Effects of Zeolite on Soil Nutrients and Growth of Barley Following Irrigation with Saline Water

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Abstract

Soil salinity is a major abiotic factor limiting crop production but an amendment with synthetic zeolite may mitigate effects of salinity stress on plants. The objective of the study was to determine the effects of zeolite on soil properties and growth of barley irrigated with diluted seawater. Barley was raised on a sand dune soil treated with calcium type zeolite at the rate of 1 and 5% and irrigated every alternate day with seawater diluted to electrical conductivity (EC) levels of 3 and 16 dS m-1. Irrigation with 16 dS m-1 saline water significantly suppressed plant height by 25%, leaf area by 44% and dry weight by 60%. However, a substantial increase in plant biomass of salt stressed barley was observed in zeolite-amended treatments. The application of zeolite also enhanced water and salt holding capacity of soil. Post-harvest soil analysis showed high concentrations of Ca2+, Mg2+, Na+ and K+ due to saline water especially in the upper soil layer but concentrations were lower in soils treated with zeolite. The overall results indicated that soil amendment with zeolite could effectively ameliorate salinity stress and improve nutrient balance in a sandy soil.

Keywords: Barley Growth, Saline Water, Zeolite, Soil Nutrient, Soil Salinity

Introduction

The demand for fresh water is increasing worldwide due to fast population growth and improvement in living standards. Conflicts between water use for irrigation and other uses have created interest in exploring the use of sea and other recyclable sources such as waste water. However, use of poor quality water for irrigation may lead to soil salinity and its associated problems. Accumulation of salts in the root zone affects plant performance through creation of water deficit and disruption of ion homeostasis (Munns, 2002) which in turn cause metabolic dysfunctions. These stresses change hormonal status and impair basic metabolic processes (Munns, 2002; Loreto et al., 2003) resulting in growth inhibition and reduction in yield (Mass, 1993). Irrigation management practices aim for the efficient use of saline water by maintaining salt accumulation in the root zone at lower levels and cultural practices may dramatically improve the performance of crops in saline environments. Soil permeability problems may be prevented or corrected by using soil or water amendments.

Synthetic zeolite produced from coal ash is a beneficial soil amendment because it enhanced the absorption and retention of plant nutrients and water and supplemented micronutrients (Burriesci et al., 1984). Since calcium (Ca) plays a vital nutritional and physiological role in plants, the restricted plant growth due to effects of specific ion or Na^{+}/Ca^{2+} imbalance may be ameliorated using Ca-type zeolite. Barley (*Hordeum vulgare* L.) is an important salt tolerant cereal crop grown under various climatic, soil and water conditions. Thus it is more amenable to irrigation with saline water than most crops. However, excessively saline water may hinder its growth and yield. We are not aware of studies into the use of Ca-type zeolite to mitigate the impacts of low-quality (saline) water on the productivity of agricultural crops. The objectives of this study were thus to evaluate changes in some soil properties and determine if the growth of barley irrigated with saline water can be improved with zeolite application.

Materials and Methods

The study was conducted in a glass house at the Arid Land Research Center, Tottori University, Japan. We used a sand dune soil whose properties are shown in Table 1. The soil texture was determined by the pipette method (Gee and Bauder, 1986). Exchangeable cations were leached from the soil with neutral ammonium acetate and their concentrations determined using an atomic absorption spectrophotometer (Model Z-2300 Hitachi Corp, Japan). Electrical conductivity and pH of the soil: water suspension of 1: 5 were also measured with pH and EC meters (Accumut M-10 and Horiba DS-14) respectively. The analysis of the seawater used for irrigation is also shown in Table 1.

