

Alleviation of adverse effects of salt stress on sunflower (*Helianthus annuus* L.) by exogenous application of potassium nitrate

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Summary

To assess whether the adverse effects of salt stress on sunflower could be mitigated by exogenously applied potassium nitrate, a greenhouse experiment was conducted. There were two salt treatments (0 or 150 mmol/l NaCl) and different concentrations of KNO₃ [NS (No spray), WS (spray of water + 0.1% Tween 20 solution), 0.5% K⁺ + 0.8% NO₃⁻, 1.0% K⁺ + 1.6% NO₃⁻, 1.5% K⁺ + 2.4% NO₃⁻, and 2.0% K⁺ + 3.2% NO₃⁻ in 0.1% Tween 20 solution] which were applied foliarly two times i.e., one week after the commencement of salt stress and the second, one week after the first application to non-stressed and salt stressed plants. Varying levels of KNO₃ improved the growth, achene yield, chlorophyll contents, net CO₂ assimilation rate, F_v/F_m , leaf turgor, and leaf K and N contents in the salt-stressed plants of sunflower. Of the various KNO₃ levels applied foliarly, 1% K⁺ and 1.6% NO₃⁻ from KNO₃ were found to be the most effective in up-regulating different growth and physiological processes under saline conditions. In conclusion, exogenous application of KNO₃ increased the photosynthetic rate and leaf turgor which in turn resulted in enhanced growth and yield in sunflower plants subjected to salt stress.

Introduction

High salt concentration in the root zone causes a number of adverse effects on plants such as osmotic effects, ion toxicity, hormonal imbalance, generation of reactive oxygen species, and nutritional imbalance (ASHRAF, 1994; 2004; FLOWERS and FLOWERS, 2005; MUNNS, 2005). These salt effects may cause membrane disorganization, production of toxic metabolites, and inhibition in photosynthesis, leading to reduced growth and yield in plants (FLOWERS and FLOWERS, 2005). Optimal nutrient concentration is the primary requirement for growth of plants under normal or stress conditions. Under saline conditions, availability of nutrients is usually reduced and thus demand of essential nutrients for the plant is increased (MARSCHNER, 1995). It is generally believed that high amounts of Na⁺ reduce uptake of essential nutrients (GREENWAY and MUNNS, 1980; MARSCHNER, 1995; GRATTAN and GRIEVE, 1999; ASHRAF, 2004; FLOWERS and FLOWERS, 2005). For example, KHAN et al. (2000), while working with *Atriplex griffithii* var. *stocksii*, found that NaCl stress caused reduction in uptake of K⁺, Ca²⁺ and Mg²⁺ thereby causing reduced plant growth. Likewise, GHULAM et al. (2002) observed that the leaf K⁺ was decreased in the salt stressed plants of sugar beet, whereas root K⁺ remained unchanged. Similarly, a number of studies have shown that salt stress can reduce N accumulation in different crop plants, e.g., green bean (PESSARAKLI, 1991), sunflower (ASHRAF and SULTANA, 2000), tomato (FLORES et al., 2000), and *Bruguiera parviflora* (PARIDA and DAS, 2004).

From all these reports, it can be concluded that salt stress causes nutrient deficiencies due to competition of Na⁺ and Cl⁻ with nutrients such as K⁺, Ca²⁺, H₂PO₄⁻ and NO₃⁻ (SUBBARAO et al., 2003; HU and

SCHMIDHALTER, 2005). Such salt-induced nutritional disorders can be alleviated by the addition of mineral nutrients in the growth medium. For example, addition of N to the growth medium improved growth and/or yield of maize (RAVIKOVITCH, 1973), tomato (PAPADOPOULOS and RENDIG, 1983), and grape (TAYLOR et al., 1987). While working with tomato, AWAD et al. (1990) demonstrated that addition of P increased crop salt tolerance over a wide range of salt treatments (10-100 mmol/l NaCl).

Numerous studies with a wide variety of horticultural crops have shown that K⁺ uptake is impaired by salinity, which leads to reduced K⁺/Na⁺ ratio (PEREZ-ALFOCEA et al., 1996). Salt stress is also known to perturb the uptake of NO₃⁻ in many plant species, most likely due to high Cl⁻ content of most salt affected soils (GRATTAN and GRIEVE, 1994; KHAN and SRIVASTAVA, 1998). However, DUBEY and PESSARAKLI (1995) found that addition of N to the growth medium improved plant growth under saline conditions.

Different researchers have already shown that the deleterious effects associated with reduced uptake and translocation of K⁺ by plants grown in high Na⁺ could be mitigated by the addition of K⁺ to the growth medium, e.g., in tomato (SATTI and LOPEZ, 1994; SONG and FUJIYAMA, 1996), maize (BOTELLA et al., 1997), sunflower (DELGADO and SANCHEZ-RAYA, 1999), and bean and sunflower (BENLOCH et al., 1994). A few years back, while reviewing salinity interaction with mineral nutrition in horticultural crops, GRATTAN and GRIEVE (1999) concluded that under field conditions, K⁺ in soil solution remains relatively low even after the addition of K fertilizer. Thus, it is not easy to completely correct Na-induced K deficiencies by the addition of K fertilizers in soil. In the last three decades, it has been shown that foliar feeding with macro-nutrients is beneficial in overcoming nutritional deficiencies, e.g., in cotton (HOWARD et al., 1998), citrus (CALVERT, 1969), avocado (SING and MCNEIL, 1992), and 'French' prune trees (SOUTHWICK et al., 1996). Foliar fertilization can therefore be a complementary measure taken to provide nutrients during a critical phase of restricted nutrient supply. OOSTERHUS (1998) reported that foliar feeding of a nutrient might actually promote the root absorption of the same nutrient. Furthermore, foliar application also reduces the quantity of fertilizer applied to the soil.

