / Control	2.55de	9.94d
EC3 / A1	3.09a	10.99bc
EC3 / A2	2.35de	12.33a
EC3 / B1	2.52def	10.64c
EC3 / B2	2.77bc	11.28bc
EC6 / Control	2.15f	8.71e
EC6 / A1	2.58de	11.42b
EC6 / A2	2.80b	11.05bc
EC6 / B1	2.52def	9.68d
EC6 /B2	2.76bc	8.16e

A1 and A2 respectively 0.5 g L^{-1} and 1 g L^{-1} of lithovit®-guano25, B1 and B2 respectively 5 g L^{-1} and 10 g L^{-1} of sorbitol. Means *(n = 3)* followed by different letter within each column are significantly different according to Duncan's multiple range tests.

at EC1.5, EC3 and EC6, by respectively 72, 22 and 20 mg g^{-1} fresh weight compared to control. Again, sorbitol spraying with high concentration (B2) did not improve this pigment as compared to control at E3 and EC6. On the contrary, B1-treated plants showed more or less some ameliorative effects compared to control regarding carotenoids content.

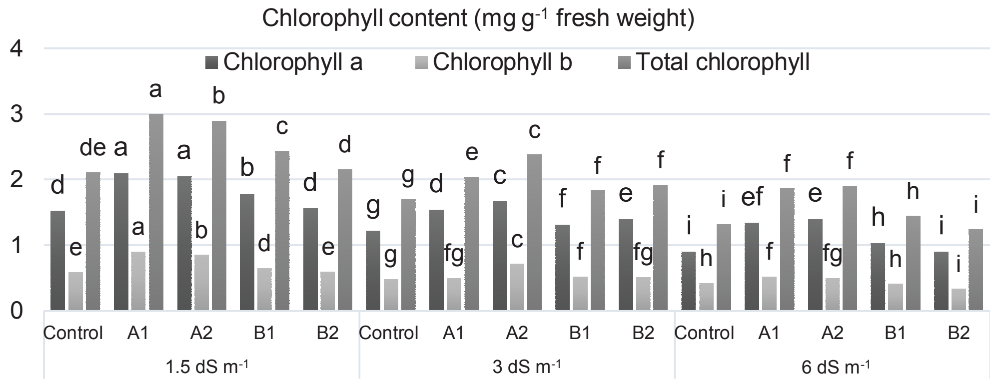

Figure 3. Effects of lithovit®-guano25 and sorbitol on chlorophyll content of salt-stressed eggplant. A1 and A2 respectively 0.5 g L^{-1} and 1 g L^{-1} of lithovit®-guano25, B1 and B2 respectively 5 g L^{-1} and 10 g L^{-1} of sorbitol. Means (*n = 3*) followed by different letter for each indicator are significantly different according to Duncan's multiple range tests.

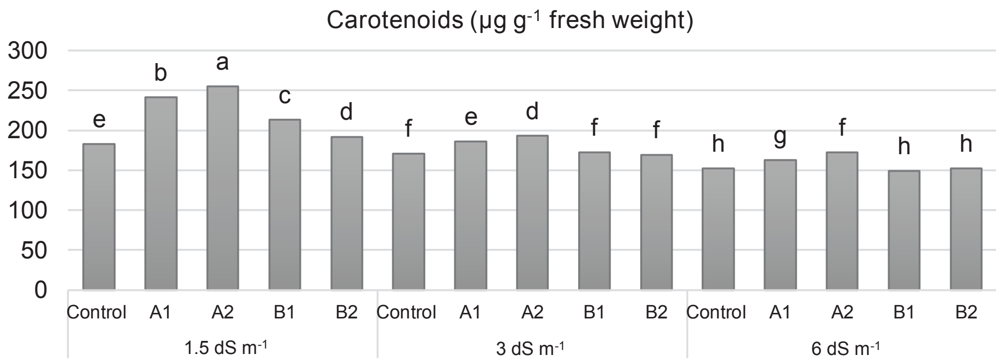

Figure 4. Effects of lithovit®-guano25 and sorbitol on carotenoids content of salt-stressed eggplant. A1 and A2 respectively 0.5 g L^{-1} and 1 g L^{-1} of lithovit®-guano25, B1 and B2 respectively 5 g L^{-1} and 10 g L^{-1} of sorbitol. Means (*n = 3*) followed by different letter are significantly different according to Duncan's multiple range tests.

