Vol.3, No.2, 241-248 (2012)
http://dx.doi.org/10.4236/as.2012.32028

Pepper plants growth, yield, photosynthetic pigments, and total phenols as affected by foliar application of potassium under different salinity irrigation water

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Received 14 December 2011; revised 30 January 2012; accepted 11 February 2012

ABSTRACT

Irrigation with high salinity water influences plant growth, production of photosynthetic pigments and total phenols, leading to reduction in crop yield and quality. The objective of this study was to investigate the effects of potassium (K) foliar application in mitigating the negative effects of salt stress on pepper plants. A greenhouse experiment was conducted to investigate the effects of foliar application of potassium (K) on pepper plants grown with different salinity water irrigation (3000 and 6000 ppm as compared to tap water with salinity level of 300 ppm). Irrigation using high salinity water decreased plant height, biomass production, and fruit yield as compared to those of the plants irrigated by tap water. Photosynthetic pigments and total phenols increased in the former as compared to those of the latter plants. The most serious affect was for the plants under highest salinity irrigation (6000 ppm) as compared to that of the plants under moderate salinity irrigation (3000 ppm). Foliar application of potassium mono phosphate (KMP) at 200 ppm concentration increased the plant growth, biomass production, and fruit yield. Chlorophyll_a content and total phenols increased significantly with foliar application of 100 ppm KMP. Further increase in foliar KMP concentration to 200 ppm had no significant benefits on photosynthetic pigments and total phenols content. This study demonstrated that foliar application of KMP, to some extent, mitigated the negative effects of high salinity water irrigation on pepper plant growth and fruit yield.

Keywords: Diluted Sea Water; Potassium Mono Phosphate; Chlorophyll_a; Chlorophyll_b; Carotenoids; Potassium Nutrition

1. INTRODUCTION

Pepper (*Capsicum annuum* L.) plants are sensitive to drought stress and moderately sensitive to salt stress [1,2]. In greenhouse conditions, pepper plants grown under water deficit with excess fertilizers accumulate large amounts of sodium (Na), potassium (K), phosphorus (P), and chloride (Cl) ([3]). This leads to an excess ion uptake and an imbalance of various mineral elements. Plants exposed to high salinity exhibit membrane destabilization and inhibition of exposed photosynthetic capacity ([4]).

Negative effects of salinity on pepper plants can be overcome, to some extent, by foliar application of macro and/or micro nutrients [5]. Studies have also shown an increase in pepper yields with foliar application of calcium (Ca) [6] and K [7]. Foliar application of P, K, zinc (Zn) and manganese (Mn) significantly increased yield and cold tolerance in maize [8].

The physiological effects of interactions between salinity and mineral nutrition in horticultural crops are extremely complex. Crop performance may be adversely affected by salinity-induced nutritional disorders. These disorders may result from the effect of salinity on nutrient availability, competitive uptake and transport or partitioning of nutrients within the plant. For example, salinity reduces phosphate uptake in crops grown in soils primarily by reducing phosphate availability. In solution cultures, ion imbalance may primarily result from competitive interactions. Increased uptake of Na^+ and Cl^- under saline growing conditions may decrease K^+ and NO_3^- uptake, respectively. Salinity can also cause a combination of complex interactions that affect plant metabolism, nutrient requirement, and susceptibility to injury [9].

Optimum and balanced availability of macro and micro nutrients can mitigate negative effects of some stress factors on growth, yield, and quality of vegetable crops ([10-12]). The objective of this study was to investigate the effects of foliar application of K on pepper plants in mitigating negative effects of salt stress.

2. MATERIALS AND METHODS

2.1. Preparation of Pots

A pot experiment was conducted in a greenhouse in the National Research Centre, Dokki, Cairo, Egypt during the 2007 summer season using Pepper (*Capsicum annum* L.) variety Balady red. The treatments were as follows: 1) two irrigation water salinity levels compared to tap water with salinity levels of: 6000, 3000, and 300 ppm, or 9.38, 4.69, and 0.47 dS/m, respectively; 2) foliar spray of distilled water compared to water containing 100 or 200 ppm potassium mono phosphate (KMP). There were six replications of each treatment.