The experiment was conducted in plots as well as in pots (30 cm in height and 16 cm in diameter) containing five kg of soil. The seawater was diluted to electrical conductivity (EC_w) levels of 3 and 16 dS m^{-1}. Synthetic Ca-type zeolite was applied at the rate of 0, 1% and 5% (equivalent to 0, 1 and 5 kg m^{-2}). The two saline water treatments were factorially combined with the three levels of zeolite and arranged into a completely randomized design with four replications. Barley was the test crop and being salt tolerant, the saline water of 3 dS m^{-1} was used as control treatment. The crop was irrigated on alternate days depending on the crop evapo-transpiration (ETc) which was measured gravimetrically in the pots. In addition to applying water equivalent to ETc, an extra water with a leaching fraction of 0.4 was applied to the plants. A basal dose of fertilizer containing 180 kg ha^{-1} N, 45 kg ha^{-1} P and 80 kg ha^{-1} K was added in the irrigation water. Soil salinity and moisture content in plots were measured continuously using Time Domain Reflectometry (TDR). A portable wet sensor was used to monitor the water content and salinity of soil at 0-10 cm depth. Direct soil sampling was also carried out to evaluate soil salinization and moisture content at depths of 0-10 and 10-20 cm.

Table 1. Selected physicochemical characteristics of soil and natural seawater studied

Soil	Value	Seawater	Concentration
EC (1: 5) water	0.03 dS m^{-1}	Nitrogen	630 μgL^{-1}
pH	6.36	Phosphorus	99 μgL^{-1}
Total N	0.021 %	Potassium	398 mgL^{-1}
Available-P	1.5 mg $P_2O_5$100g^{-1}	Sodium	10.8 gL^{-1}
Exchangeable K^+	0.06 $cmol_c$ kg^{-1}	Magnesium	1.29 gL^{-1}
Exchangeable Ca^{2+}	0.34 $cmol_c$ kg^{-1}	Calcium	412 mgL^{-1}
Exchangeable Mg^{2+}	0.45 $cmol_c$ kg^{-1}	Manganese	165 ngL^{-1}
Exchangeable Na^+	0.10 $cmol_c$ kg^{-1}	Zinc	590 ngL^{-1}
CEC Cation exchange capacity	2.40 $cmol_c$ kg^{-1}	Sulfur	900 mgL^{-1}
Bulk density	1.47 g cm^{-3}	Iron	140 ngL^{-1}
Infiltration rate	30.0 mm min^{-1}	Chromium	260 ngL^{-1}
Hydraulic conductivity	0.05 cm sec^{-1}	Copper	380 ngL^{-1}
Texture	Sand	Nickel	700 ngL^{-1}

Fortnightly measurement of plant height was carried out and the leaf area was measured using a portable area meter LI-3000A. After 10 weeks of growth, plants were sampled for determination of fresh biomass yield. The dry biomass was estimated after drying shoots in an oven at 65 ^oC for 48 h. Soil samples were collected from the plots and pots at 0-10 and 10-20 cm depth. The moisture content, pH and electrical conductivity (EC) in soil-water suspensions (1: 5) were measured as described above. The infiltration rate in the zeolite amended soils was also determined by double ring infiltrometer. Soil and plant samples (0.5 g) were digested with concentrated hydrochloric acid (HCl) to determine total Ca^{2+}, Mg^{2+}, Na^+ and K^+ using inductively coupled plasma (ICP) system. Data were analyzed statistically using the analysis of variance and the means were compared at the probability level of 5% using least significant difference (LSD).

Results and Discussion

Soil Salinity and Moisture

During the study, climatic conditions in the glass house varied with an average temperature of 24°C and relative humidity of 65%. The wet sensor data (Fig. 1) showed that the effects of seawater irrigation on soil salinity were significant. Zeolite application increased water content under both saline treatments. Moreover, soil under the higher salinity treatment had more water than that in the lower salinity treatment and this was due either to reduced water uptake by barley or enhanced water density, viscosity and formation of salt crust which resulted in low evaporation from the soil surface. Al-Busaidi and Cookson (2005) reported that salt crust formation on the soil surface, inhibited evaporation and reduced leaching efficiency under saline irrigation. Salt accumulation increased with frequency and EC of irrigation water (Fig. 1) and zeolite application, notably at 5% increased both the content of salt and water, especially in the soil surface.