A few reports are also available in the literature which indicates that foliar applied K can alleviate the adverse effects of salt stress on growth and yield of different crops. For example, foliar spray of KH₂PO₄ corrected the deficiencies of both P and K in salt stressed strawberry (KAYA et al., 2001a), and tomato (SATTI and AL-YAHYAI, 1995). KAYA et al. (2001b) found that foliar spray of KH₂PO₄ alleviated the negative effects of salinity on the growth of spinach under saline conditions by correcting Na-induced K deficiency as well as improving K⁺/Na⁺ ratio from 1.61 to 2.72. Recently, AHMAD and JABEEN (2005) have found that 250 mg/l solution of KNO₃ not only inhibited the toxic effects of salt on fruit formation in *Lagenaria siceraria* grown, but also under saline conditions it increased its production by 76.9% with respect to weight per plant. Similarly, exogenously applied potassium nitrate through the root zone significantly mitigated the adverse effects of salt stress on growth and fruit yield of melon (*Cucumis melo* L.), and the alleviating effects of potassium nitrate were attributed to maintenance of membrane

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permeability, and enhanced concentrations of Ca^{2+} , N and K^+ in the leaves of salt stressed melon plants (KAYA et al., 2007). One of the primary benefits of using nitrate nitrogen with potassium for foliar application is maximum utilization of K^+ and nitrate nitrogen by the plants ([http://www. Spraygro. Com. Au/Editorials/Potassium nitrogen ratio.asp](http://www.Spraygro.Com.Au/Editorials/Potassium%20nitrogen%20ratio.asp)).

In view of all these reports, it was hypothesized that foliar application of potassium nitrate could alleviate the adverse effects of salt stress on sunflower plants, particularly where soil conditions such as high soil salinity restrict nutrient availability to root. Thus, the principal objective of the present investigation was to elucidate the physiological processes responsible for sustaining growth of KNO_3 supplied sunflower plants grown under saline conditions.

Materials and methods

Experiments were conducted during spring 2005 in a naturally lit wire-house in the Botanic Garden, Department of Botany, University of Agriculture, Faisalabad, Pakistan (latitude $31^{\circ}30' \text{N}$, longitude $73^{\circ}10' \text{E}$ and altitude 213 m). Achenes of sunflower (*Helianthus annuus* L. cv. SF -187, Monsanto, USA) were obtained from the Regional Office of Pakistan Seed Council Faisalabad, Pakistan. During the experiment, day and night temperatures were $30.6 \pm 5.1^{\circ}\text{C}$, and $18.3 \pm 7.6^{\circ}\text{C}$, respectively, relative humidity (RH) was 35.9 ± 6.5 , and the day-length from 10 to 11 h were recorded. Achenes of sunflower (*Helianthus annuus* L.) were surface sterilized in 5% sodium hypochlorite solution for 10 minutes before further experimentation. Ten sunflower achenes were directly sown in each plastic pot of 28 cm diameter, but after germination, seedlings were thinned to three of almost uniform size in each pot. Each pot contained 12.50 kg of well washed sand. The experiment was arranged in a completely randomized design with four replicates. All pots were irrigated with full strength Hoagland's nutrient solution for 18 days after which NaCl treatments in Hoagland's nutrient solution were begun. The NaCl treatments used were 0 or 150 mmol/l in full strength Hoagland's nutrient solution. Salt solution was applied in aliquots of 50 mmol/l every day. Two liters of treatment solution was applied to each pot after every week, however, moisture content of the sand was maintained daily by adding 200 ml distilled water to each pot. Different concentrations of KNO_3 [NS (No spray), WS (spray of water + 0.1% Tween 20 solution), 0.5% K^+ + 0.8% NO_3^- , 1.0% K^+ + 1.6% NO_3^- , 1.5% K^+ + 2.4% NO_3^- , and 2.0% K^+ + 3.2% NO_3^- in 0.1% Tween 20 solution] were applied foliarly two times to non-stressed and salt stressed sunflower plants. First foliar application of KNO_3 solution was done one week after the commencement of salt treatment. The second foliar application was done one week after the first application. Each KNO_3 treatment or blank solution was prepared in 0.1% Tween-20 solution and its pH was maintained at 6.5 to ensure the maximum penetration of salt into the leaf tissue and to avoid the leaf injury.

Twenty two days after the initiation of salt treatment, the data for gas exchange characteristics, chlorophyll fluorescence, leaf chlorophyll content, and water relation parameters were recorded.

Gas exchange characteristics: Measurements of net CO_2 assimilation rate (A), transpiration rate (E), stomatal conductance (g_s), and substomatal CO_2 concentration (C_i) were made on a fully expanded youngest leaf by using an open system LCA-4 ADC portable infrared gas analyzer (Analytical Development Company, Hoddeson, England). These measurements were made from 10 a.m. to 2 p.m. with the following conditions/adjustments of the leaf chamber: leaf surface area 11.35 cm^2 , ambient CO_2 concentration (C_{air}) $342.12 \mu\text{mol mol}^{-1}$, temperature of leaf chamber (T_{ch}) varied from 39.2 to 43.9°C , leaf chamber volume gas flow rate (v) 396 ml min^{-1} , leaf chamber molar gas flow rate (U) $251 \mu\text{mol s}^{-1}$, ambient pressure

(P) 99.95 kPa , molar flow of air per unit leaf area (U_s) $221.06 \text{ mol m}^{-2} \text{ s}^{-1}$, PAR (Q leaf) at leaf surface was maximum up to $918 \mu\text{mol m}^{-2}$. Water use efficiency was calculated as CO_2 assimilation rate/transpiration.

