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Monitoring Saline Irrigation Effects on Barley and Salts Distribution in Soil at Different Leaching Fractions

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Abstract: Population growth and global warming would substantially impact the availability and quality of existing freshwater supplies. The utilization of marginal water resources for agriculture is getting considerable importance. The lands irrigated with saline water are required to reduce salts accumulations through leaching and/or drainage practices. A greenhouse experiment was carried out to investigate the effects of saline irrigation and leaching fractions on barley (*Hordeum vulgare* L.) and salts accumulations in sand dune soil. For this purpose seawater was diluted to the salinity levels of 3 and 13 dS m^{-1} and applied by drip irrigation at 0.1 and 0.4 leaching fractions (LF). The results of the experiment showed that the saline water significantly impaired barley growth. Higher LF lowered the soil salinity and increased soil water contents. Both quantity and quality of water regulated salts distribution within the soil. The salts were found higher near or immediate below the soil surface. An enhanced LF carried more salts down the soil horizon. Low salts were accumulated in the vicinity of emitters as compared to distant wet area. Higher saline irrigation inhibited evaporation. Infiltration rate and hydraulic conductivity of soil were statistically unchanged across the treatments. Conjunctive use of marginal water at proportional LF could be effective to enhance the yield potential of crops in water scarce areas.

Key words: Salt accumulation, electrical conductivity (EC), drip irrigation

INTRODUCTION

Scarcity of good quality water in several regions in the world emphasizes the need to use marginal waters such as brackish water or reclaimed effluent to meet its increasing demands, which in turn increases the possibility of soil salinization and yield reduction (Chartzoulakis *et al.*, 2001). Poor management of saline water may increase the soil salinity to a level higher than crop tolerance. The lands irrigated with saline water are required to reduce salts accumulations through leaching and/or drainage practices. The amount of water that is applied in excess to the crop in order to control salts is referred as leaching fraction. In regions where the rainfall is low, higher water fraction is added to irrigation water as drainage to lower the salt accumulation in the soil (NATO, 1994). Oron *et al.* (2002) reported that high saline water has an agricultural potential with proper irrigation management. By increasing the volume of irrigation water, the soil salinity may be reduced due to water percolation below the root zone (Petersen, 1996).

The freshwater resources available for agriculture are declining quantitatively and qualitatively. The water demands for irrigation are projected to rise, bringing increased competition between agriculture and other users. Therefore, the use of lower-quality supplies will inevitably be practiced for irrigation purposes to maintain an economically viable agriculture. Several countries have adopted the use of marginal water for irrigation to overcome water scarcity (Oron *et al.*, 2002). A critical challenge is to manage poor quality water for sustainable agricultural production system. Barley is one of the important cereal crops grown in variety of soils, waters and climatic conditions in various parts of the world and classified as salt tolerant crop (Shannon, 1984). The studies on the utilization and management of marginal waters on barley crop are scanty. The present study was aimed to evaluate the effects of saline irrigation water and leaching fraction on the barley growth and salt accumulations/distribution in soil.

MATERIALS AND METHODS

The greenhouse experiment was carried out on the effects of saline water on the evapo-transpiration of barley and salt accumulation in soil under different

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leaching fractions at Arid Land Research Center, Tottori University, Japan. A composite soil sample was air-dried and sieved (<2 mm). Soil texture was determined by the pipette method. Exchangeable cations were leached from the soil with neutral ammonium acetate. Their concentrations were determined using atomic absorption spectrophotometer. Electrical conductivity (EC) and pH of the soil: Water suspensions (1: 5) were also measured with pH meter and conductivity meter (Horiba DS-14) respectively (Table 1).

The area covered by greenhouse was divided in to 8 plots (size 1.4×1.2 m) by inserting plastic sheet to 0.6 m soil depth in order to seal salt flow from adjacent plots. Three tubes lines 0.2 m apart (attached with flow meter) were laid down on each plot for irrigation. There were 3 emitters in each line. Calibrated TDR (Time Domain Refractometer) sensors were installed to measure soil salinity at soil depth of 20 and 40 cm. Twelve barley plants (*Hordium vulgare* L.) were grown in the command of each emitter in April, 2005. Seawater was diluted to achieve the level of 3 and 13 dS m^{-1} salinity for irrigation. Water treatments were factorially arranged into randomized complete block design with two leaching fractions (LF: 0.1 and 0.4). Irrigation was started on daily basis after 18 days of sowing. These LF were equivalent to 1.1 and 1.4 mm of evapo-transpiration (ETc) consecutively. The ETc was calculated by a pot experiment conducted in the greenhouse under similar treatments. A recommended basal dose of NPK liquid fertilizers was applied in the irrigation water. Plants were harvested and fresh/dry weights were recorded. Plant height and leaf area (using a portable area meter LI-3000A) were also measured.

Post-harvest soil was sampled at depth of 0, 10, 20, 30, 40 and 50 cm from the profile of each plot whereas samples were taken up to 80 cm in central emitter command area. Soil moisture content was determined by oven drying the samples at 105°C for 24 h. Electrical conductivity, pH, infiltration rate and hydraulic conductivity of post-harvest soil were also determined. Data were analyzed statistically for analysis of variance (ANOVA) and the means were compared at probability level of 5% using Duncan's Multiple Range test.