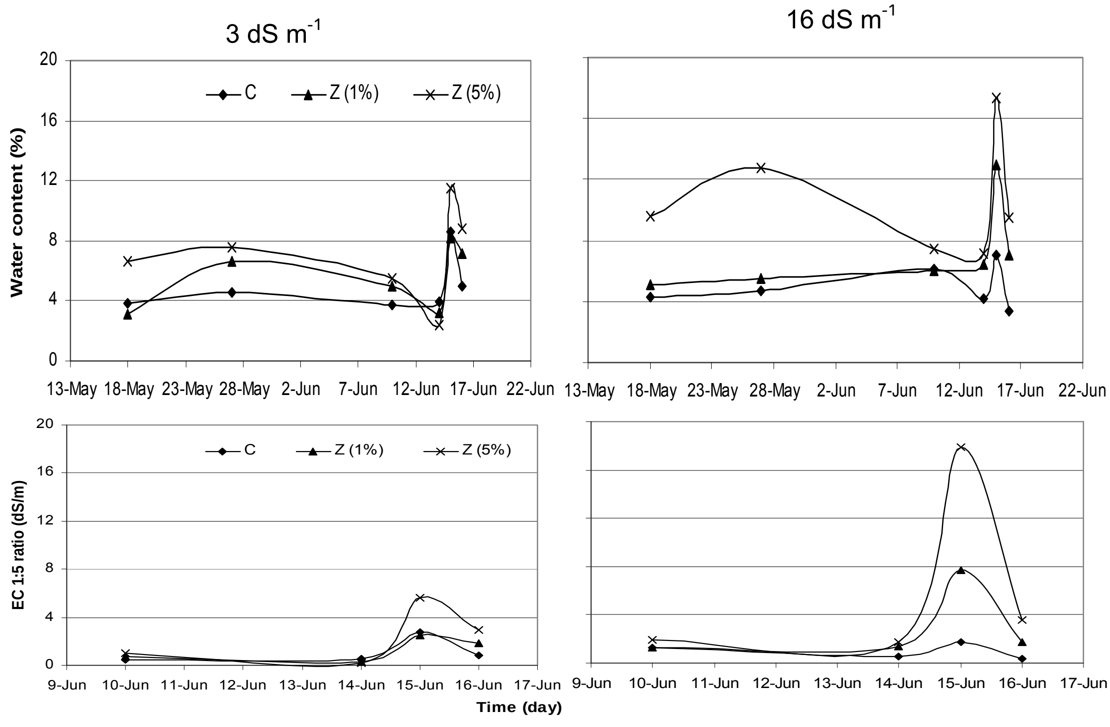

Figure 1. Water content and soil salinity at 0-10 cm depth as monitored by wet sensor. For this and subsequent figures: C denotes control or unamended soil and Z (1%) and Z (5%) denote zeolite application rates of 1 and 5%.

Zeolite treatment maintained higher soil water level than the control, thus confirming that its application enhanced the water holding capacity of the soil. However, amending soils with zeolite increased soil salinity (Fig. 2). The increase was directly related to the amount of minerals present in the zeolite or its salt retention capacity. The fluctuation in soil EC was possibly due to the amount of salts either drained out in the water or taken up by the plants.

The infiltration rate of soil was negatively affected by zeolite (Fig. 3) as the fine particles and micro pores of zeolite slowed the percolation of water in the soil. The reduced soil filtration increased the content of water in the soil. Thus we suggest that zeolite application may enhance the residence of water and restrict nutrient or salt leaching to lower soil horizons.

