Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 7 (16): 2272-2276, 2007
ISSN 1812-5654

The Ameliorative Effect of Artificial Zeolite on Barley under Saline Conditions

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Abstract: This investigation was aimed to evaluate the effects of zeolite in conjunction with seawater irrigation on barley (*Hordeum vulgare* L.) growth and salt composition of soil. A sand dune soil was amended with Ca-type zeolite at the rate of 1 and 5% and the seawater was diluted up to the electrical conductivity of 3 and 16 dS m^{-1}. Present results showed that zeolite application significantly increased water holding capacity of the soil and accumulated more salts. The zeolite mixed soils improved plant growth compared to the un-amended control. Higher saline water significantly suppressed the growth of barley than the water with low salinity. The restricted plant growth due to the effects of specific ion or Na^+/Ca^{2+} imbalance may be ameliorated using Ca-type zeolite. We may conclude that soil amendment with zeolite could alleviate the adverse effects of salts on plants following irrigation with higher saline water.

Key words: Saline water, plant growth, artificial zeolite, salt accumulation

INTRODUCTION

Excessive salinity in the soil has been considered the main limiting factor for the plants in the natural habitat and the problem is severely increasing in many parts of the world. Usually saline conditions are characterized by low nutrient ion activities and extreme ratios of Na^+/Ca^{2+} and Na^+/K^+ resulting nutritional disorders as well as reduced crop growth (Pessarakli, 1994). Irrigated agriculture using saline water in arid and semi-arid region may lead to the salt build-up in soil and reduction in yield and soil resource sustainability, if proper management practices are not followed. The salinization of soils and water places substantial constraints on crop productivity in the arid and semi-arid regions (Royo *et al*., 2000).

Applying amendment to the salt affected soils could decrease the adverse effects of salinity and support plant growth. Synthetic zeolite produced from the coal ash is a beneficial soil amendment because it enhanced the absorption and retention of plant nutrient and water supply and supplemented micronutrients (Ayan *et al*., 2005). Since Ca plays a vital nutritional and physiological role in plants, the restricted plant growth due to the effects of specific ion or Na^+/Ca^{2+} imbalance may be ameliorated using Ca-type zeolite. The addition of the zeolite showed significant plant growth probably as a result of the sorption of heavy metals and buffering effect of pH (Querol *et al*., 2006). Cramer *et al*. (1985) found that enhanced Ca^{2+} may protect the plant from NaCl toxicity by reducing the displacement of membrane-associated Ca^{2+} or by reducing Na^+ uptake/transport to the shoots or by their combined effects.

Barley (*Hordeum vulgare* L.) is one of the important salt tolerant cereal crops in many countries. However, using seawater as a source of irrigation could provide plant with nutrients but high concentration of some ions such as Na^+ could case salinity stress problems. The fundamental understanding on the effects of seawater irrigation together with zeolite could be useful for the barley production in arid and semi arid countries. The current investigation was carried out to evaluate the ameliorative effects of zeolite on barley growth irrigated with saline water in a sandy soil.

MATERIALS AND METHODS

The experiment was carried out at Arid Land Research Center of Tottori University Japan in a plastic greenhouse. Sand dune soil was used for the study and the relevant properties are shown in Table 1. Soil texture was determined by the pipette method. Exchangeable cations were leached from the soil with neutral ammonium acetate and their concentrations were determined using a Polarized zeeman atomic absorption spectrophotometer (Model Z-2300 Hitachi corp, Japan). The cation exchange capacity (CEC) was measured according to the procedure described by the Jackson (1965). Electrical conductivity and pH of the soil: water suspensions (1:5) were also measured with pH and EC meters (Horiba DS-14), respectively.

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Table 1: Selected physicochemical characteristics of soil

Property	Value
EC (1:5) water	0.03 dS m^{-1}
pH	6.36
Exchangeable K^+	0.06 $cmol_c$ kg^{-1}
Exchangeable Ca^{2+}	0.34 $cmol_c$ kg^{-1}
Exchangeable Mg^{2+}	0.45 $cmol_c$ kg^{-1}
Exchangeable Na^+	0.10 $cmol_c$ kg^{-1}
Cation exchange capacity	2.40 $cmol_c$ kg^{-1}
Bulk density	1.47 g cm^{-3}
Infiltration rate	30.0 mm min^{-1}
Hydraulic conductivity	0.05 cm sec^{-1}
Texture	Sand

Barley was grown in April 2006 in the 5 L pots and irrigated with two levels of diluted seawater with electrical conductivity of 3 and 16 dS m^{-1} denoted as low and high, respectively. The air dried zeolite was mixed in the soil at the rate of 1 and 5% (50 g kg^{-1}) denoted as Z 1 and Z 5%, respectively. The control or no zeolite application was denoted as C. The treatments were arranged in randomized complete block design with three replications. Plant was irrigated at every two days depending on the evapo-transpiration value which was measured gravimetrically. Additional water as 0.4 leaching fraction was also applied to the pots. A basal dose of liquid fertilizer of NPK was added to plant in the irrigation water to the 5 kg soil in each pot.