Metallic pots of 35 cm diameter and 50 cm depth were used. The inner surface of the pot was coated with three layers of bitumen to prevent direct contact between the soil and metal, and 2 kg of gravel (particles about 2 - 3 cm) was placed at the bottom of the pot. Each pot contained 30 kg of air dried clay loam soil (**Table 1**). Calcium super phosphate (6.8% P) and potassium sulfate (40.3% K) were added (broadcasted on the soil surface) to the soil in the pot at 4.5 and 2.5 g/pot, respectively.

2.2. Planting

Pepper seedlings were transplanted on July 15, 2007, and thinned to 3 plants per pot after two weeks. Nitrogen was applied as ammonium sulfate (20.5% N) in three applications of 9.0 g/pot each, 2, 4, and 6 weeks after planting. Diluted seawater to attain two salinity levels (3000 and 6000 ppm) were used for high salinity irrigation began two days after planting. For those treatments, each high salinity water irrigation was alternated with fresh water irrigation. The pots were irrigated on three days frequency. Foliar application KMP was done twice, *i.e.* 21and 35 days after planting.

2.3. Response Parameters

At the completion of the experiment (120 days after planting), plant height was measured. Leaves were stripped from the plants and leaf area was measured for all the leaves per plant. Fruit length and diameters were measured. Fresh weights of plant stem, leaves, and fruits were recorded. These plant parts were dried at 70˚C for 72 h and dry weights were also recorded.

Concentrations of photosynthetic pigments *i.e.* Chlorophyll_a, Chlorophyll_b and total carotenoids were measured in leaf samples taken 120 days after planting following the procedure described by von Wettstien *et al.* [13].

Total Phenols in leaves were determined using the method described by Titto [14]. Data collected were subjected to the statistical analysis as described by Snedecor and Cochran [15].

3. RESULTS AND DISCUSSION

3.1. Salt Stress

3.1.1. Growth

Irrigation with high salinity water significantly decreased pepper plants height, leaf area, fruit length and

Table 1. Some physical and chemical characteristics of the soil used in this study.

A. Particle size analysis

Coarse Sand (>200 μm)	Fine Sand (200 - 20 μm)	Silt (20 - 2 μm)	Clay (<2 μm)
(%)			
7.20	14.25	30.22	48.33

B. Soil chemical analysis

pH (1:2.5)	EC (dS·m^{-1}) (1:5)	$CaCO_3$ (%)	CEC (C mole·Kg^{-1})	OM (%)	Soluble cations and anions (meq/100g soil)							
					Na^+	K^+	Ca^{2+}	Mg^{2+}	CO_3	HCO_3^-	Cl^-	SO_4^{2-}
7.15	1.3	2.53	33.5	1.3	1.82	0.23	2.38	1.27	0.0	0.91	1.9	1.89

Available macro-nutrients (g/kg)			Available micro-nutrients (mg/kg)			
N	P	K	Zn	Fe	Mn	Cu
4.7	2.5	9.5	3.1	4.8	7.3	5.2

OM = Organic matter; CEC = Cation Exchange Capacity.

diameter, as well as stem, leaves and fruit weight as compared to those of the plants irrigated by tap water (**Table 2**). Chartzoulakis and Klapaki [16] reported significant reduction in growth of pepper plants irrigated with water containing 100 and 150 mM NaCl. They also reported significant reductions in plant height, leaf area, and dry weight of the plants irrigated with water containing ≥25 mM NaCl.

These adverse effects of salt stress may be due to the effects of salts on the availability and uptake of water leading to decreased water content in the plant tissues which altered the metabolic processes inside the cells. Furthermore, increased salt content in the irrigation water may cause direct and indirect effects on leaf water relations and stomatal closure which influence CO_2 exchange and photosynthetic rate. Increased salt content in irrigation water may be directly toxic to plants, which in turn, lowered carbohydrate accumulation in the plants [17,18].

Furthermore, negative effects of salinity have been attributed to disturbance in either protein assimilation [19, 20], mineral uptake and distribution [21], activities of growth hormones [22-24], enzymes activities [25,26] and oxidative defense ([25-27]).

3.1.2. Photosynthetic Pigments

Concentrations of chlorophyll_a (chl_a), chlorophyll_b (chl_b), carotenoids, or total phenols increased with increased salinity in irrigation water (**Table 3**). The highest value of chl_a: chl_b ratio was in leaves of the plants irrigated by saline water with EC = 4.69 dS/m. Mousavi, *et al*. [28] also reported a decrease in chlorophyll_a and b in young olive cultivars with an increase in salinity up to 40 mM. The results of this study are in agreement with those of Azooz *et al.* [29] for sorghum, Dagar *et al.* [30] for *Salvadorapersica*, and Lee [2] for hot pepper.