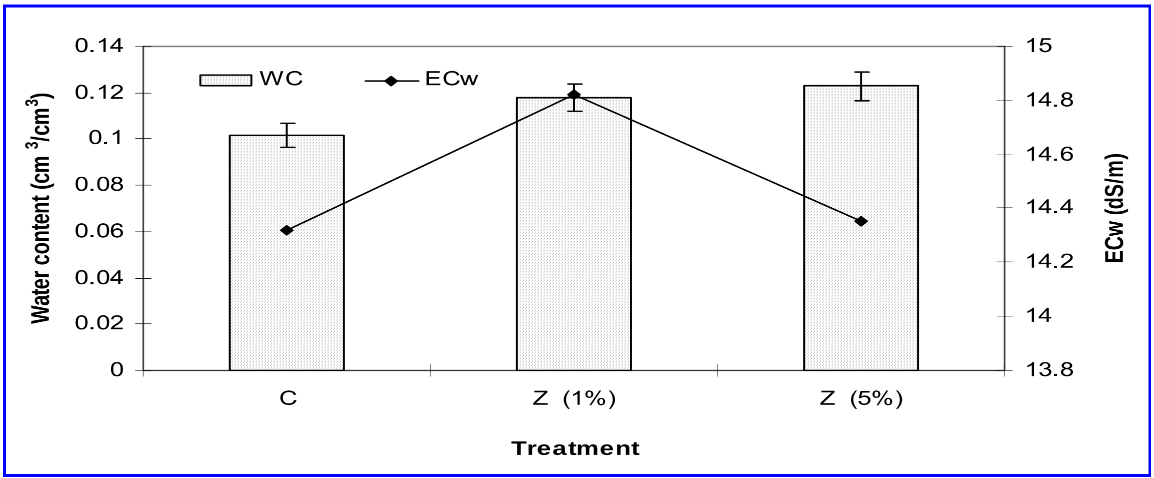

Figure 2. Average soil water content and salinity at 25 cm depth as measured with TDR.

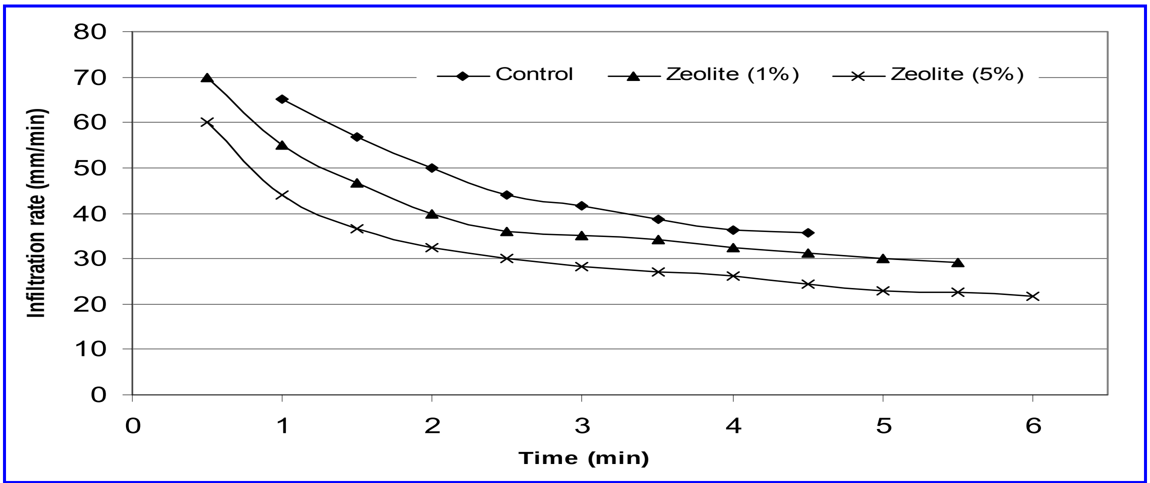

Figure 3. Infiltration rate of soil as affected by zeolite application under high salinity treatment

Soil Properties

The chemical composition of the soil was altered by saline water irrigation and zeolite amendment (Fig. 4). Concentrations of cations increased significantly with increasing salinity of irrigation water. Magnesium, Ca^{2+}, Na^+ and K^+ concentrations decreased down the profile due to salt movement by the capillary action of water. At 3 dS m^{-1} irrigation water, Mg^{2+} was the highest in soil followed by Ca^{2+}, K^+ and Na^+ but at 16 dS m^{-1}, Na^+ and Mg^{2+} appeared to be the dominant cations. Compared with other ions, Mg^{2+} concentration increased down the profile. Concentrations of elements in soil were definitely related to their relative concentrations in the irrigation water.

