SAHEL ALMARIFAH JOURNAL

مجلة ساحل المعرفة للعلوم الإنسانية والتطبيقية
Sahel Almarifah Journal of Humanities and Applied Sciences
تصدر عن الاكاديمية الليبية فرع الساحل الغربي

المجلد الثاني – العدد الأول - 2026 – الصفحات (39- 50)

الأكاديمية الليبية
The Libyan Academy
فرع الساحل الغربي

The Effect of Potassium Supply and Salinity on Potassium Concentration in Plant Tissues

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تأثير إمداد البوتاسيوم والملوحة على تركيز البوتاسيوم في الانسجة النباتية

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Received: March 12-2026   Accepted: April 15-2026   Published: May 01- 2026

الملخص

قامت هذه الدراسة بتقييم تأثير ملوحة مياه الري وإمدادات البوتاسيوم (K) على أداء النمو وتراكم الكاتيونات في نبات الشعير (Hordeum vulgare L.) أُجريت تجربة في أواني داخل بيت محمي باستخدام تصميم عشوائي كامل، وشملت ثلاثة معاملات للري (مياه عذبة، مياه بحر مخففة، و150 ملي مول من كلوريد الصوديوم (NaCl)، ومستويين من إضافة البوتاسيوم (0 و150 كغ/هكتار)، ونوعين من قوام التربة .تم تقييم نمو النبات من خلال قياس إنتاج المادة الجافة ومساحة الأوراق، بينما تم تحديد تركيزات أيونات K^+ و Na^+ وCa^{2+} وMg^{2+} في كل من الأجزاء الهوائية والجذور. أدت الملوحة إلى انخفاض ملحوظ في مساحة الأوراق، مما يشير إلى أن تمدد الأوراق أكثر حساسية لإجهاد الملوحة مقارنة بتوفر البوتاسيوم. في المقابل، كان إنتاج المادة الجافة متأثرًا بشكل طفيف فقط بالملوحة ولم يُظهر استجابة معنوية لتسميد البوتاسيوم .كانت تركيزات البوتاسيوم في أنسجة النبات محكومة بشكل أساسي بالملوحة نتيجة للتداخل التضادي بين أيونات Na^+ و K^+. كما أدت الملوحة إلى زيادة تراكم Na^+ وMg^{2+} مع انخفاض متزامن في تركيزات Ca^{2+}. ولم يساهم تطبيق البوتاسيوم في التخفيف من القيود على النمو الناتجة عن الملوحة.

الكلمات المفتاحية :إجهاد الملوحة، تغذية البوتاسيوم، الري، جودة المياه

ABSTRACT

This study evaluated the effects of irrigation water salinity and potassium (K) supply on growth performance and cation accumulation in barley (Hordeum vulgare L.). A greenhouse pot experiment was carried out using a completely randomized design, comprising three irrigation treatments (freshwater, diluted seawater, and 150 mM NaCl), two potassium application levels (0 and 150 kg ha^{-1}), and two soil textures. Plant growth was assessed through measurements of dry matter yield and leaf area, while the concentrations of K^+, Na^+, Ca^{2+}, and Mg^{2+} were determined in both shoots and roots. Salinity caused a significant reduction in leaf area, indicating that leaf expansion was more sensitive to salinity stress than to potassium availability. Conversely, dry matter production was only slightly influenced by salinity and showed no significant response to potassium fertilization. Potassium concentrations in plant tissues were predominantly controlled by salinity due to antagonistic Na^+–K^+ interactions. Salinity led to increased Na^+ and Mg^{2+} accumulation and a concomitant decrease in Ca^{2+} concentrations. Potassium application did not alleviate the growth constraints induced by salinity.