Chlorophyll fluorescence: The polyphasic rise of fluorescence transients was measured by a Plant Efficiency Analyzer (PEA, Hansatech Instruments Ltd., King's Lynn, UK) according to STRASSER et al. (1995). The transients were induced by red light of $3000 \mu\text{mol m}^{-2} \text{ s}^{-1}$ provided by an array of six light emitting diodes (peak 650 nm), which focused on the sample surface to give homogenous illumination over exposed area of sample surface. All the samples were dark adapted for 30 min. prior to fluorescence measurements and maximal quantum yield of PSII was calculated as F_v/F_m .

Water relation parameters: A fully expanded youngest leaf was excised from each plant and leaf water potential measurement was made with a Scholander type pressure chamber (Arimad-2- Japan) early in the morning between 6 to 8 a.m.

The same leaf that was used for water potential measurements was frozen into 2 cm^3 propylene tubes for two weeks at -20°C in an ultra-low freezer, after which time the leaf tissue was thawed and extracted by crushing the material with a metal rod. After centrifugation ($8000 \times g$) for four min. the sap was used directly for osmotic potential determination in a vapor pressure osmometer (Wescor, 5520). The leaf turgor potential was calculated as the difference between osmotic potential and water potential values following (NOBEL, 1991) and (TAIZ and ZEIGER, 1998).

Photosynthetic pigments: Chlorophylls a and b were determined according to the method of ARNON (1949). Fresh leaves weighed (0.2 g) were cut and extracted overnight with 80% acetone at -4°C . The extract was centrifuged at $10,000 \times g$ for 5 min. Absorbance of the supernatant was read at 645 and 663 nm using a spectrophotometer (Hitachi-220 Japan). The concentration of chlorophylls a and b were worked out by using appropriate equations.

Relative membrane permeability: Relative membrane permeability (RMP) of the leaf cells were determined by the method described by YANG et al. (1996). A fully expanded young leaf from each plant was cut into one- cm^2 discs. These freshly prepared discs (0.5 g) were placed into test tubes containing 20 ml deionized distilled water. After vortexing the samples for 3 s, initial electrical conductivity (EC_0) of each sample was measured. The samples were then stored at 4°C for 24 h and electrical conductivity (EC_1) was measured again. Samples were then autoclaved for 15 min. cooled to room temperature and electrical conductivity (EC_2) measured for the third time. The relative permeability of cell membrane was calculated by using the following formula:

$$\text{Relative permeability (\%)} = (EC_1 - EC_0) / (EC_2 - EC_0) \times 100$$

Growth and yield: After all these measurements, one plant from each pot was harvested and used for determining biomass and mineral nutrient status of plants, while the remaining two plants were used for the estimation of yield and yield components. Plant roots were carefully removed from the sand and washed in cold LiNO_3 solution isotonic with the corresponding treatment in which plants were growing. One mmol/l of $\text{Ca}(\text{NO}_3)_2 \times 4\text{H}_2\text{O}$ solution was added to LiNO_3 solution to maintain membrane integrity. Fresh weights of shoots and roots were recorded. Fresh plant material was oven-dried at 65°C for one week and dry weights measured. At maturity, heads of sunflower were removed from plants and data for number of achenes per capitulum, 100-achene weight, and achene yield/plant were recorded.

Inorganic elements: For the determination of N, P, K^+ , Ca^{2+} , Mg^{2+} , and Na^+ , the dried ground leaf and root material (0.1 g) was digested with sulphuric acid and hydrogen peroxide (Merck) and Na^+ , K^+ , and Ca^{2+} in the digests were determined with flame photometer (Jenway, PFP-7). Mg^{2+} was estimated with an atomic absorption spectrophotometer (Perkin Elmer Analyst 300, USA). Nitrogen was

estimated by micro-Kjeldhal's method (BREMNER, 1965). Phosphorus (P) was determined spectrophotometrically following JACKSON (1962). For the determination of Cl^- contents, leaf and root samples (100 mg) were ground and extracted in 10 ml of distilled water, heated at 80 °C till the volume became half. The volume was again maintained to 10 mL with distilled water. Cl^- content was determined with a chloride analyzer (Model 926, Sherwood Scientific Ltd., and Cambridge, UK).

Experimental design and statistical analysis: The experiments were set up in a completely randomized design (CRD) with four replicates. Analysis of variance of all parameters was computed using the COSTAT computer package (CoHort software, Berkeley, USA). Mean values of each attribute were compared using least significance

difference test (LSD) at 5% probability following SNEDECOR and COCHRAN (1980).

