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Full Length Research Paper

Photosynthetic pigments, nitrogen status, and flower behavior in eggplant exposed to different sources and levels of potassium

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The aim of this study was to investigate (i) the influence of different sources and levels of potassium on photosynthetic pigments, (ii) measure nitrogen status in leaf, (iii) evaluate flower behavior in eggplant (*Solanum melongena* L.), and (iv) to identify a better potassium source to cultivation of this species. The experiment design used was in factorial scheme with randomized blocks, being composed by 2 potassium sources (KCl and K_2SO_4), combined with 4 levels of K_2O (250, 500, 750 and 1000 kg ha^{-1}). Nitrogen accumulation in leaf at 50 days after transplanting had a higher value with KCl compared with K_2SO_4. Results linked to aborted fruits presented similar effects to KCl and K_2SO_4. This study revealed that eggplant exposed to excess potassium did not have a negative effect on chlorophyll a and b, and nitrogen concentration in leaf was significantly modified due to increase in potassium level. In addition, greater levels of potassium produced negative consequences linked to flower and fruit abortion. Therefore, potassium source indicated for eggplant is potassium sulfate.

Key words: *Solanum melongena* L., potassium, flower, pigments, nutrition plant.

INTRODUCTION

Eggplant (*Solanum melongena* L.) is a horticultural species that has been largely consumed in the world due to medical and nutritive potentials (Kittas et al., 2006; Raigón et al., 2008). Kayamori and Igarashi (1994) studying an anthocyanin extracted of *S. melongena L.* reported that this fruit promotes reduction of the total cholesterol in rats. Vinson et al. (1998) described that eggplant fruit contain high ascorbic acid and phenolic contents, both being powerful antioxidants. The major limitations to the cultivation of eggplant are related to the low availability of water and nutrients in the soil during the cycle. The response of plant species to abiotic factors such as salinity and water stress has been little studied in the culture of eggplant (Oliveira et al., 2008).

Currently domestic production of potash fertilizer in Brazil as K_2O is above 16% and import is 83% (Potafos, 2010). The main potassium fertilizer used in agriculture is potassium chloride (KCl) followed by potassium sulphate (K_2SO_4) to a lesser extent. Potassium sulfate is less “salty” than the potassium chloride. Its salt content per unit of K_2O is half the rate of potash, which makes it

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more suitable for soils with a tendency to salinization (Nogueira et al., 2001). Potassium has a number of functions related to plant energy storage. Among the various functions is improved efficiency of water use, due to control of stomata opening and closing (Malavolta, 1996).

Other aspect of potassium is linked to assimilation, because under adequate supplement in soil, the plant absorption of potassium can be four times higher than that of phosphorus, and equal to or greater than nitrogen. Akram et al. (2007) described beneficial effects of the exogenous application of K^+ in *Helianthus annuus* plants induced to salt stress.

Growth and adaptation of a species to environment is related with its reproductive efficiency, and this aspect also is linked to photosynthetic pigments, because adequate work of photosynthetic apparatus can produce greater number flowers and consequently fruits (Almeida et al., 2004). Researchers (Furlani Junior et al., 1996; Silveira et al., 2003) have used chlorophyll level to evaluate plant nutritional state in relation to nitrogen (N), because chlorophyll molecule is constituted by nitrogen, and there is a strong relationship between chlorophyll and nitrogen level.

Excessive fertilization normally promotes an increase in salinity soil, and this condition can be reached by the frequent use of large amounts of chemical compounds in mineral nutrition of plants. Besides being a problem for the soil, there are other negative consequences for plant, such as decreases in growth, and yield (Medeiros et al., 2009).

Study conducted by Zhang et al. (2004) working *Scaevola aemula* plants on different potassium levels revealed significant effects on flower number. In addition, number and quality of fruit is an important parameter linked to eggplant production, which it suffers interference of potassium supply as reported by Costa et al. (2004) studying *Cucumis melo* plants. In other hand, potassium deficiency promotes decrease in photosynthetic pigments such as chlorophylls, besides affect photosynthesis rate and chloroplast structure (Zhao et al., 2001).