The environmental conditions during the experiment were varied with an average temperature of 24°C and relative humidity of 65%. Soil salinity status and moisture content was monitored by wet sensor. Prior to the plants harvesting for their fresh and dry weights, plant height and leaf area (using portable area meter LI-3000A) were also measured. Post-harvest soil samples were collected from each pot at different depths (0-10 and 10-20 cm). The samples were analyzed for moisture content and the electrical conductivity (EC) was measured in the ratio of 1:5 soil-water suspension. The electrical conductivity of the drainage water (ECd) was also regularly measured. Data were analyzed statistically for analysis of variance (ANOVA) and the means were compared at probability level of 5% using least significant difference (LSD) test.

RESULTS AND DISCUSSION

Soil salinity and moisture: The variations in temperature with time were the main reason for high evapo-transpiration and salt accumulations in the soils (Fig. 1). It was observed that zeolite treated soils exhibited the lowest water loss and longer water retention for plants as compared to the control soil.

It was noticed that zeolite retained the highest level of soil water under both saline treatments (Fig. 2). Since evapo-transpiration was negatively related to the quality of irrigation water the content of the saline water in the soils was higher. The main reason for this phenomenon is the presence of salt in the saline irrigation that inhibited evapotranspiration and reduced water consumption. Moreover, water density, viscosity and formation of salt crust can play main rules in reducing evaporation and keeping higher water content. Al-Busaidi and Cookson (2005) reported salt crust formation on the soil surface due to saline irrigation, inhibited evaporation and reduced leaching efficiency.

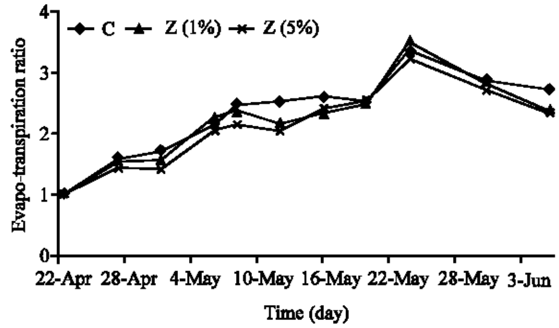

Fig. 1: Evapo-transpiration ratio during study period as affected by zeolite application

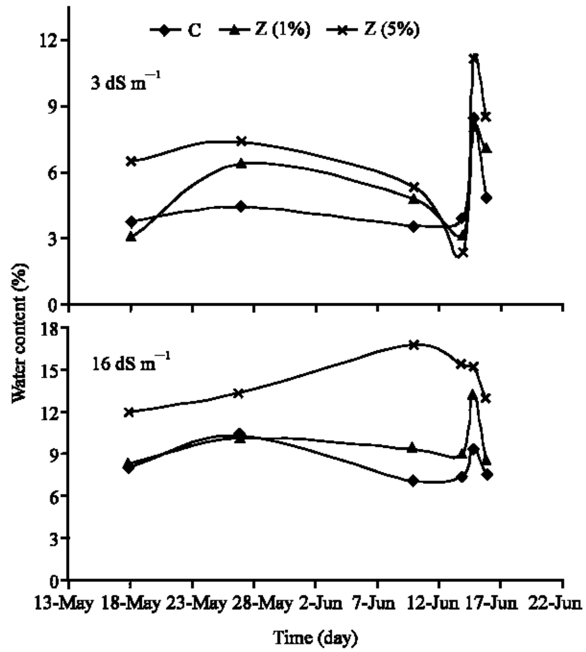

Fig. 2: Water content recorded by wet sensor under saline treatments

The amending soils with zeolite produced higher soil salinity (Fig. 3). The higher salinity due to zeolite is directly related to amount of minerals present in the zeolite or its salts obstructing capacity in the soil. Salt accumulation in each treatment varied significantly with

EC of seawater. At harvesting time under both saline irrigation waters, the salinity status of the soil did not differ for zeolite applied and control soils (Fig. 4). The fluctuation of soil EC could be due to the amount of salts either drained out in the water or taken up by the plants.