Results

Salt stress caused a significant ($P \leq 0.001$) reduction in shoot fresh and dry weights of sunflower plants. However, exogenous application of varying levels of potassium nitrate (KNO_3) improved shoot fresh and dry weights of sunflower plants under both non-saline and saline conditions. However, a maximum increase in shoot fresh and dry weights of control and salt-stressed plants was observed when 1% K^+ of KNO_3 applied as a foliar spray. Further increase in the level of

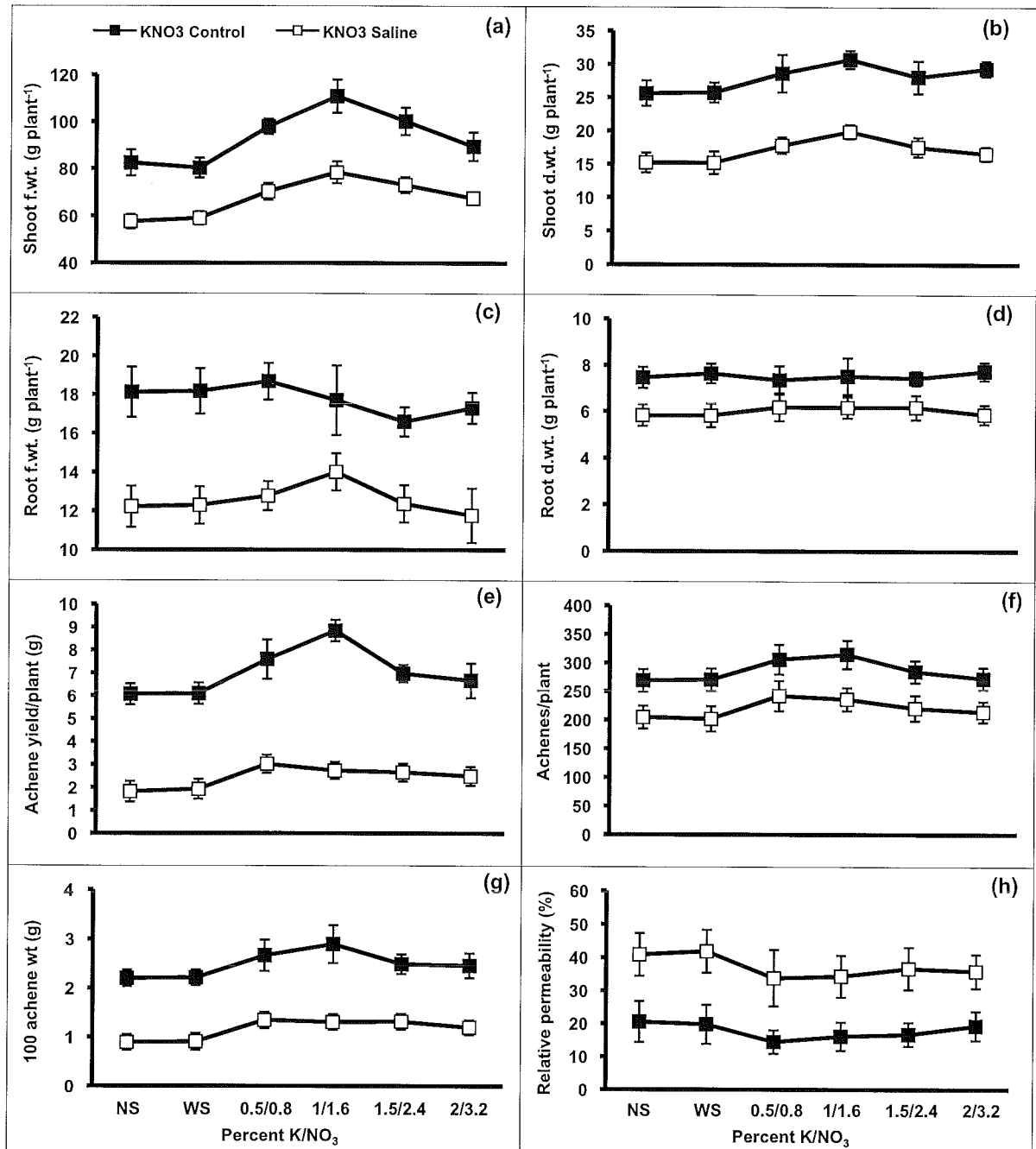


Fig. 1: Fresh and dry weights of shoots and roots, yield components and relative membrane permeability of sunflower (*Helianthus annuus* L.) when varying levels of KNO_3 were applied twice as a foliar spray to 18-day old plants subjected to normal or saline conditions.

KNO_3 applied did not improve shoot fresh and dry weights of non-salinized or salinized sunflower plants (Fig. 1a, b).

Similarly, salt stress of the growth medium caused a significant inhibitory effect ($P \leq 0.001$) on the root fresh and dry weights of sunflower plants. Exogenous application of different levels of KNO_3 did not improve root fresh and dry weights of non-salinized and salinized plants, however, a slight increase in fresh weight was observed in the salinized plants at 1% K^+ as KNO_3 applied as a foliar spray (Fig. 1c, d).

Achene yield and yield components such as number of achenes and 100-achene weight were significantly ($P \leq 0.001$) reduced due to salt stress. However, exogenous application of different levels of K^+ from KNO_3 improved all these yield attributes of both non-stressed and salt

stressed plants, and a maximum increase in these yield attributes was observed at 1% K^+ + 1.6% NO_3^- level in the non-stressed plants, while in the stressed plants a maximum improvement in achene yield was achieved at 0.5% K^+ + 0.8% NO_3^- level (Fig. 1e, f, g).