KEYWORDS: *Salinity stress; Potassium nutrition; Irrigation, water quality*

1. INTRODUCTION

Salinization is the presence of high salt concentrations and dissolved solids in the water and soil as a result of natural or human processes [1]. Many places all over the world are subjected to potential salinity, making it one of the biggest threats to global agricultural production. Martinez-Beltran and Manzur have estimated that there are about 830 million hectares of the world’s land area that are influenced by either salinity or sodicty. Resources of fresh potable water for irrigation and human consumption are limited as salt water makes up 97.5% of available global water [2]. For this reason, many researchers are attempting to take advantage of water with specific concentrations of salts in agricultural production in order to exploit arable land which will help provide the human requirements which are under increasing pressure due to the rapid increase in world population. For example, the irrigated areas in the world have increased during the past two decades, from 8 million hectares in 1800 to 220 million hectares in 1990. However, about half of the irrigated area is affected by salinity due to indiscriminate use of water which has been a serious problem for maintaining optimal agricultural production [3]. There are two sources of salinity: (1) natural processes; and (2) human activities. The natural processes are known as primary salinization and include two factors: (a) the seas and oceans, which are the largest store of salinity on the surface of the earth; and (b) the processes of weathering of parent materials, which contain the salts that eventually become dissolved in waters. The human activities are known as secondary salinization. These are the accumulation of salts in the soil profile or ground water due to human activities such as irrigating with saline water without drainage channels and leaching which transports dissolved salts into groundwater [4]. Nevertheless, soil salinity and saline irrigation water are considered the most important sources of salinity which can have extremely negative impact on agricultural production. The most important factors that lead to an increase in soil salinity are the use of saline water in irrigation as more than half of groundwater supplies used for irrigation is saline. Most plants cannot complete their life cycle under high salt concentrations. However, salt-tolerant plants can grow when exposed to waters in which salinity exceeds 10 dS m^{-1} [5]. Most saline ground waters and drainage waters have an EC which ranges between 2 and 10 dS m^{-1}. If the saline water has an EC of more than 4 dS m^{-1} this may cause toxicity to the crops grown in areas which have 250 mm or less annual rainfall. Whilst 10-25 dS m^{-1} is representative of EC values in groundwater and the recycled second generation wastewaters, it is possible that these waters may be useful for growing tolerant crops. The harmful impacts of saline irrigation water are associated with the increase of salt concentrations in the soil solution. This may lead to the reduction of water absorption by plants, which in turn can lead to delays in the seed germination processes and decrease in the rate of growth [6]. Salinity affects plant growth in a number of different ways: for example: osmotic effects, ionic toxicities and nutritional imbalances [7]. Salinity has a direct impact on plant growth and is a main reason for reductions in plant productivity. However, this effect varies between plant species and depends on the plants' resistances to salinity [8]. Salt-tolerant plants are affected differently from plants which are sensitive to salinity. This resistance is attributed to the ability of some salt tolerant plants to sequester Na^+ and Cl- ions in the vacuoles thus preventing the accumulation of salts in the cell cytoplasm, and therefore preventing salt toxicity [9]. Another salt tolerance mechanism is described by Bohnert et al. and Bohnert and Jensen who reported that "The cellular response to turgor reduction is osmotic adjustment. The cytosolic and organellar machinery of glycophytes and halophytes is equivalently sodium and Cl sensitive; so osmotic adjustment is achieved in these compartments by accumulation of compatible osmolytes and osmoprotectants. Typically, the size and leaf area depends on the cell elongation and cell division. Thereby, increased salt concentrations in plant shoot influence the cell elongation and cell division. However, cell elongation and cell division differ in their resistance to salinity. For example, in sugar beet salinity had no effect on leaf initiation that was controlled by cell division, whilst leaf extension was sensitive to salt stress [10]. Farhad and Mohammad observed that leaf area was reduced with salt concentration increasing in barley tissue water. The highest leaf area was recorded under non-saline treatments and lowest was recorded at the highest level of salt concentration. It is well known that the decrease of leaf area due to increasing level of salinity has negative effects on many physiological processes, which in turn lead to reductions of plant growth such as shoot dry weight, plant height and grain yield. Under saline conditions, the nutritional balance in the plant is altered due to the presence of high concentrations of sodium chloride in the soil solution which leads to higher ratios of Na^+/K^+, Na^+/ Mg^{2+}, and Na^+/ Ca^{2+} in saline soils [11]. In high concentrations, NaCl has also a big role in the increase and decrease of nutrients in plant tissue and root. For example, the application of excessive amounts of NaCl led to an increase in the concentrations of Na, P, Zn, Mn and Cl in the maize shoot and root. As well as this, use of NaCl tends to lead to reduction of nitrogen, calcium, and iron concentrations in the shoots and the increase of these elements in the roots. As mentioned before, potassium is required to complete their physiological processes at different stages of growth. High salt concentrations in irrigation water, could adversely affect potassium uptake which can lead to reduction in growth, so high Na^+ concentrations in soil solution could reduce K^+ concentrations in plant tissue as a result of an antagonistic relationship between Na and K [12].