Treatment with zeolite increased cation concentrations in the upper soil layer and decreased concentrations down the profile. The lower salt accumulation in the subsurface soil or root zone may offer a reduced salt stress on plants. Thus, an application of higher doses of zeolite may filter harmful salts from the root zone, thereby creating a favorable environment for plant growth. Vassilis and Inglezakis (2005) reported a wide use of zeolites for ion-exchanges in the soil solution.

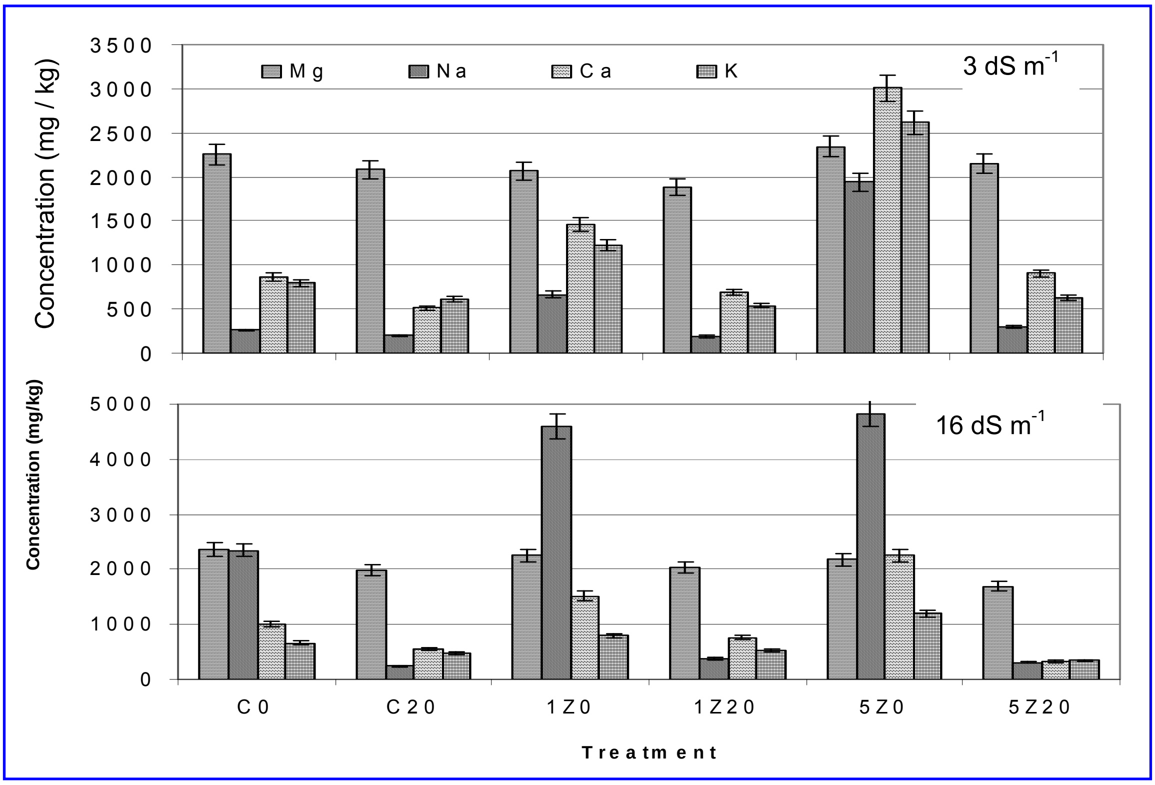

Figure 4. Major elements of soil as affected by zeolite and saline water.

For this and subsequent figures: C0 = unamended soil sample taken from 0-10 cm depth, C20 = unamended soil sample (10-20 cm), 1Z0 = 1% zeolite treated soil (0-10 cm) and so on.

Plant Growth

A summary of the two-way analysis of the interactive effects of zeolite and water EC on plant growth is given in Table 2. Plants irrigated with saline water with an EC of 3 dS m^{-1} were taller and had larger leaf area than those irrigated with 16 dS m^{-1} saline water (Table 3). Salinity stress retards plant growth through its influence on several vital plant physiological processes e. g., osmotic adjustment, nutrient uptake, photosynthesis, organic solute accumulation, alteration in respiration rates and soil water potential (Pessarakli, 1994). The adverse effect of salinity on plant growth has been reported by various researchers (Cramer et al., 1990; Mass and Hoffman, 1977; Song and Fujiyama, 1996a). Response of plants to salt stress is also a function of salt concentration, type of ions, stage of plant development and other environmental factors. Saline soils inhibit plant growth through reduced water absorption, reduced metabolic activities due to salt toxicity and nutrient deficiencies caused by ionic interferences (Yeo, 1983).