The ratio of chlorophyll a over chlorophyll b (Table 4) was also reduced by salinity in control plants. However, plants treated with B1 (2.75), A1 (3.09) and A2 (2.8) had respectively the highest ratio respectively at EC1.5, EC3 and EC6 dS m^{-1}. Finally, the ratio of total chlorophyll over carotenoids, which was also lowered in control plants with increasing in salinity stress from 1.5 to 6 dS m^{-1}, was maximized in plants treated respectively with A1 (12.45), A2 (12.33) and A1 (11.42) at EC1.5, EC3 and EC6 dS m^{-1}.

Regression analysis

Results of regression analysis showed that yield plant^{-1} was significantly correlated the most with some traits (Fig. 5) and less with others. However, a linear relationship was observed between yield plant^{-1} and respectively fruit number ($R^2 = 0.673$; $Y = 1.04E^2x-77.05$) and fruit weight ($R^2 = 0.632$; $Y = 3.43x-12.49$). Moreover, a quadratic relationship was found between yield plant^{-1} and respectively fresh weight of roots ($R^2 = 0.847$; $Y = 12.05x^2-36.93x+52.42$), fresh weight of stems ($R^2 = 0.858$; $Y = 2.09x^2-24.79x+52$), fresh weight of leaves ($R^2 = 0.722$; $Y = 0.72x^2-5.66x+22.53$) and total chlorophyll content ($R^2 = 0.768$; $Y = 1.17E^2x^2-1.59E^2x+35.49$). The positive significant, regression coefficients of such independent variables indicate that increasing in their amount will promotes yield plant^{-1}. In other terms, the application of various treatments in the current study under different salinity level enhanced yielding capacity of stressed eggplant due to an improve in, fruit number and weight, fresh weights of plants parts and photosynthetic pigments.