Based in this overview, the aim of this study was to (i) investigate the influence of different sources and levels of potassium on photosynthetic pigments, (ii) measuring nitrogen status in leaf, (iii) evaluating flower behavior, and (iv) to define a better potassium source for cultivation of eggplant (*S. melongena L.*).

MATERIALS AND METHODS

Experimental and climate conditions

Study was conducted in Departamento de Produção Vegetal – Horticultura of Universidade Estadual Paulista (UNESP), Botucatu city, São Paulo State, Brazil (22°51'S and 48°26'W). Plants were grown under greenhouse environment in altitude of 815 m and climate classification using Koppen description of Cwa (Cunha and Martins, 2009). The medium photoperiod was 12 h under light and air temperature minimum/maximum of 17/23°C, respectively.

Soil characteristics

Soil used in this study is classified as red dystroferric latosol (Embrapa, 1997), with medium texture composed by 615, 45, and 340 g kg^{-1} of sand, silt, and clay, respectively. The soil chemical analysis following procedure described by Raij et al. (1996) presented pH 4.1, OM 17g kg^{-1} P 2 mg dm^{-2}, and 0.2, 2 and 1 mmolc dm^{-3} of K^+, Ca^{+2} and Mg^{+2}, respectively.

Soil treatment and pots

The soil correction was promoted with dolomitic limestone and soil base saturation was maintained at 80% (Raij et al., 1996). This adjusted soil was filtered with sieve of 5 mm and placed into pots with capacity of 32 L. Subsequently, the nitrogen (N) and phosphorus (P) supplementations were based on previous studies of this crop: 3.2 g of ammonium sulfate, 28.2 g of phosphate thermo master and 160 g organic matter in each pot.

Plant material and seedling obtaining

The eggplant seeds of cv. Embu were placed to germinate in containers with sterile substrate denominated Plantmax® and watered with distilled water. The seedlings were transplanted from container to pots at the 35th day after experiment implementation, in which 3 or 4 definitive leaves were present. In addition, one plant per pot was used in this study.

Experimental design

The experimental design used was factorial scheme with randomized blocks (2 × 4), 2 potassium sources (KCl and K_2SO_4) combined with 4 potassium levels (250, 500, 750 and 1000 kg $K_2O.ha^{-1}$). This experiment was composed of 5 replicates and 40 experimental units, therefore 1 plant in each unit.

Experimental conditions

The pots were distributed into greenhouse with spacing of 0.60 and 1.00 m between plant and line, respectively. Staking of plants was conducted with metallic rods during experiment. The lateral stems were shortened until height of first flower, being maintained only 4-5 lateral stems. The fertilization started on 15th day after transplanting and applied in constant intervals of 15 days. The fertilization was performed using as N source the calcium nitrate at 22.8 g pot^{-1} divided in 14 applications. The fertilization for K was made from two sources, chloride and potassium sulphate, as described in Table 1.

Irrigation

The irrigation was performed based on data from soil water matrix potential, which was measured with tensiometer placed in pot medium point under distances of 0.2 and 0.15 m of the primary root and soil surface, respectively. The soil matrix potential was maintenance during experiment in -30 kPa.

Table 1. Total amount of KCl and K_2SO_4 used for soil fertilization, with the proposed treatment.

Treatment (kg.ha^{-1})	KCl (58% K_2O) (g.pot^{-1})	K_2SO_4 (44% K_2O) (g.pot^{-1})
Treatment 250	6.81	8.31
Treatment 500	13.63	16.76
Treatment 750	20.44	25.14
Treatment 1000	27.26	33.52

Table 2. Chlorophyll *a* levels in eggplant exposed to different sources and levels of potassium.