Figure 3-4 showed that zeolite increased soil salinity in the initial days of the study compared to control. The EC difference became insignificant with time possibly due to higher drainage of salts in the water under the effects of zeolite (Fig. 5). Zeolite can enhance exchange capacity of soils, hold cations on the surface and release them at the expense of salts in the saline water. The accumulation and release of salts could also depend on the quality and quantity of irrigation water, soil type and plant response.

Plant growth: As a result of saline irrigation plant can give different biomass yields depending on how much salts precipitated in the soil. Low treatment of salinity gave higher plant growth as compared to the higher salinity treatment (Table 2). The application of zeolite in the low salinity treatment was not highly effective compared to the control soil. Whereas, higher salinity treatment significantly impaired plant parameters especially fresh and dry biomass. Salinity stress was reported to retard 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 conditioning of saline soil with special amendment could help in alleviating salts stress and as salinity increase, zeolite can exchange cations, provides different nutrients to plant and reduce salt stress problem. However, barley responded positively to the zeolite amendment especially in the higher salinity treatment (Table 2). Zeolite can provide alternative cation of Ca^{2+} to plant reducing the ratio of Na^{+}/Ca^{2+}. As the increased Na^{+} content disturbs the nutritional balance and upset the osmotic regulation in the plant tissues. An antagonistic relation may happen between Na and K. The provision of Ca^{2+} from zeolite in the root media could prevent the accumulation of toxic Na ion in the plants. Cramer *et al.* (1990) reported that Ca^{2+} and Mg^{2+} imbalances in the saline medium cause leaf chlorosis. The ameliorative effects of the Ca-type zeolite on the growth were due to a decrease in the Na concentration of shoots as well as Na^{+}/Ca^{2+} and Na^{+}/K^{+} ratios of shoots and roots (Song and Fujiyama, 1996).