Table 2. Summary of two-way analysis of variance on saline water and zeolite effect on soil and plant parameters

Parameter	Saline water (S)	Zeolite (Z)	S x Z
		F-value	
Soil EC	226.8*	NS	10.8*
Soil cations			
Magnesium	80000*	21350*	141650*
Sodium	24290.4*	9104.9*	10498.4*
Calcium	94429.2*	48318.9*	158145.0*
Potassium	103121.8*	6382.9*	32210.7*
Dry biomass	2385.4*	330.6*	90.5*

*denote the level of significance ($P < 0.05$) and NS denotes non-significant effect.

Barley crop responded positively to zeolite amendment especially in the higher salinity treatment (Table 3). Zeolite treatment at 5% produced taller plants, and more grains and plant biomass than at 1%. This response was possibly associated with water, salt and nutrient dynamics in zeolite mixed soils. The improvement in growth may also be related to the essential nutrients contained in zeolite. Ayan et al. (2005) reported increased cation exchange ability, water retention and plant nutrients following zeolite application. Usually the higher Na^+ content in saline soils disturbs the nutritional balance and upsets the osmotic regulations of plant tissues (Pessarakli, 1994). Zeolite provides an alternative Ca^{2+} cation to the soil-plant system reducing the ratio of Na^+/Ca^{2+}. The provision of Ca^{2+} from zeolite in the root media would prevent an accumulation of toxic Na^+ ion in plants. Song and Fujiyama (1996) ascribed the ameliorative effects of the Ca-type zeolite on the rice and tomato growth to decreases in Na^+ concentration in shoots as well as Na^+/Ca^{2+} and Na^+/K^+ ratios of shoots and roots. The greater need for Ca^{2+} by plants in the saline-sodic soils and reduced activities of Ca^{2+} due to ionic interactions and precipitation are partially responsible for reduced yields under saline or sodic conditions (Janzen and Chang, 1987; Rengasamy, 1987). The conditioning of saline soil with zeolite could mitigate the stress effects of salts on plants.

Table 3. Plant growth parameters as affected by salinity and zeolite treatments

Treatment		Height	Leaf area	Grain	Fresh weight	Dry weight
Saline water	Zeolite treatment	cm	cm^2	No.	g	g
3 dS m^{-1}	Control	85.0	36.5	186	1615.2	417.0
	Zeolite 1%	81.5	34.8	188	2039.7	448.7
	Zeolite 5%	81.5	37.8	195	1727.7	454.5
16 dS m^{-1}	Control	63.5	20.3	91	902.5	166.6
	Zeolite 1%	67.7	20.0	106	916.5	187.2
	Zeolite 5%	69.6	22.1	116	988.5	205.4

Plant Tissue Analysis

Higher elemental concentrations, especially of K and Na ions, were observed in shoots after irrigation with diluted sea water (Fig. 5). Much of the K^+ was attributed to the K added to the irrigation water (fertigation) whereas the [Na^+] was essentially related to the higher level contained in the seawater. Nutrient availability and uptake in saline environments are related to (James, 1990): i) the activity of nutrient ions in the solution, which depends on pH, pE and salt composition, ii) the concentration and ratios of accompanying elements that influence the uptake and transport of this nutrient by roots, and iii) numerous environmental factors. In plant nutrition K^+, Mg^{2+} and Ca^{2+} all play the same role, i. e., they act as a buffer system of plant cells, and hence they can be substituted for each other (Rabie and Kumazawa, 1988). Classen and Wilcox (1974) reported that the uptake of K^+ by plants at high salinity levels was reduced by increasing availability of Ca^{2+}, Mg^{2+} and Na^+ from added salts. Salt addition to the soil plant system may add or remove essential elements. The higher amount of Na^+ in the root zone could decrease the uptake of other essential cations e. g., Ca^{2+}, Mg^{2+}, K^+ by the plants due to cation-balance (Pessarakli, 1994).