Levels (K_2O kg ha^{-1})	Chlorophyll *a* (µg.cm^{-2})							
	KCl				K_2SO_4			
	Treatments							
	30	60	90	110	30	60	90	110
250	1.00 Aa	1.02 Ba	0.98 Aa	1.31 Aa	0.99 Aa	1.02 Aa	1.04 Aa	1.73 Aa
500	0.99 Aa	1.32 Aa	1.03 Aa	1.70 Aa	0.98 Aa	1.02 Aa	1.00 Aa	0.99 Aa
750	0.98 Aa	1.42 Aa	1.01 Aa	1.21 Aa	1.00 Aa	1.06 Aa	0.99 Aa	1.46 Aa
1000	1.00 Aa	1.34 Aa	0.98 Aa	1.29 Aa	1.01 Aa	1.00 Aa	0.99 Aa	1.10 Aa

Averages followed by the same lowercase letter comparing potassium sources (KCl and K_2SO_4) in same period, and uppercase letter comparing potassium levels (250, 500, 750 and 1000 kg K_2O. ha^{-1}), do not differ among themselves by the F test at 5% of probability.

Photosynthetic pigments

Chlorophyll a and b were determined using leaf disk with 1.04 cm^2 of diameter. Tissue samples were homogenized with 1 ml of dimetilformamide and stored in the dark at 10°C for 48 h. Chlorophyll a and b were quantified using a spectrophotometer according to the methodology described by Lee et al. (1987). The leaf pigments were expressed in µg cm^2.

N and K contents in leaf

To determination of nitrogen and potassium was used fourth leaf starting from apex. Leaves were harvested 50 and 110 days after transplanting, and procedure was based in methodology described by Malavolta et al. (1997).

Flower and fruit evaluations

Flower number, aborted flower number, and aborted fruit number were measured at regular intervals of 2 days, beginning from the 48th day after transplanting until harvest period. Five plants per treatment were evaluated for these parameters. In aborted flower number was obtained by subtraction among actual evaluation and previous evaluation. Aborted fruit number was evaluated in fruit harvest period.

Data analysis

Data were subjected to analysis of variance (F test), and the results of chlorophyll a and b obtained are presented in Tables 1 and 2. In addition, other parameters evaluated were applied F test and test of polynomial regression to first or second-order, in which there was a significant effect, as recommended by Ferreira (1999) and Steel et al. (2006).

RESULTS AND DISCUSSION

Photosynthetic pigments

Chlorophyll *a* level in leaf did not indicate significant differences due to sources KCl and K_2SO_4. However, in samples collected in 60th day after transplanting and exposed to KCl were showed higher levels of chlorophyll a, compared with other potassium levels in same period (Table 2). In addition, chlorophyll *b* was not significantly different, and it was at higher values in treatments with lower potassium levels (Table 3) during 30 and 110 days after transplanting, independently potassium sources (KCl and K_2SO_4). These data suggest that salinity did not affect chlorophyll content in eggplant leaf during experimental period and potassium concentrations evaluated.

In this study, greater concentration of potassium can have induced the reduction in chlorophyll a/b ratio of eggplant (Figure 1).

These results on photosynthetic pigments suggest that higher potassium levels reduced pigment production in eggplant. In other words, reductions showed in this species under salt stress can be strongly related with lower capacity of synthesis or higher chlorophyll degradation. Seedlings conserve, in part, their capacity for chlorophyll synthesis, due to constant process of

Table 3. Chlorophyll *b* levels in eggplant exposed to different sources and levels of potassium.

Levels (K_2O kg ha^{-1})	Chlorophyll *b* (µg.cm^{-2})							
	KCl				K_2SO_4			
	Treatments							
	30	60	90	110	30	60	90	110
250	0.63 Aa	0.60 Aa	0.57 Aa	0.75 Aa	0.61 Aa	0.58 Aa	0.61 Aa	1.54 Aa
500	0.59 Ba	0.75 Aa	0.60 Aa	0.93 Aa	0.60 Aa	0.60 Aa	0.57 Ab	0.57 Bb
750	0.59 Ba	0.85 Aa	0.58 Aa	0.68 Aa	0.60 Aa	0.62 Aa	0.57 Aa	0.81 Ba
1000	0.59 Ba	0.78 Aa	0.56 Aa	0.74 Aa	0.59 Aa	0.58 Aa	0.57 Aa	0.63 Ba

Averages followed by the same lowercase letter comparing potassium sources (KCl and K_2SO_4) in same period, and uppercase letter comparing potassium levels (250, 500, 750 and 1000 kg K_2O. ha^{-1}), do not differ among themselves by the F test at 5% of probability.