All gas exchange parameters like CO_2 assimilation rate (A), stomatal conductance (g_s), and transpiration rate (E) were significantly reduced due to salt treatment. Varying levels of KNO_3 caused an increase in all these gas exchange attributes in sunflower plants grown under saline or non-saline conditions. Net CO_2 assimilation rate (A) was maximally increased in non-salinized and salinized plants at 1.0% K^+ from KNO_3 , but at higher levels of KNO_3 , it remained almost unchanged (Fig. 2a). Stomatal conductance was generally enhanced with the exogenous application of different levels of KNO_3 , but

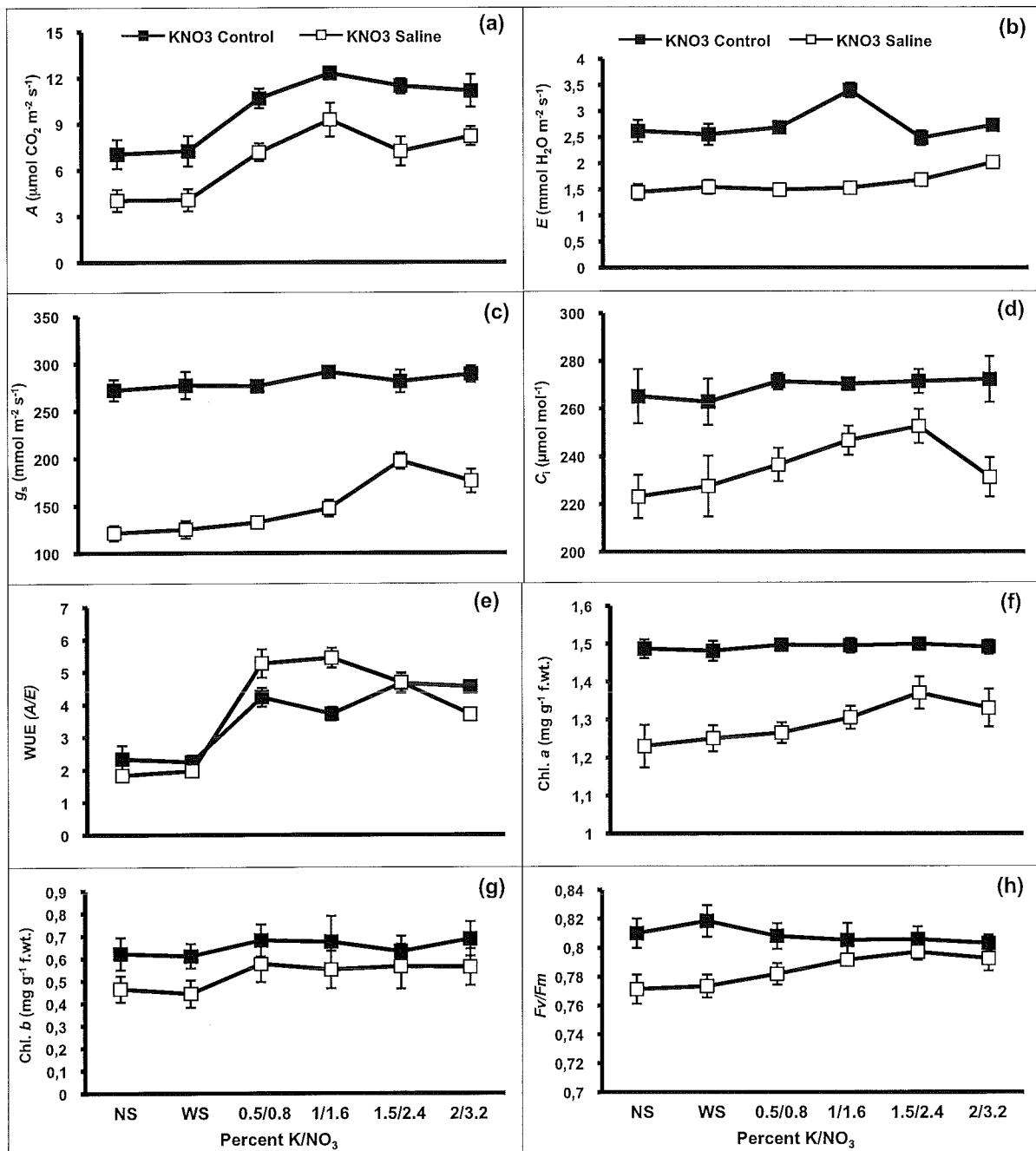


Fig. 2: Gas exchange characteristics, photosynthetic pigments, and quantum yield (F_v/F_m) of photosystem II of sunflower (*Helianthus annuus* L.) when varying levels of KNO_3 were applied twice as a foliar spray to 18-day old plants subjected to normal or saline conditions.

this enhancement was more pronounced in the salt stressed plants. A maximum value of g_s was observed at 1.5% K^+ as KNO_3 in the salt stressed plants (Fig. 2c). Sub-stomatal CO_2 concentration (C_i) was increased slightly in the non-stressed plants due to the exogenous application of varying levels of KNO_3 , whereas in the stressed plants all K^+ levels showed a consistent increase in this gas exchange attribute and a maximum value of C_i was observed at 1.5% K^+ level from KNO_3 (Fig. 2d). Transpiration rate of the non-stressed and stressed plants was not much affected due to the exogenous application of varying K^+ levels, except at 1.0% K^+ where

transpiration rate of the non-stressed plants was maximum. Water use efficiency (calculated as A/E ; WUE) was markedly enhanced in both salinized and non-salinized plants due to foliarly applied varying KNO_3 levels (Fig. 2 b, e).

Although chlorophylls a and b were significantly reduced due to the addition of salt to the rooting medium of sunflower plants, exogenous application of varying KNO_3 levels caused a significant increase in chlorophyll a in the salt stressed plants. However, a non-significant effect of exogenous KNO_3 was observed on chlorophyll b in non-stressed or stressed plants (Fig. 2 f, g).