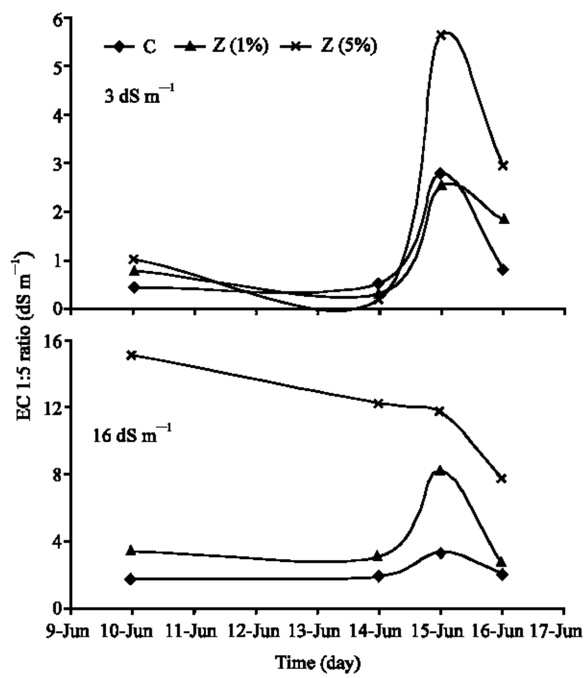

Fig. 3: Soil salinity as monitored by wet sensor under saline water irrigation

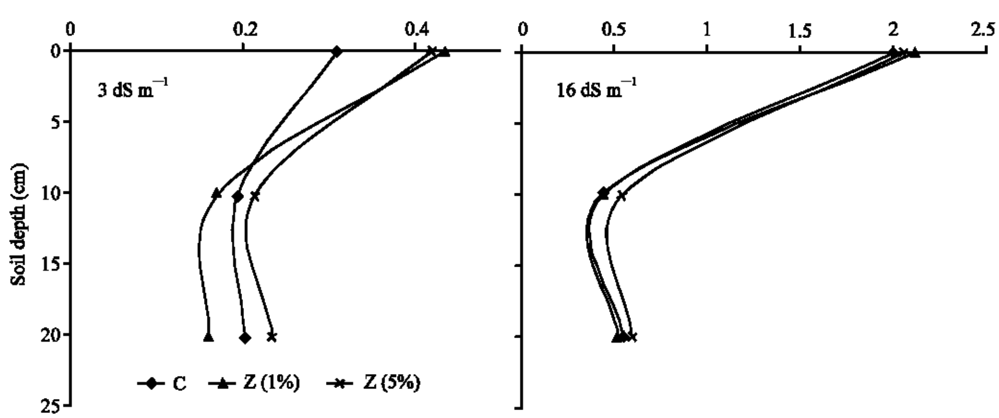

Fig. 4: Soil salinity measured by wet sensor at harvesting time

Table 2: Plant growth parameters as affected by salinity and zeolite treatments

Saline water	Zeolite treatment	Height (cm)	Leaf area (cm^2)	Fresh weight (g)	Dry weight (g)
3 dS m^{-1}	Control	85.0	36.5	538.4	139.0
	Zeolite 1%	81.5	34.8	679.6	149.6
	Zeolite 5%	81.5	37.8	575.9	151.5
16 dS m^{-1}	Control	63.5	22.6	246.5	77.7
	Zeolite 1%	67.7	19.5	286.8	89.9
	Zeolite 5%	69.6	20.4	264.9	86.4

Table 3: Summary of two-way analysis of variance on saline water and zeolite effect of selected soil and plant parameters

Parameter	Saline water (S)	Zeolite (Z)	S×Z
	-----------------	p-value	------------------
Evapotranspiration ratio (ETr)	0.0001*	0.041*	NS
EC (1:5)	0.0001*	0.0001*	NS
Drainage water salinity (ECd)	0.0001*	0.0001*	0.0001*
Plant height	0.0001*	NS	0.0001*
Dry biomass	0.0001*	0.0001*	NS

*Denotes the level of significance at p-value <0.05 and NS denotes non-significance

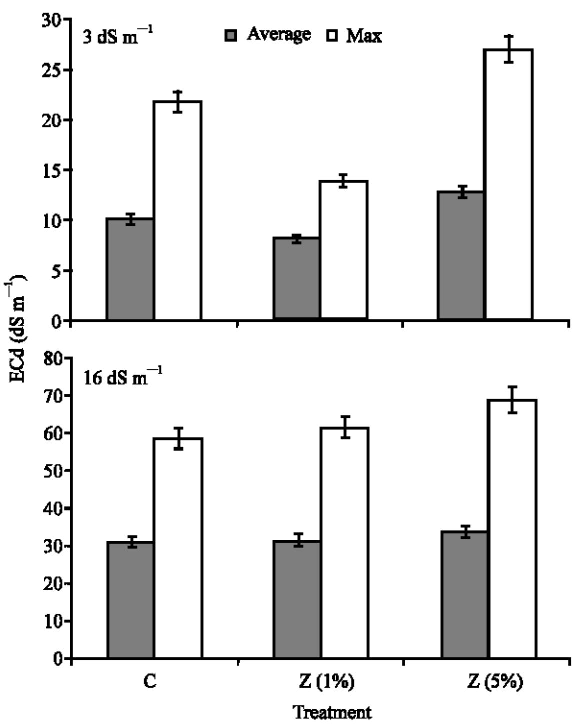

Fig. 5: Salinity of drainage water (ECd) as affected by zeolite application

The zeolitic material, in addition to the buffering capacity, possesses an important exchange capacity that could reduce the soluble metal concentration and eliminate the pollution in the leaching. Vassilis and Inglezakis (2005) also reported that zeolites were used in ion-exchange applications in soil solution and used for the removal of heavy metals from the wastewaters. There is general consensus that mineral nutrition of plants under saline conditions is complex. Any addition to the soil-plant system may add or remove essential elements. In present study zeolite addition influenced the soil and plant parameters (Table 3). The growth of the plants was mitigated possibly by reducing the salinity stress via Ca^{2+} ion that could regulate the absorption of other essential elements under saline irrigation.

CONCLUSIONS

Based on the findings of this experiment, it could be concluded that the deleterious effects of saline water on barley crop in a sandy soil can be mitigated with zeolite amendment. Higher cation exchange capacity of zeolite may provide more nutrients to the plant or regulate the plant nutrition in saline soils by avoiding Na^+ toxicity. Zeolite can also enhance water retention in the soils. The use of saline water for irrigation needs comprehensive information on the relationship between soil and plant. However, adopting a proper soil amendment like zeolite could have beneficial effects on such interactions. To mitigate the adverse effects of salts on various crops in the field would be the subject of our future studies.

ACKNOWLEDGMENT

The authors would like to thank Chubu Electric Power Company for the financial assistance and supply of zeolite material. We are also thankful to Dr. K. Nishino and his whole team for their untiring efforts and supervision during the experiment.

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