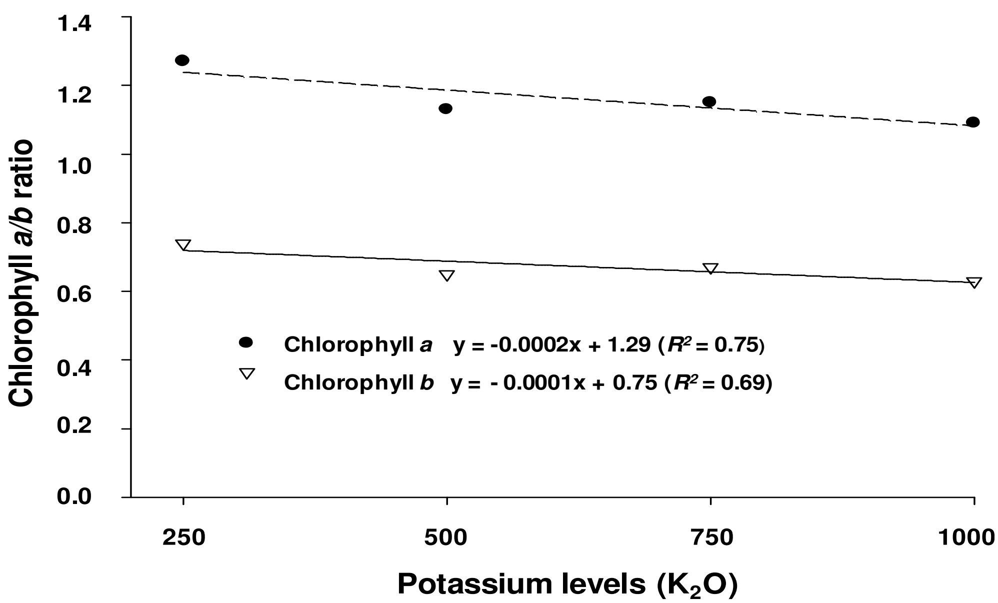

Figure 1. Chlorophyll *a/b* ratio in eggplant exposed to different sources and levels of potassium.

degradation and synthesis during growth and development (Lichthenthaler, 1987).

Results on photochemical damages showed in this research are similar with those found by Allakhverdiev et al. (2000), in which there is strong evidence that cells subjected to salt stress presented lower rate of electron transport between photosystems. Minor electron transport possibilities reduced ATP and NADPH productions, in which are essentials to biochemical fixation of carbon compounds, and these modifications in metabolism induced by salinity are consequences of several plant physiological responses such as changes in ionic balance, stomatal behavior, and photosynthetic efficiency. In addition, reduction in photosynthesis produced by salinity is related to stomatal closing and produced as consequence of inhibition in carbon fixation (Heuer, 1997).

Nitrogen accumulation

Nitrogen accumulation in leaf during 50 days after transplanting was at a higher value with KCl, if compared with K_2SO_4 (Figure 2A). KCl application promoted increase in this parameter proportional to potassium level, however when used K_2SO_4 in different levels were obtained oscillation in values of nitrogen accumulation.

In 120 days after transplanting, accumulation in K_2SO_4 was higher compared with KCl (Figure 2B). Nitrogen accumulation in leaf decreased in treatments using 500, 750 and 1000 kg K_2O. ha^{-1} for both fertilizer types, in relation to application of 250 kg K_2O. ha^{-1}. These results suggest that salt stress produced by potassium reduced nitrogen amount absorbed by plant, and this fact is also showed by Pessarakli et al. (1989) investigating concentration of this nutrient in young leaves of