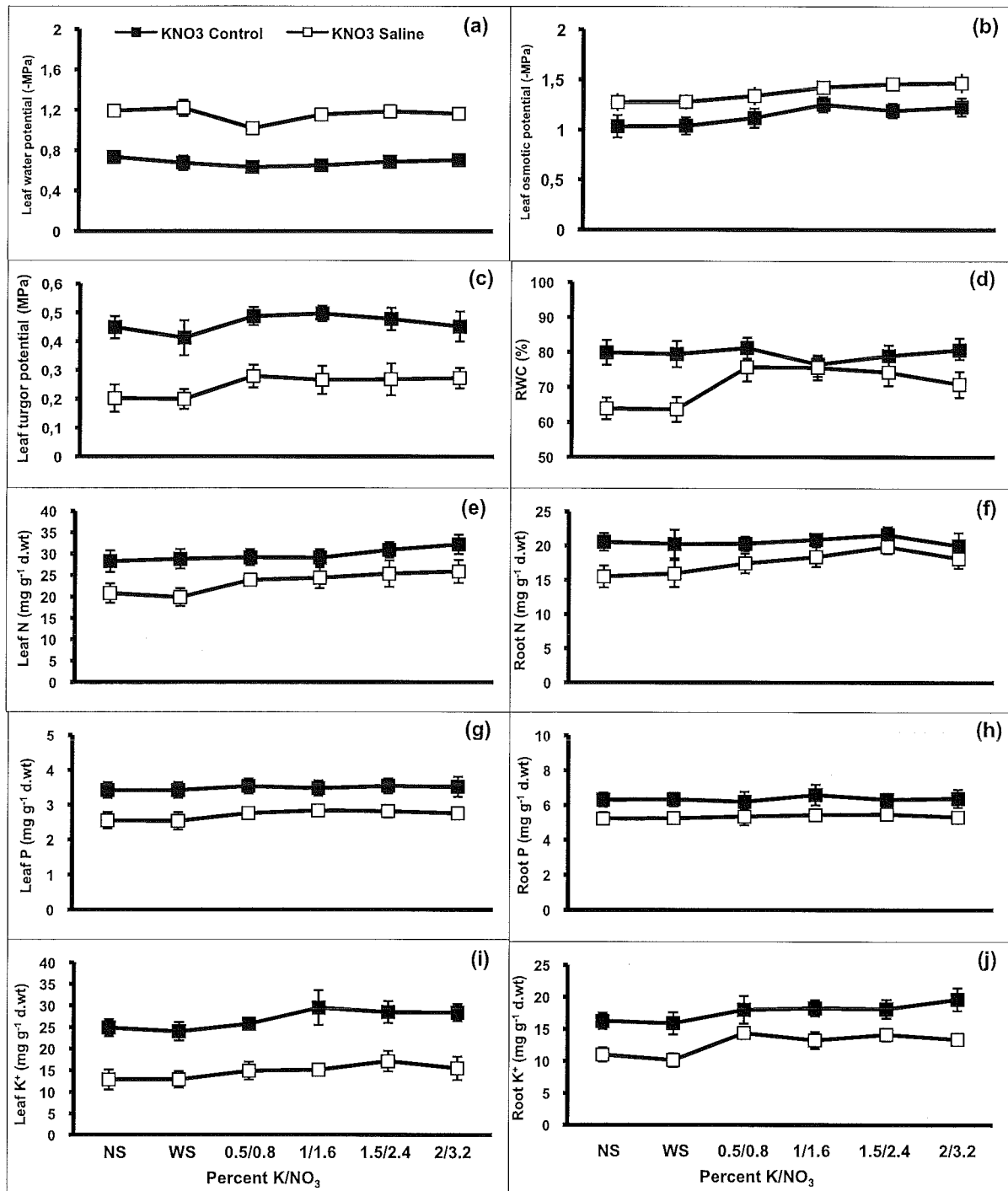


Fig. 3: Leaf water potential, osmotic potential, turgor potential, and relative water content, and N, P, and K concentrations of leaf and root of sunflower (*Helianthus annuus* L.) when varying levels of KNO_3 were applied twice as a foliar spray to 18-day old plants subjected to normal or saline conditions.

Salt stress significantly reduced the quantum yield (F_v/F_m) of photosystem II (PSII) in sunflower plants. However, application of varying levels of KNO_3 as a foliar spray alleviated the adverse effects of salt stress on quantum yield because there was a consistent increase in F_v/F_m with increase in the level of exogenous KNO_3 (Fig. 2 h).

Although salt stress caused a marked reduction in leaf water potential of sunflower plants, different doses of potassium nitrate applied foliarly did not alter this water relation component. Leaf osmotic potential was significantly reduced due to external NaCl treatment. Exogenous application of different doses of KNO_3 further reduced ($P \leq 0.05$) leaf osmotic potential (more negative values), because leaf osmotic potential of the salt stressed or non-stressed plants

was consistently decreased with increase in the level of foliarly applied KNO_3 . Leaf turgor potential was significantly reduced due to imposition of salt stress in the growth medium. However, there was a consistent increase in leaf turgor potential in both salt-stressed and non-stressed plants with increase in the level of exogenous KNO_3 (Fig. 3 a, b, c).

Relative water contents (RWC) of sunflower plants were significantly reduced due to salt stress. However, exogenous application of different levels of KNO_3 caused an increase in RWC of the salt-stressed plants. A maximum increase in RWC was observed in the salt stressed plants at 1% K^+ from KNO_3 , thereafter at all KNO_3 levels the RWC remained unaffected (Fig. 3 d).