2. Hypotheses

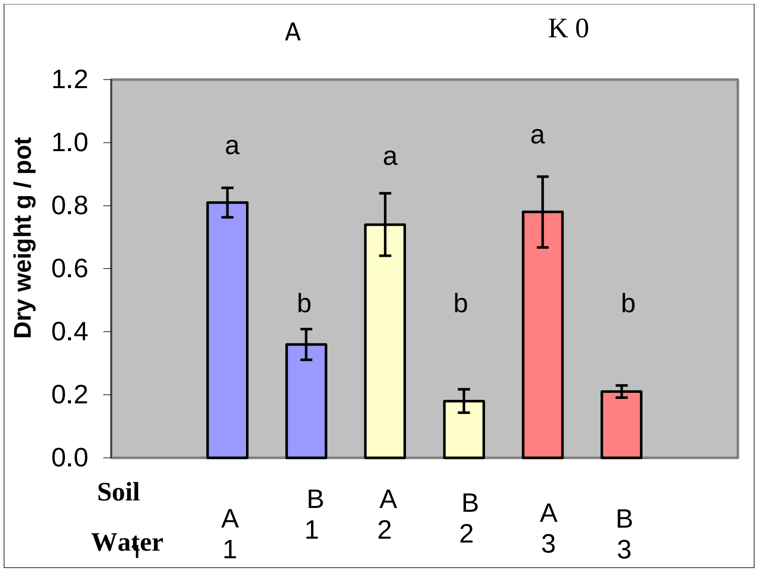
1. Plant growth in terms of dry weight responds more strongly to K supply than to salinity.
2. Plant growth in terms of leaf area responds more strongly to salinity than to K supply.
3. Concentrations of other cations (Na^+, Ca^{2+} and Mg^{2+}) respond to salinity in the same way as does K^+ concentration.

3. Material and methods

The greenhouse experiment was carried out during winter 2022; air temperature ranged from 15-25 °C. The experiment was conducted in polyethylene pots sized 14.5 cm diameter x 15 cm and were arranged in a completely randomized design with four replicates of each treatment. Each pot contained 1 kg of soil. Nitrogen and phosphorus fertilizers were applied to each single pot in all treatments. Both fertilisers were applied during soil preparation. The equivalent of 150 kg ha^{-1} as super phosphate (16 % P_2O_5) was added. The equivalent of 300 kg ha^{-1} nitrogen was added as ammonium sulphate (20 % N). N, P, and (where appropriate) K fertilisers were mixed many times with the soil samples prior planting in the pots. The barley variety that used for experiment was Pearl, because in addition to its resistance to salinity it has good resistance to diseases. Three different irrigation water sources were used. (1), fresh water as control (treatment 1); (2) diluted sea water (treatment 2) ;(3) 150 mM NaCl solution (treatment 3). The rationale for these treatments is as follows. 100 mM Na demonstrated that this concentration of NaCl solution did not have any significant influence on any barley varieties during six weeks [13]. For this reason, 150 mM NaCl solution was chosen. This solution was prepared in the laboratory by adding 43.8 g of NaCl to 5 liters of distilled water. Sea water samples were collected from the Middeterain Sea at Tripoli beach, and then diluted with fresh water 1:3 to obtain a Na^+ concentration of about 150 mM. At the beginning of the experiment all treatments were irrigated with fresh water for two weeks to avoid the effects of salinity on germination and onset growth following this the plants were treated with different saline water concentrations until plants reached an age of 42 days old from the beginning of treatment. Irrigation water was given about once a week, depending on plant water requirement, in order to keep soil water content close to field capacity. The plants were irrigated by fresh water (EC= 0.1 dSm^{-1}) for two weeks and they were harvested after 6 weeks of treatment with saline water. The length and width of growing leaves was recorded every ten days on one plant of each pot in all treatments from which leaf areas were calculated assuming triangular geometry [14]. All plants were harvested after 6 weeks' growth. Roots were washed repeatedly in distilled water to remove soil particles and surface salts. All plant fractions were weighed to get fresh weight (FW) then oven dried at 80 °C for 2 days. Plant parts were weighed again to determine dry weight (DW). After that all samples were ball-milled [15]. 0.1 g of each sample was digested. K^+, Na^+, Ca^{2+}, and Mg^{2+} in digests were measured by flame photometer (Perkin Elmer A Analyst 100 AAS). The cation concentrations are given in parts per million (ppm), and converted to mg g^{-1}.The statistical analysis was achieved using MINTAB software using General Linear Model. Tukey tests were used to determine significant ($P < 0.05$) differences between means.