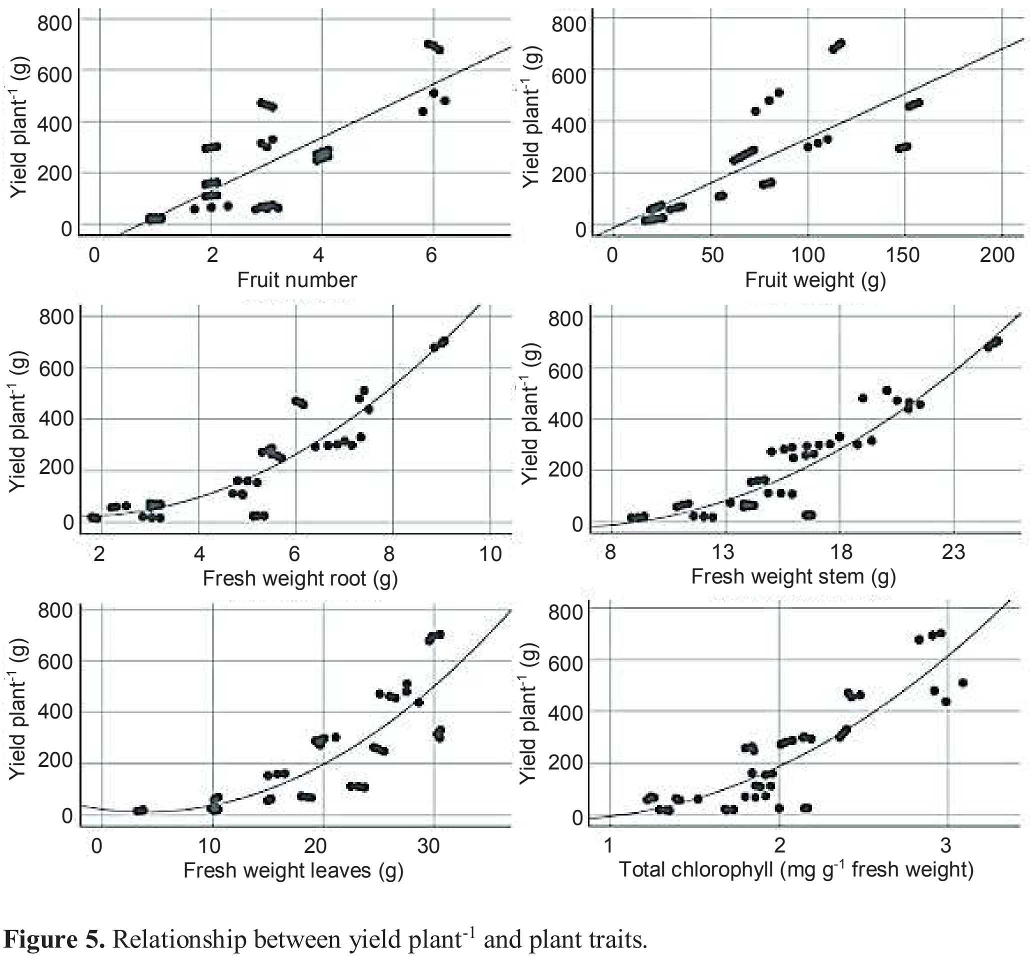

Figure 5. Relationship between yield plant^{-1} and plant traits.

In the current experiment, increasing in salt-stress from 1.5 dS m^{-1} to 6 dS m^{-1} caused severe reductions in the majority of the measured traits mainly yielding capacity, photosynthetic pigments and vegetative growth. Previously, several authors reported the inhibitory effects of salinity on vegetables including eggplants, eggplant, tomato etc. (Cabãnero et al., 2014; Machado & Serralheiro, 2017; Sajyan et al., 2019d). Based on such findings, the accumulation of sodium in the roots zone causes an osmotic stress, preventing the accumulation of important nutrients (K^+, Ca^{2+}, and NO_3^-) (Paranychianakis & Chartzoulakis, 2005). Reductions in yielding capacity of eggplant was previously reported by Gül & Sevgican (1992) due to inhibition in water flow towards fruits, leading to reductions in fruit weight and number. Taiz & Zeiger (2002) stated that the accumulation of detrimental ions leads to, a damage in chloroplast membrane and an inhibition in protein synthesis. Similar findings were observed in the current study were salinity increased cell electrolyte leakage and reduced photosynthetic pigments in stressed non-treated plants.