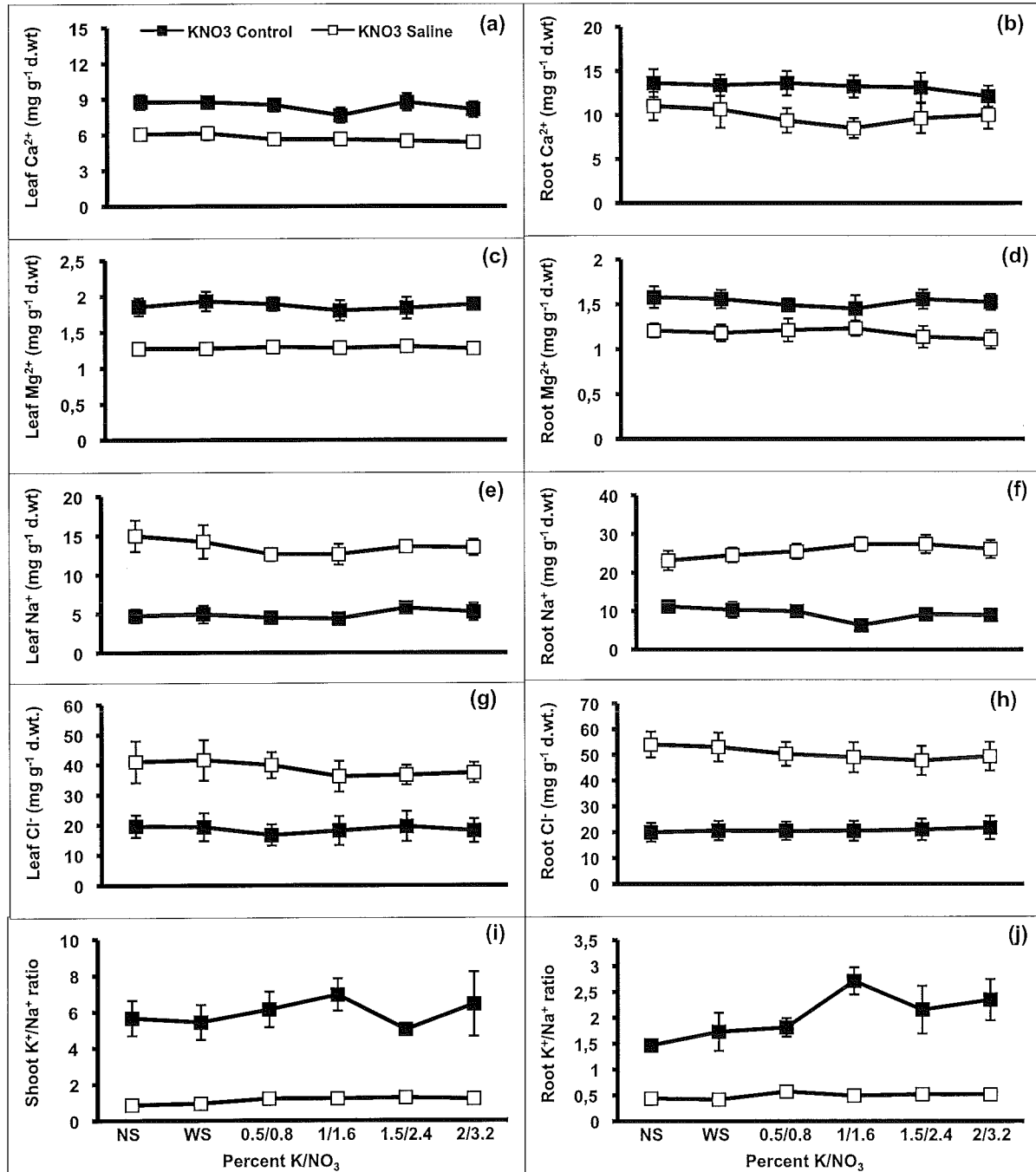


Fig. 4: Ca²⁺, Mg²⁺, Na⁺, and Cl⁻ concentrations and K⁺/Na⁺ ratios in the leaves and roots of sunflower (*Helianthus annuus* L.) when varying levels of KNO_3 were applied twice as a foliar spray to 18-day old plants subjected to normal or saline conditions.

A marked increase in relative leaf cell membrane permeability was observed due to salt stress imposed in the growth medium. Foliar spray with KNO_3 slightly reduced relative leaf cell membrane permeability, particularly in the salt-stressed plants of sunflower (Fig. 1h).

Salt regime of the rooting medium significantly reduced the leaf or root N, P, K^+ , Ca^{2+} and Mg^{2+} . Exogenously applied varying levels of KNO_3 significantly enhanced the accumulation of only N^+ and K^+ in the leaves and roots of both stressed and non-stressed plants (Fig. 3 a-f). However, in contrast, no effect of varying levels of KNO_3 could be discerned on leaf or root Ca^{2+} and Mg^{2+} . The concentrations of Na^+ and Cl^- in the leaves and roots were significantly increased in sunflower plants under salt stress. Exogenous application of different levels of KNO_3 did not alter the leaf or root Na^+ , Cl^- and K^+/Na^+ ratios (Fig. 4 a-j).