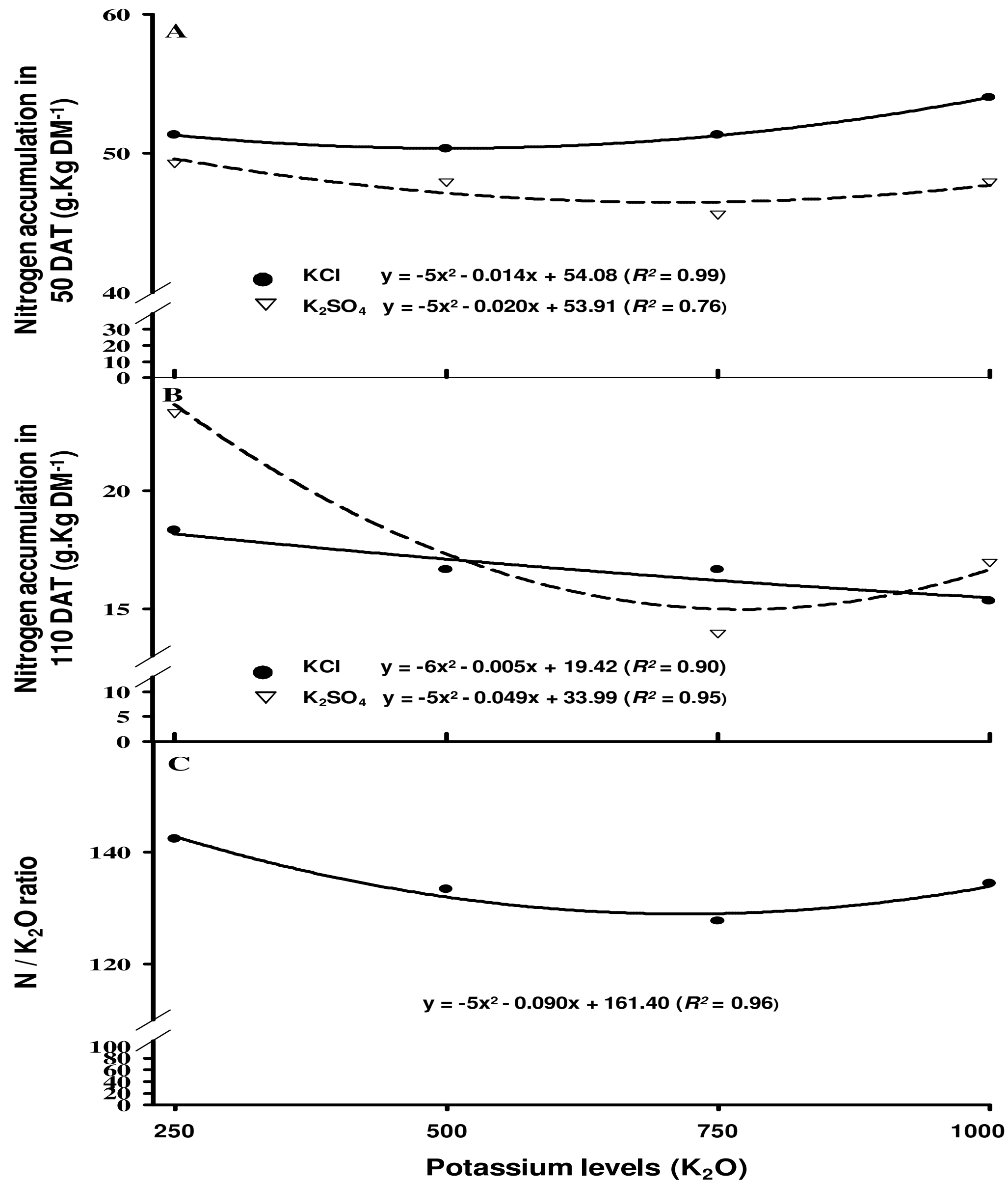

Figure 2. Nitrogen accumulation in leaf during 50 (A) and 120 (B) days after transplant, and N/K_2O ratio (C) in eggplant exposed to different sources and levels of potassium.

Phaseolus vulgaris plants. In addition, an increase in water salinity can provoke problems of toxicity and reduction in absorption of several nutrients such as nitrogen.