The application of lithovit®-guano25 and sorbitol showed ameliorative effects on stressed eggplant. lithovit®-guano25 applied in high concentration (A2: 1 g L^{-1}) maximized yielding capacity and traits of eggplant more than sorbitol. The former product was not previously tested on vegetables under salt-stress. In fact, lithovit is available in many formulations (such as urea 50%; boron; guano 25%; amino acids 25%, etc.). The mutual point among all formulations is the presence of carbonate coupled with calcium and magnesium. Such products have the ability to slow down respiration and promotes photosynthesis process though increase in atmospheric CO_2 (Bilal, 2010). This promoting effect was observed following the application of lithovit®-guano25 through an increase in photosynthetic pigments (chlorophyll a, chlorophyll b, total chlorophyll and carotenoids). This product also improved weights and water content of plant parts reflecting a better water movement and potential in stressed plants compared to control. In previous study, the application of lithovit product on salt-stressed tomato did not improved fresh weight of plant parts (Sajyan et al., 2019a). Contradictory findings were reported on such effects. However, one of the important factors of lithovit®-guano25 product is its richness in nutrients in nanoscale (nitrogen, potassium, phosphorus, calcium, iron, silicon, magnesium). Its nano-particle size makes easier the contact with pores of leaves and faster its translocation in plant vessels (xylem and phloem) (Rico et al., 2011). According to Taiz & Zeiger (2002), foliar spraying of a nano-fertilizer is highly efficient for cations (mainly iron, calcium and magnesium and manganese), it increases the availability of nutrient. As mentioned previously, foliar spraying of lithovit-guano was not tested previously on stressed and non-stressed vegetables. However, compounds that are found in lithovit-guano were separately applied and promoted stimulatory effects. For instance, foliar spraying of Ca improved fruit number, decreased Na and increased Ca and K contents of salt-stressed tomato crop (Tuna et al., 2007; Nizam et al., 2019). In addition, the separate application of magnesium also maximized plant growth and production of tomato and strawberry under salt-stress (Carvajal et al., 1999; Yildirim et al., 2009). The application of iron nanoparticles improved yielding components of drought-stressed safflower and salt-stressed sunflower by promoting photosynthesis activity and reducing Na accumulation (Davar et al., 2014; Torabian et al., 2017). In fact, iron play a role in chlorophyll synthesis where it enters in many mechanisms related to photosynthesis and respiration such as oxido-redox reactions (Curie & Briat, 2003). In addition, the presence of Si in oxide form seemed to activate the defense mechanism facing salt-stress. similarly, Siddiqui et al. (2014) stated the effect of silicon oxide on squash plants under salt-stress. Si application also improved water use efficiency and photosynthesis of salt-stressed tomato (Romero-Aranda et al., 2006). Basically, similar results were observed in the current study where it seemed that the amelioration in photosynthetic pigments (Chlorophyll and carotenoids) was due to a sufficient supply by Mg, Ca, Fe and Si.

On the other hand, sorbitol product which showed significant effects when applied in low concentrations, had adverse effects when applied in high concentrations. Sorbitol accumulation is considered as an adaptative response of plants to drought, salinity or chilling stress. Biosynthesis of sorbitol is restricted mainly to source leaves whereas metabolic utilization is restricted to sink tissues (Escobar Gutiérrez & Gaudillère, 1996). The restricted positive effect of sorbitol is due to a protecting role played on cytoplasmic proteins and cell membranes from desiccation. Such effects are equally observed by sugar alcohols (sorbitol and mannitol) and osmoregulators (proline, betaines etc.) (Balal et al., 2012). As a result, low concentration of sorbitol enhanced cell membrane stability and improved yielding capacity of stressed eggplant rather than high concentrations. Sorbitol treatment was less efficient compared to lithovit-guano. However, compared to control, its application caused stimulatory effects (mainly with low concentrations) on photosynthetic pigments, yielding traits and vegetative attributes. Similar findings were reported by Gul et al. (2017) on stressed spinash. On maize, sorbitol induced accumulation in dry matter and inhibition in biochemical and photosynthetic traits (Jain et al., 2010). Additionally, on salt-stressed rice seedlings, sorbitol application improved more or less tolerance of the crop by reducin g Lipid peroxidation (malondialdehyde) and H_2O_2 (Theerakulpisut & Gunnula, 2012). Noteworthy, sugar alcohols including sorbitol, mannitol are endogenously accumulated in stressed plants and confer tolerance to abiotic stress (Williamson et al., 2002). This ability is due to the effect of polyols on osmotic balance, water movement in the apoplast and sodium sequestration to the vacuole (Kanayama et al., 2006). This ability protects provide protection to cell membrane. This was reflected in the current study by a reduction in cell electrolyte leakage following sorbitol spraying. Conclusively, both products had different mechanisms by which they helped plants in counteracting the adverse effect of salinity.

CONCLUSIONS

From the current study, it could be concluded that lithovit®-guano25 was more beneficial on such stress more than sorbitol. The rate of application was a limiting factor for sorbitol where increasing in its application rate caused adverse effects. For lithovit®-guano25, the opposite was observed; its application in higher rates was the most efficient treatment and helped in mitigating the negative effects of salinity on eggplant.

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