Discussion

It is evident from the results of the present study that sodium chloride added to the growth medium caused a significant reduction in growth and yield of sunflower plants. However, exogenous application of varying levels of KNO_3 improved the growth and yield of sunflower plants under both non-saline and saline conditions. These results can be related to some earlier studies in which it has been observed that exogenously applied K^+ promotes growth and counteracts salt-induced growth inhibition in different crop species, e.g., strawberry (KAYA et al., 2001a), spinach (KAYA et al., 2001b), cucumber and pepper (KAYA et al., 2003). Similarly, foliar spray with 1 mmol/l KNO_3 mitigated the adverse effects of salt stress on growth and yield of rice plants (IKEDA et al., 2004). AHMAD and JABEEN (2005) have also reported that 250 mg/l solution of KNO_3 inhibited the toxic effects of salt on fruit formation in *Lagenaria siceraria*, and hence increased its production. Recently, KAYA et al. (2007) have shown that supplementary KNO_3 applied through the rooting medium significantly improved plant growth and fruit yield in the salt stressed plants of melon (*Cucumis melo* L.). The optimum level of KNO_3 in the present study to alleviate the adverse effects of salinity on sunflower plants was found to be 1% K^+ and 1.6% NO_3^- . Likewise, in the present study, rate of photosynthesis of the salt stressed sunflower plants was improved due to exogenous KNO_3 , despite the improvement in growth and achene yield. Thus, a significant positive relationship was observed between photosynthetic rate and each of shoot fresh weight, shoot dry weight, achene yield, 100 achene weight and number of achenes in the salt stressed plants supplied with KNO_3 , which indicates that increased photosynthetic rate due to exogenous application of KNO_3 might have a substantial contribution to biomass production and grain yield in sunflower plants under non-saline or saline conditions. Optimum level of NO_3^- -N is known to promote CO_2 assimilation in sunflower plants (ASHRAF, 1999).

Stomatal regulation is a very important factor in controlling photosynthetic rate as well as water balance of plants growing under stressful environments (DUBEY, 2005; ATHAR and ASHRAF, 2005). Exogenously applied KNO_3 in the present study enhanced stomatal conductance, particularly of the salt stressed plants. It is known that higher stomatal conductance in plants up-regulates CO_2 diffusion into leaf thereby increasing photosynthetic rates. A positive relationship between leaf K^+ and leaf turgor, or leaf turgor and stomatal conductance has been observed in the present study, which indicates the potential role of K^+ in stomatal regulation in the salt-stressed sunflower plants supplied with KNO_3 . This could have been due to the role of K^+ as a major osmoticum in vacuole, for maintaining high tissue water content under stressful environments (MARSCHNER, 1995), because stomatal regulation largely depends upon the distribution of K^+ in epidermal cells, guard cells, and leaf apoplast (SHABALA et al., 2002).

Chlorophyll *a* content in the salt stressed plants was generally

increased with increase in exogenous KNO_3 application in the present study that might have been due to increased biosynthesis or reduced degradation of the pigment. SANTOS (2004) reported a greater inhibitory effect of salt stress on chlorophyll biosynthesis than on chlorophyllase mediated degradation in sunflower plants. Thus, changes in photosynthetic rate might have been due to the protective effect of K^+ or NO_3^- -N on salt-induced adverse effects on chlorophyll biosynthesis. Improvement in photochemical efficiency of PS II (F_v/F_m) with enhanced levels of exogenous KNO_3 and leaf K^+ and N content in the salt stressed sunflower plants further support this view. Generally, high transpiration rate increases salt stress susceptibility in plants (AN et al., 2001; LI et al., 2001) which may be due to increased translocation of Na^+ along with water (YEO et al., 1987). In the present study, such a positive relationship between transpiration rate and leaf Na^+ was found because both attributes were not affected due to externally supplied KNO_3 . These results do not support the earlier findings of AN et al. (2001) who reported that Na^+ translocation to shoot was independent of the transpiration rate in a salt tolerant cultivar of soybean.

In the present study, salt stress increased cell membrane permeability and ion leakage, but foliar spray with different doses of potassium nitrate slightly reduced cell membrane permeability and ion leakage in the salt stressed plants. These results are similar to the earlier findings of KAYA et al. (2001b) in which it was observed that foliarly applied KH_2PO_4 reduced the ion leakage in spinach grown under saline conditions.

A positive association was found between leaf water potential, leaf turgor potential, or leaf relative water content (RWC), and leaf K^+ in the present study, whereas a negative relationship was found between plant water status and leaf Na^+ . This suggests that foliar application of K^+ as KNO_3 can alleviate salt induced osmotic stress. Such mitigation can be related to the findings of some other studies in which it has been observed that increase in leaf K^+ due to supplemental K^+ caused maintenance of leaf turgor and RWC by decreasing leaf osmotic potential under water stress conditions e.g., in wheat (PIER and BERKOWITZ, 1987), maize (PREMACHANDRA et al., 1990), *Vigna radiata* (NANDWAL et al., 1998), and sorghum (JONES et al., 1980).

Data for different nutrients of leaf or root show that salt stress increased the accumulation of Na^+ and Cl^- coupled with a decrease in N, P, K^+ , Ca^{2+} and Mg^{2+} in the salt stressed sunflower plants which is expected in view of the general phenomenon that plants growing under saline conditions suffer ionic imbalance, nutrient deficiency and specific ion toxicity (ASHRAF, 1994; 2004; MUNNS, 2002, 2005). However, exogenously applied potassium nitrate did not alter leaf or root Na^+ , Cl^- , Ca^{2+} , and Mg^{2+} in sunflower plants, but it enhanced the levels of N and K^+ in plant tissues. The increase in accumulation of K^+ and N in the leaves and roots of sunflower plants shows that foliar applied KNO_3 was efficiently absorbed by the leaves and translocated downward to the roots as has earlier been observed in *Lathyrus sativus* L. grown in rice (SARKAR and MALIK, 2001).

Conclusion

Exogenous application of KNO_3 increased photosynthetic rate and leaf turgor which in turn resulted in improved growth and yield in sunflower plants subjected to salt stress. Foliar applied KNO_3 increased leaf K^+ and N, and regulated the opening and closing of stomata thereby maintaining plant water use efficiency.

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