4. Results

The effect of saline water and K supply on barley dry weight Dry matter production by plants grown in the clay soil and irrigated by fresh water was double the amount of dry matter for corresponding plants cultivated in the sandy soil (Fig 1 a, b). Salinity had a marginal effect on dry weight ($P < 0.007$). However, dry weight was slightly decreased by increasing salt concentration. In the sandy soil, the highest dry matter was recorded in the plants irrigated by fresh water and the lowest was in plants irrigated by diluted sea water (Fig 1 a, b). K supply did not cause any significant effect on dry weight ($P < 0.15$). Nevertheless, the average accumulation of dry weight in plants which did not receive K supply was almost similar to that in plants which fertilized.



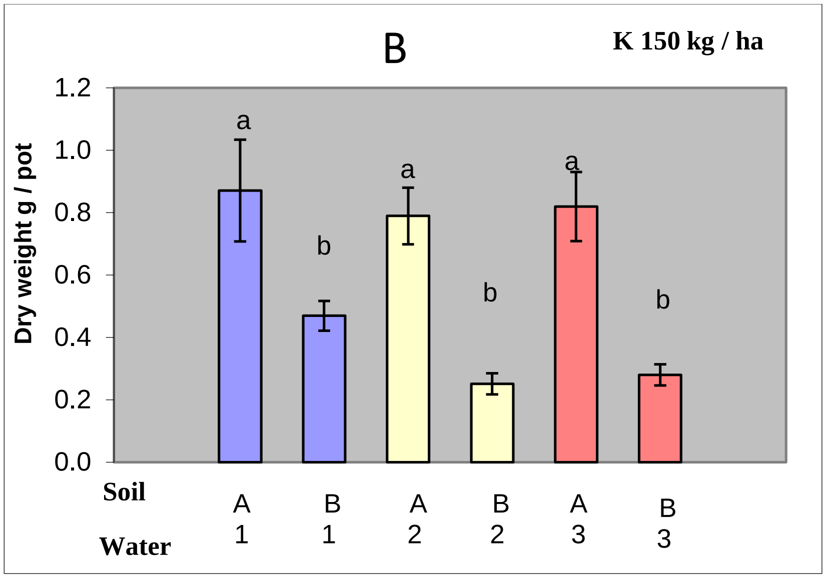


Fig 1 a, b. The effect of different saline irrigation water, two soil textures and two K levels on mean dry matter production (± SE). Where water 1= fresh water, 2= diluted sea water EC = 20 dS m^{-1}, 3 = 150 mM NaCl solution, EC = 16 dS m^{-1}. Soil A= clay, Soil B = sandy. Means followed by the same letter are not significantly different at p = 0.05 (Tukey test). In term of salt concentration, the highest mean value of plant dry weight was recorded in plants which were irrigated by fresh water, and the lowest in plants treated by diluted sea water. Despite approximately equal concentrations of NaCl in salt diluted sea water and 150 mM NaCl solution the dry weight was less in plants irrigated with diluted seawater than in plants receiving 150 mM NaCl solution (Fig.1 a, b). The response of leaf area to salinity and K supply. Irrigation water also caused significant effects on leaf area, the smallest leaf area was observed in plants irrigated with high salt concentration (EC = 20 dS m^{-1}), while the biggest leaf area was in plants irrigated with fresh water (Fig.2 a, b). On the other hand, K supply did not have statistically significant effects on barley leaf area ($P < 0.859$).