For each EC level of seawater, concentrations of Na and K ions in tissues peaked at the zeolite level of 1% but those of Ca^{2+} and Mg^{2+} were not affected by zeolite application. Cramer et al. (1985) ascribed the low concentration of Ca^{2+} to: i) its less uptake by plants compared to N, P or K^+, ii) its presence in zeolite in less bioavailable form, and iii) competition for absorption or activities in the soils from other cations contained in sea water. Such physiochemical changes in the system may deregulate plant nutrition under saline conditions.

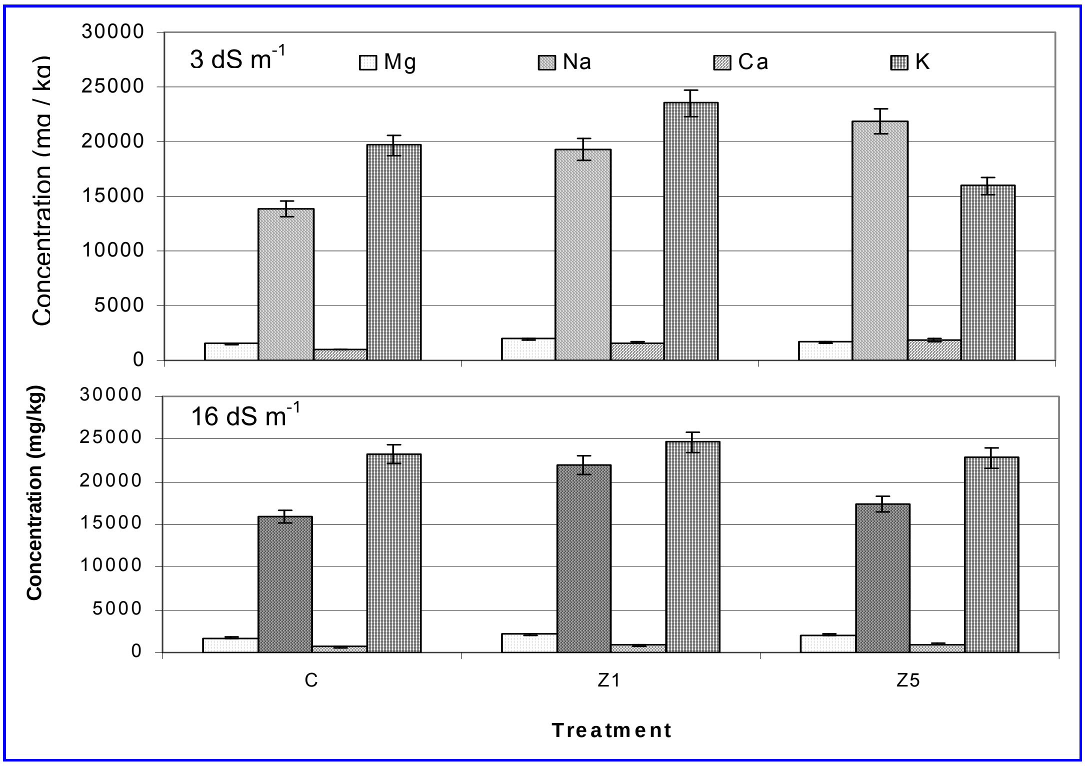

Figure 5. Major cations concentrations in barley as affected by zeolite and saline water.

Conclusion

Using zeolite to amend soil irrigated with saline water could mitigate the harmful effects of salinity on barley because it improved plant production and sustained higher soil-water. There were higher concentrations of Na, K, Mg and Ca under saline water in the upper soils following irrigation with saline water, but this decreased down the profile. Amending a sandy soil with zeolite may filter some toxic substances and produce a conducive environment for plant growth. Although use of saline water for irrigation is not widely practiced for obvious reasons, a soil amendment like zeolite seems to be a promising management tool under such conditions.

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