The reduction in leaf chlorophyll content of the plants grown in NaCl stress has been attributed to the destruction of chlorophyll pigments and instability of the pigment protein complex [31]. Furthermore, increased salt content also interferes with protein synthesis and influences the structural component of chlorophyll [32].

3.1.3. Total Phenols

Concentration of total phenols in pepper leaves significantly increased with an increase in irrigation water salinity (**Table 3**). Chartzoulakis [33] reported that total phenol content in olive leaves was not affected by moderate NaCl salinity (EC_w of 5 dS/m). Ben Dkhil and Denden [34] observed greater accumulation of sugar and phenols in *Abelmoschus esculentus* L. (Moench.) seedlings with an increase in salinity of up to 100 mM NaCl.

3.2. Foliar Application of KMP

3.2.1. Growth

Foliar application of KMP significantly increased the plant height, leaf area, fruit diameter, stem and fruit fresh and dry weights (**Table 4**). El-Tohamy *et al.* [35] re-

Table 2. Growth response of pepper plants to irrigation by tapwater or two high salinity water.

Salinity (dS/m)	Plant height (cm)	No. of Leaves	Leaf area/plant (cm^2)	Fruit		Fresh weight (g)			Dry weight (g)		
				Length (cm)	Diameter (cm)	Stem	Leaves	Fruits	Stem	Leaves	Fruit
0.47 (tap water)	50.7	48	1721	4.8	4.6	30.1	26.7	24.0	4.5	5.2	5.9
4.69	36.5	32	1160	3.7	3.5	19.6	19.5	20.7	4.3	4.5	4.7
9.38	35.5	29	878	3.8	3.0	14.5	13.3	13.7	2.7	2.7	3.2
LSD (P ≤ 0.05)	2.68	NS	44.5	1.0	1.3	7.5	6.5	9.0	NS	0.8	1.6

LSD = Least Significant Difference; NS = Non Significant.

Table 3. Effects of irrigation with tap water or two high salinity water on photosynthetic pigments and total phenols in leaves of pepper plants.

Salinity (dS/m)	Chl_a (ppm)	Chl_b (ppm)	Carotenoids (ppm)	(Chl_a: Chl_b) ratio	(Chl_a + Chl_b): Carotenoids ratio	Total phenols mg/100g dry weight
0.47 (tapwater)	3.716	2.607	1.956	1.425	3.233	325
4.69	5.322	2.543	2.101	2.093	3.744	405
9.38	6.955	3.848	2.697	1.807	4.008	624
LSD (P ≤ 0.05)	0.413	0.726	0.273	NA	NA	36

NA = Not applicable; LSD = Least Significant Difference; Chl = Chlorphyll.

Table 4. Growth response of pepper plants to foliar application of different concentrations of potassium mono phosphate (KMP).

KMP (ppm)	Plant height (cm)	No of leaves	Area of leaves (cm^2)	Fruit		Fresh weight (g)			Dry weight (g)		
				Length (cm)	Diameter (cm)	Stem	Leaves	Fruits	Stem	Leaves	Fruits
0[(1)]	36.0	33	870	3.6	3.4	15.4	16.7	14.7	3.3	3.3	3.3
100	40.0	37	1176	4.0	3.6	25.1	21.6	20.2	3.5	4.0	4.3
200	46.4	39	1704	4.7	4.0	23.7	21.1	23.6	4.7	5.0	6.2
LSD ($P \leq 0.05$)	6.7	NS	79.6	NS	0.5	8.7	NS	2.2	1.3	NS	2.04

[(1)]Distilled Water; NS = Non Significant; LSD = Least Significant Difference.

ported that foliar application of nutrients, especially P, Ca and K, can improve growth and yield of pepper plants grown in sandy soils during winter season. Fawzy *et al.* [36] discovered that the best vegetative growth, total yield, and fruit quality were obtained by two foliar applications (10 day intervals) of potassium sulfate solution with K concentration of 2.5 g/l during flowering stage. Beneficial effects of foliar application of K during vegetative and fruiting stages of several vegetable crops were also reported by Gupta and Sengar [37], Harneet-Kaur, *et al.* [38], and Kotepong *et al.* [39].