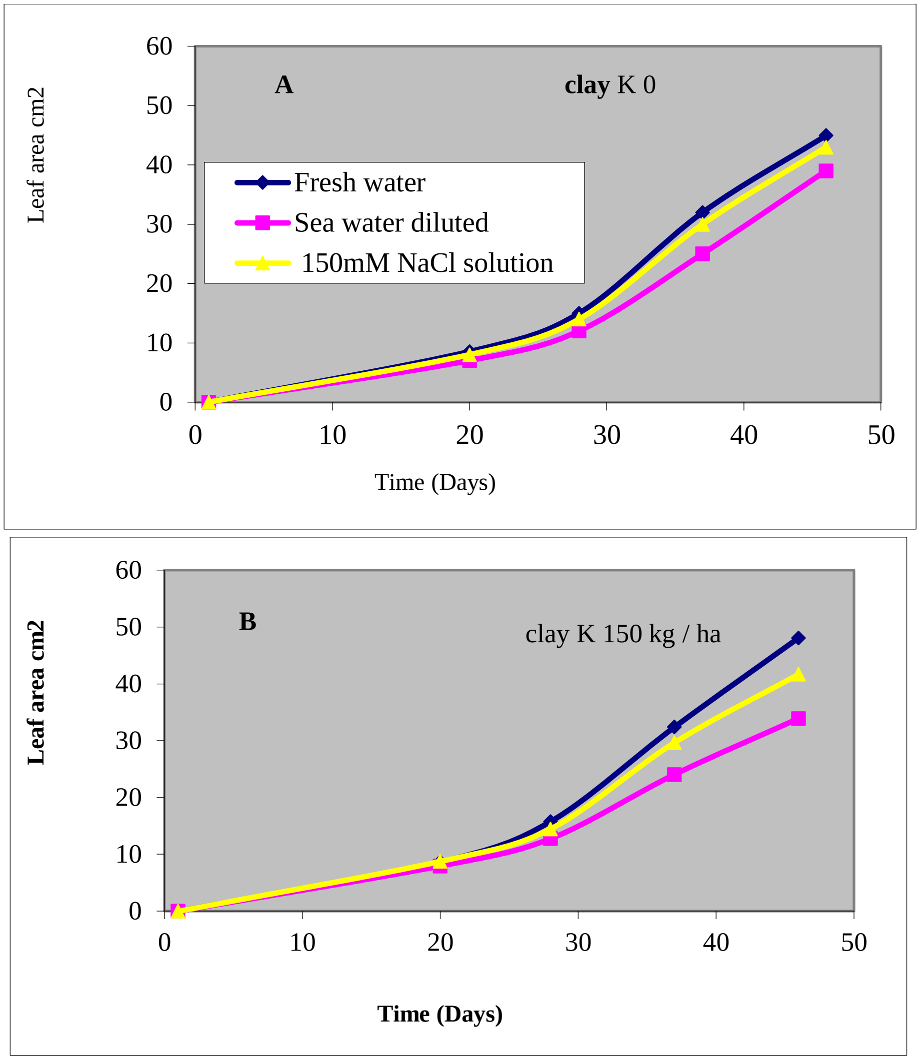


Fig .2 a, b The effect of irrigation water and K supply on leaf area in clay soil. In fig.2 a plants did not receive K fertiliser; in fig.2 b plants received 150 kg ha^{-1} K. The effect of saline water and soil environment on cation concentration in shoot and root.

K^+ concentration in Green leaves

Irrigation water had highly a significant effect on K^+ concentration per unit tissue water. The highest K^+ concentration was recorded in the plants irrigated by dilute sea water (19 mg g^{-1}) and the lowest observed in plants watered by non saline water (10 mg g^{-1}). K fertiliser did not affect K^+ concentration per unit water ($P > 0.05$). K^+ concentration in the plants that did not receive K fertiliser were similar to plants received 150 kg ha^{-1}. Although K^+ concentration in plant tissue water was not influenced statistically by K fertiliser.

Roots

Plants which received 150 kg ha^{-1} K maintained K^+ concentrations in their root tissue water more than roots which did not receive K fertiliser.

Na^+ concentration in Green leaves

The effect of irrigation water on Na^+ concentration was different from that on K^+ concentration, where irrigation water had a greater influence on Na^+ concentration Irrigation water had highly significant effects on Na^+ concentration ($P < 0.001$). Increased salt concentration in the soil solution led to increased Na^+ concentration in plant tissue water. The highest means of Na^+ in tissue water were recorded in plants irrigated by NaCl solution (3.86 mg g^{-1}), and the lowest one was in the control treatments (0.14 mg g^{-1}). Statistically, there was no significant difference in the effect on Na^+ concentrations between plants irrigated with diluted sea water

or NaCl solution, except for those grown without K fertiliser. Salt-stressed plants had a Na^+ concentration in their tissue

which was about 17-fold greater than plants watered by fresh water. Once again, K fertiliser did not produce any significant effect on Na^+ concentration in the tissue ($P < 0.085$).