Results linked to N/K_2O ratio in leaf describes decrease in N accumulation produced by increase in K_2O (Figure 2 C), and higher value showed in this study was obtained in 250 Kg K_2O ha^{-1}.

Therefore, other levels evaluated cause negative effects that probably can be explained by salinity. Salt stress produced by potassium promotes interference on metabolism, resulting in ionic toxicity and disequilibrium nutritional (Werner and Finkelstein, 1995). In addition, this toxic action induced by potassium is, in part, provoked by inadequate nutrient acquisitions such nitrogen and phosphorus.

Flower and fruit behaviors

In relation to flower, number had similar effects independent of potassium source used (Figure 3A), and quadratic equations was obtained in both potassium treatments (KCl and K_2SO_4). In addition, treatment with

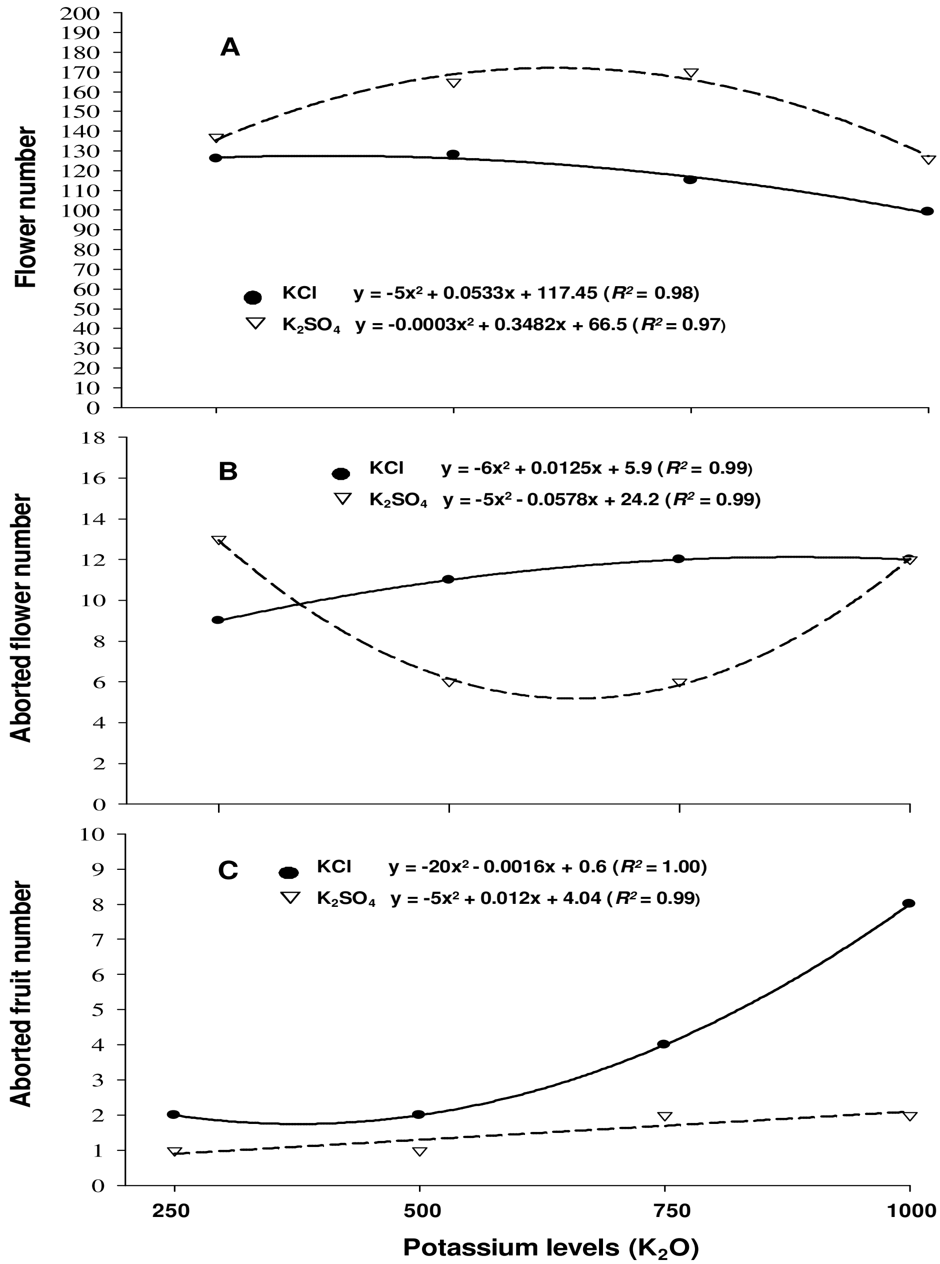

Figure 3. Flower number (A), aborted flower number (B), and aborted fruit number (C) in eggplant exposed to different sources and levels of potassium.

K_2SO_4 promoted higher flower number independently of dose used. Points with maximum value of 128 and 170 flowers produced by KCl and K_2SO_4 were estimated in 500 and 580 Kg ha^{-1}, respectively (Figure 3A). Higher flower production with K_2SO_4 can be related to minor salinity produced in soil, compared with KCl. Large and regular applications of fertilization based on KCl are normally associated with an increase in chloride level in plant and induction of chlorosis and necrosis in leaf, flower drop and consequent decrease in yield. Brandão Filho (2001) working with eggplant hybrid showed 180 flowers per plant. Results found in this study suggest that KCl promoted mineral stress.

Flower aborting showed significant interaction between factors (sources and doses). With K_2SO_4 there are reductions in applications of 500 and 750 kg ha^{-1} K_2O (Figure 3B). Probably higher flower aborting in sub-optimal dose can be associated with nutritional insufficiency. On the other hand, increase in aborting rate in supra-optimal dose resulted in flower abortion as well, and this fact probably is due to negative effect produced by fertilizing in greater dose. For KCl, the effect was contrary in proportion that is increased KCl doses occurring increases flower aborting.