These beneficial effects were attributed to increased root growth leading to enhanced uptake of water and mineral nutrients [2,16,40], optimal water adjustment in cell wall, and efficient translocation of sugars from source to sink [41,42]. Furthermore, K is required for activity of some enzymes [41,43].

3.2.2. Photosynthetic Pigments

Chlorophyll_a, and total phenols in the leaves were increased in the plants which received KMP foliar spray as compared to those without KMP application (**Table 5**). El-Tohamy *et al.* [35] reported that foliar K fertilization reduced electrolyte leakage, thus increased total chlorophyll content as compared to that of the plants without foliar fertilization. Shafeek *et al.* [40] demonstrated greater concentration of leaf pigments in pea plants with foliar application of P and K as compared to those in the plants without foliar fertilization. Our results also agree with the findings of Vigay *et al*. [44].

3.2.3. Total Phenols

Total phenols concentration significantly increased in the leaves of the plants that received foliar application of 100 ppm KMP as compared to that of the plants which received no KMP (**Table 5**). However, further increase in KMP concentration to 200 ppm failed to show significant increase in leaf phenol content. These results agree with the conclusion of Li *et al.* [45] on maize and Nguyen *et al.* [46] on basil.

3.3. Salinity X Potassium Fertilizer

3.3.1. Growth

Foliar spray of 200 ppm KMP improved all growth parameters across each irrigation water salinity (**Table 6**). The differences were significant only on fruit length, diameter, and weight. Hussein, *et al.* [21] demonstrated that the positive effects of foliar application of P and K was marked under different salt levels. Kaya, *et al.* [47] concluded that foliar application of 5 mM KH_2PO_4 solution maintained membrane permeability by decreasing electrolyte leakage from leaves of plants grown in high salinity conditions. This beneficial response appears to be due to the effects of salts on the osmotic pressure of soil solution and the toxicity of salts on the root and shoot tissues ([48,49]).

Adequate K nutrition is important for osmo-regulation, maintenance of electrochemical equilibria in cells and its compartments, and regulation of enzyme activities [50]. Potassium has a crucial role in the energy status of the plant (Imas and Bansal, 1999)[1], translocation and storage of assimilates, and maintenance of tissue water relations [51]. K plays a key role for enhancing crop quality. It improves fruit size and stimulates root growth. It is necessary for the translocation of sugars and formation of carbohydrates. K also provides resistance against pest and diseases, drought, and frost stresses [52]. Phosphorus is an essential nutrient and is a major building block of DNA molecules, thus, encouraging plant growth [53]. Adequate P availability is important for maintaining vigorous plant growth [54]. Phosphorus is important for nucleic acid synthesis, energy transfer processes, and carbohydrate metabolism. Phosphorus deficiency leads to decreased photosynthetic carbon fixation [55].

The interaction between salinity and KMP levels was significant. Plant biomass decreased with increasing salinity of the irrigation water. Increasing salinity levels resulted in smaller fruit size, higher soluble solid content (SSC) and decreased the pH of the fruit juice. Water use

[1]Imas, P. and Bansal, S.K. (1999) Potassium and integrated nutrient management in potato. Presented at the global conference on potato, December 6-11, New Delhi, India.

Table 5. Photosynthetic pigments and total phenols in leaves of pepper plants as affected by foliar application of potassium mono phosphate (KMP).

KMP (ppm)	Chl_a (ppm)	Chl_b (ppm)	Carotenoids (ppm)	(Chl_a: Chl_b) Ratio	(Chl_a + Chl_b): Carotenoids Ratio	Total phenols (mg/100g dry weight)
0[(1)]	4.157	3.022	2.080	1.370	3.451	304
100	5.907	2.975	2.437	1.921	3.592	495
200	5.930	3.001	2.201	2.003	4.058	555
LSD ($P \leq 0.05$)	0.403	NS	NS	NA	NA	88

[(1)]Distilled Water; NS = Non Significant; LSD = Least Significant Difference; NA = Not Applicable.

Table 6. Growth response of pepper plants to foliar application of different concentrations of potassium mono phosphate (KMP) across three different salinity levels in irrigation water.