Roots

Salt water had strong effects on Na^+ concentration in the root tissue. Dramatic increases in Na^+ concentration in the root were observed under increasing salt level in the external soil solution.

Ca^{2+} concentration in Green leaves

Again, irrigation water had a significant influence on Ca^{2+} concentration in green leaf tissue water ($P < 0.001$). Ca^{2+} concentration was reduced by salt level increasing in irrigated water. For example, the lowest Ca^{2+} concentration in plant per unit water occurred at plants irrigated by the highest level of salinity (diluted sea water; 0.6 mg g^{-1}). Plants grown in non-saline water treatments had greater Ca^{2+} concentration than did salt stressed plants. Saline water had a stronger effect than K fertiliser on Ca^{2+} concentration. Nevertheless, the accumulation of Ca^{2+} in the plant tissue water that was treated with saline water was similar to non-saline treatments. K supply had a significant influence on Ca^{2+} concentration ($P < 0.04$). Ca^{2+} concentration decreased in all treatments when K was applied. For example, plants which did not receive K fertiliser maintained Ca^{2+} concentrations in their tissues more than plants that received 150 kg ha^{-1} even though these variations statistically were quite small.

Roots

The concentration of Ca^{2+} ion in the root tissue was affected by water salinity and K supply. Saline irrigation water had also a large significant effect on Ca^{2+} concentrations ($P < 0.001$). Plant roots had different responses to salt concentration according to salt concentration in soil solution. The concentration of Ca^{2+} decreased with salinity except in plants which were cultivated in sandy soil and watered by diluted sea water K supply had also a statistically significant effect on Ca^{2+} concentration ($P < 0.002$).

Mg^{2+} concentration in Green leaves

The concentration of Mg^{2+} was also affected by irrigation water as was Ca^{2+} concentration but Mg^{2+} concentration increased in plant tissue with increasing salt concentration ($P < 0.001$). The highest concentration of Mg^{2+} in all treatments was in the plants watered by diluted seawater (0.35 mg g^{-1}). Plants irrigated by fresh water maintained Mg^{2+} concentration in their tissue of about 0.27 mg g^{-1}. Mg^{2+} concentration in plant tissue was increased in salt stressed plants even though plants did not receive Mg fertiliser, where levels in plant leaves were almost doubled. Statistically, K supply had a small but significant effect on Mg^{2+} concentration ($P < 0.05$). Mg^{2+} concentration was reduced when treatments were treated with 150 kg ha^{-1} K. However, the range of variation was narrow if compared with plants which did not receive K fertiliser.

Roots

The concentration of Mg^{2+} in root tissue was highly affected by irrigation water and K application ($P < 0.001$, 0.009, respectively), under all experiment conditions, the mean of Mg^{2+} concentrations in barley root either remained constant or increased by increasing salt concentration in irrigation water compared with plants irrigated by fresh water, where it's a ranged from 0.09 to 0.18 mg g^{-1} except means of plants treated with diluted sea water.

Discussion

Under these conditions the outcomes of the experiment disprove the first hypothesis that says dry weight in barley crop responds more strongly to K supply than to salinity. Regarding the second hypothesis in terms of leaf area, results supported the hypothesis that leaf area responded more strongly to salinity than K supply. Finally, results did not support thrid hypothesis, where Ca^{2+}, Mg^{2+} and Na^+ concentrations per unit tissue water differed in their response to salt concentration.

The effect of saline water and K supply on barley dry weight

High concentrations of dissolved ions in irrigation water can cause the release from soil exchange sites of specific ions, especially Na^+, increasing the concentration of sodium in the root zone. This reduces the capacity of the plant to selectively absorb other ions especially K^+ [15]. Reductions of plant dry weight due to the high concentration of salts could be due to several reasons including; (1), High salinity restricts the function of enzymes that causes reduction in plant dry matter, for example, cytoplasmic and chloroplastic enzymes cannot function well under high salt concentration [16]. (2), Unfavorable osmotic gradients disrupt normal patterns of water ("physiological drought": Mahajan and Tuteja, 2005) and solute uptake [17]; (3) High external salt concentrations reduce the capacity of cells to generate sufficient turgor pressure to expand leaves and roots. Intshae et al. (2003) found that barley dry weight was significantly decreased by increased level of salinity from 2.5 dS m^{-1} (control) to 20 dS m^{-1}.