Flower aborting in general occurs in adverse climatic conditions producing negative effects linked to pollination and fertilization, such as temperature range, high humidity, strong ventilation, and excessive fertilization. High salt concentration in soil can cause nutritional disequilibrium, induced by toxicity of ions such K^+ and Cl^-, and interfering in hormonal equilibrium that can decrease cell plasticity, causing a reduction in permeability of cytoplasmic membrane. This also can influence the photosynthetic process, because chlorophyll content in plant tissue is affected (Larcher, 1995).

In according to Marchner (1995) plants can have 2 to 20 mg g^{-1} of chlorine in dry matter, but require 0.2 and 0.4 mg g^{-1} to produce optimal growth and development. In other works, these values are 10 to 100 times less, and the problem is more commonly related to toxicity, compared with deficiency.

Results linked to aborted fruits presented have similar effects for KCl and K_2SO_4, and consequent increase in aborting rate produced by greater potassium fertilization (Figure 3C). However, KCl caused higher fruit aborting in all doses, compared with K_2SO_4. This behavior induced by potassium fertilization can be attributed to competitive inhibition produced by high potassium concentrations, in which promotes a decrease in Ca^{2+} and Mg^{2+} absorptions that combines in same ligation site. Marques et al. (2011) concluded that higher levels of potassium fertilization (K_2SO_4 and KCl) negatively affected fruit production in eggplant. Damage induced by salt stress in higher plants were defined by Levitt (1980) as a direct consequence in membranes producing loss of permeability and minor ions flux. In addition, indirect action can interfere with protein metabolism, changing enzyme activity and catabolic process.

This study reveals that higher rates of potassium fertilization produces changes in eggplant metabolism, inducing effects normally associated with salt stress, and provoking negative interference such as higher flower and fruit aborting, in which are parameters that probably affect yield.

Conclusion

This study revealed that eggplant exposed to excess potassium did not have a negative effect on chlorophyll a and b, and nitrogen concentration in leaf was significantly modified due to increase in potassium level. In addition, greater levels of potassium produced negative consequences linked to flower and fruit abortion. Therefore, the better potassium source for eggplant is potassium sulfate K_2SO_4; it produces better performance compared with KCl.

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