Salinity (dS/m)	KMP (ppm)	Plant Height (cm)	No. of Leaves	Area of leaves (cm^2)	Fruit		Fresh weight (g)			Dry weight (g)		
					Length (cm)	Diameter (cm)	Stem	Leaves	Fruits	Stem	Leaves	Fruits
	0[(1)]	46.3	44.7	1082	3.9	4.5	26.5	27.7	17.5	3.5	4.4	3.7
0.47	100	46.7	51.3	1923	4.7	4.3	35.2	29.1	25.5	4.4	5.3	5.6
	200	59.0	47.7	2158	5.8	5.1	28.6	26.2	29.05	5.5	6.0	8.4
	0[(1)]	31.3	31.7	957	3.7	3.2	12.0	18.5	18.38	4.2	3.3	3.6
4.69	100	39.3	33.7	824	3.5	3.0	24.0	20.0	17.13	3.4	4.8	3.4
	200	39.0	31.0	1700	4.0	4.2	22.8	20.1	26.47	5.2	5.3	7.0
	0[(1)]	30.3	21.7	600	3.1	2.4	7.7	9.6	7.87	2.1	2.2	2.5
9.38	100	34.0	26.7	782	3.9	3.4	16.1	15.7	17.86	2.6	2.0	4.0
	200	41.3	37.0	1253	4.3	3.3	19.7	17.1	15.31	3.3	3.7	3.2
LSD($P \leq 0.05$)		NS	NS	NS	0.9	0.8	NS	NS	3.68	NS	NS	3.7

[(1)]Distilled water; NS = Non Significant; LSD = Least Significant Difference.

by the plants decreased with increasing salinity [12]. Kaya, *et al.* [47] concluded that foliar application of 5 mM KH_2PO_4 solution maintained membrane permeability by decreasing electrolyte leakage from leaves of the plants grown in high salinity conditions.

3.3.2. Photosynthetic Pigments

Increased concentration of KMP in the foliar spray increased chl_a, chl_a + chl_b, and chl_a: chl_b ratio in plants irrigated with tap water or increased salinity irrigation water (**Table 7**). The interactions between salinity of irrigation water and KMP levels in foliar spray were not significant on the concentrations of chl_b and total carotenoids. Kaya, *et al.* [56] reported increased salinity decreased chl_a, and chl_b contents and application of KNO_3 ameliorated the adverse effects of salt stress.

3.3.3. Total Phenols

Pepper plants without the salt stress and received KMP (100 or 200 ppm) foliar application increased total phenols concentration in the leaves by 2.1 to 2.6-fold as compared to that of the plants that received no foliar application of KMP (**Table 7**). The corresponding increase for the plants irrigated with low and high saline water were 1.6 to 1.8-fold and 1.2 to 1.9-fold, respectively.

4. CONCLUSION

Saline irrigation water, even at 4.69 dS/m significantly decreased growth and biomass production of pepper plants. The photosynthetic pigments and carotenoids content increased in plants irrigated with high salinity water. Two foliar applications of potassium mono phosphate (KMP), 21 and 35 days after planting, increased plant growth and fruit yield, particularly at the intermediate irrigation water salinity. Therefore, this study demonstrates the beneficial effects of foliar application of KMP to pepper plants by mitigating the negative effects

Table 7. Effect foliar application of potassium mono phosphate (KMP) across three different salinity in irrigation water on photosynthetic pigments and total phenols in leaves of pepper plants.

Salinity (dS/m)	KMP (ppm)	Chl_a (ppm)	Chl_b (ppm)	Carotenoids (ppm)	Chl_a + Chl_b	Chl_a: Chl_b	(Chl_a + Chl_b): Carotenoids	Total phenols (mg/100g dry Weight)
0.47 (tap water)	DW	2.08	2.9	1.84	4.98	0.73	2.69	171
	100	4.44	2.4	2.11	6.84	1.68	3.22	441
	200	4.63	2.61	1.92	7.24	1.78	3.77	365
4.69	DW	4.79	2.64	1.97	7.43	1.82	3.77	275
	100	5.45	2.57	2.17	8.02	2.12	3.69	507
	200	5.73	2.42	2.16	8.15	2.36	3.77	433
9.39	DW	5.60	3.58	2.43	9.18	1.56	3.77	466
	100	7.83	3.99	3.13	11.82	1.96	3.77	536
	200	7.43	3.98	2.53	11.41	1.87	4.51	868
LSD ($P \leq 0.05$)		0.697	NS	NS	1.403	NA	NA	151.6

DW = Distilled Water; NS = Non Significant; NA = Not Applicable; LSD = Least Significant Difference; Chl = Chlorophyll.

of saline irrigation water. We highly recommend evaluation of these effects in field conditions across different soil types.

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