The response of leaf area to salinity and K supply.

In contrast to dry matter production, leaf area responded strongly to salinity. During first three weeks' leaf area was almost identical for all plants due to treatments being irrigated by non-saline water for two weeks. After the third week leaf area was significantly affected by salinity of water. Leaf areas that were reduced by increasing salt concentration could be attributed to accumulation Na^+ in leaf tissue which has effects on cell expansion and formation. Leaf area expansion of non-halophytes is always reduced when plants are grown in saline conditions compared with non-saline [18]. Similar results were reported by Farhad and Mohamed who tested 12 cultivars of barley under different level of salinity. They found that the total leaf area of all barley cultivars was significantly reduced by increasing salt concentration. For example, leaf area declined from about 110 cm2 per plant in control treatments to 25 cm2 when plants treated with 225 mmol l^{-1} NaCl and CaCl (1:2 ratio). Similarly, Merir et al. found that leaf area of bean plants decreased by about 30-44 % when plants were irrigated by two different levels of NaCl (Osmotic potential = -2.2 and - 3.7 bar, respectively).

K^+ concentration in green leaves and roots

In saline water treatments, fertiliser did not seem to affect
plants which were irrigated by saline water. This could be attributed to the increased Na^+ in the external solution, caused by disruption to K^+ uptake as a result of competition between K^+ ion and Na^+ on the absorptive sites of the crop root [19] or as a result of cation balance [20]. Nutrient imbalance occurs due to increasing salinity as a result of competitive absorption or transport within plants.

Na^+ concentration in green leaves and roots

Concentrations of Na^+ in shoot and root of the plant were affected by salinity but not K supply. The salinity effect was predictable simply because of the greater concentrations of Na^+ in soils irrigated with NaCl or seawater. Cramer et al. reported that increased Na^+ concentration in external media lead to increased Na accumulation in plant roots, and may prevent the absorption of other ions by the roots and their transfer into the shoot. The Na^+ concentration in plants irrigated by saline water was about 18-fold that of plants watered by fresh water.

Ca^{2+} concentration in green leaves and roots

Responses of Ca^{2+} concentration was completely contrary to those of Na^+ concentration. Ca^{2+} concentrations per unit tissue water in both green leaves and roots decreased with increasing salinity. This could be attributed decrease of Ca content in plant shoot due to increase level of salt concentration in external media of growth. One of the important effects of salinity on plants is changes in Ca^{2+} homeostasis [21] found that Ca content of soybean decreased significantly by about 50 % when EC of salt concentration increased from 0.5 to 8.5 dS m^{-1}. Prakash et al. (2010) reported that increased level of NaCl from 2 to 10 dS m^{-1} led to significant decrease of Ca^{2+} concentration from 4.5 to 3.1 mg g^{-1} on a dry weight basis. Applied K caused decrease in Ca^{2+} concentration in barley shoot. This could be explained by enhanced amounts of monovalent ions in soil solution which may have inhibited Ca^{2+} transport to plant shoot.

Mg^{2+} concentration in green leaves and roots

Finally, Mg^{2+} a concentration per unit tissue water in plant shoot was increased by increasing salinity especially in plants irrigated by diluted sea water, this increase could be attributed to that diluted sea water contains Mg^{2+} ions (typically about 50 mmol kg^{-1};). Mg^{2+} concentration in tomato plants increased significantly from 0.9 to 1.04 % when external salt concentration reached 60 mM (diluted sea water) compared with control treatment (0 mM) because Mg^{2+} had been included in the composition of the artificial salt solutions [22]. In terms of plants irrigated by 150 mM NaCl solution, the increased Mg^{2+} concentration could be attributed to the presence of Na^+ ion in root rhizosphere which led to enhanced membrane permeability of root cells.

5. Conclusions

Salinity was the dominant factor affecting nutrient balance and growth responses in barley under the experimental conditions. Leaf area was more sensitive to salinity stress than to potassium supply, while dry matter production was only slightly affected. Potassium concentrations in plant tissues were mainly regulated by salinity due to strong Na^+–K^+ antagonism, and potassium fertilization did not alleviate salinity-induced growth reduction. Moreover, Na^+, Ca^{2+}, and Mg^{2+} showed ion-specific responses to increasing salinity, with noticeable changes in cation composition even under constant nutrient supply, particularly for Mg^{2+}.

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