Table 1: Selected physicochemical characteristics of soil

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

RESULTS AND DISCUSSION

During the study the weather was variable with an averaged day/night temperature of 38/20°C and low humidity <30%. The evapo-transpiration ratio (evapo-transpiration/evaporation) was found higher under the effects of high temperature and totally depended on quantity and quality of irrigation water (Fig. 1). Maximum evapo-transpiration occurred with good quality water. Reduced bioavailability of water and retarded plant growth under saline irrigation produced a poor evapo-transpiration in the system. Salt accumulation in root zone causes the development of osmotic stress and reduces plant development (Heakal *et al*., 1990; Abdul *et al*., 1988). The low fraction of leaching with high saline water gave relatively lower evpo-transpiration value.

The loss of water was oppositely related to the salts of water (Fig. 2). The amount of water lost under higher saline water was lower as compared to weakly salinized water. High salt concentrations usually inhibit

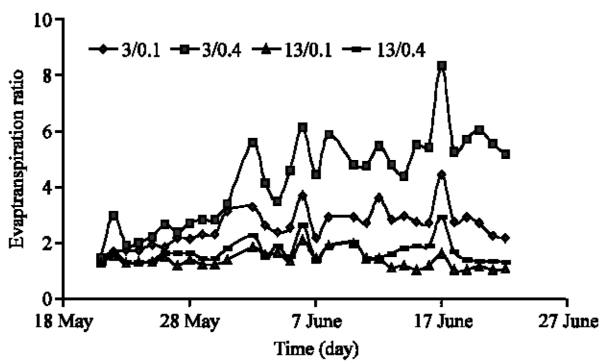

Fig. 1: Temporal evapo-transpiration ratio as affected by saline irrigation and leaching fraction

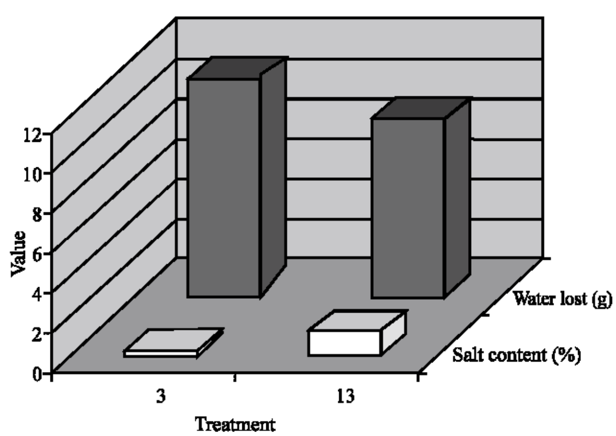

Fig. 2: Salt accumulation and water loss as affected by saline irrigation and leaching fraction

evaporation. This phenomenon could be related to the enhanced water density, viscosity and chemical bonds in the soil-salt system. High concentrations of salts also form salt crusts, which could reduce soil evaporation. Richards *et al.* (1998) reported that density, temperature and salinity affected several water characteristics e.g., evaporation etc. Al-Busaidi and Cookson (2005) reported salt crust formation on the soil surface due to saline irrigation, which inhibited evaporation and reduced leaching efficiency.

Drip irrigation economizes water use and ultimately improves water productivity. The distribution of salts in the soil was highly related to the amount of salts and quantity of irrigation water (Fig. 3).

Low salts were accumulated in the immediate vicinity of emitters due to the favorable leaching. Shalhevert (1994) reported that leaching is the key to the successful use of saline water for irrigation. Abu-Awwad (2001) reported high salt concentration on the soil surface due to evaporation. The maximum salts were noted up to a distance of 30~40 cm from the emitter. Beyond that, salinity decreased significantly. Blanco and Folegatti (2002) found that salt accumulation occurred near the soil surface and between the wet bulbs, at the wetting front. Higher application of saline water caused downward flow of salts. Higher accumulations of salts away from the emitter were appeared unavoidable.

The distribution of water and salts were highly affected by the soil horizons (Fig. 4). The water content in the soil was related to the water quality and leaching fraction. The extended leaching fraction had high water content in the deeper soil horizon. There were an inconsistent pattern of soil water due to the varied plants density and rooting depth. For instance under low saline water (EC_w: 3) with higher LF, the water content down the profile was found even less. This loss could be attributed to the substantial water taken up by higher rooting density. Water uptake by plants and evaporation from the soil surface are the major causes of salt accumulation in the root zone and salts are proportional to the water volume removed by these processes (Ben-Hur *et al.*, 2001; Bresler *et al.*, 1982). In case of high saline water under both LF conditions, the amount of water in the deeper zones was also higher due to thin and hampered rooting system due to the influence of salts.

The salt accumulation and distribution in the soil profile was affected by the amount of salts and quantity of irrigation water applied (Fig. 5). Salts deposits depended on the soil moisture and plant root development. Higher application of water leached down more salts to the deeper horizons as compared to low water fraction. Salts in the soil fluctuated more under

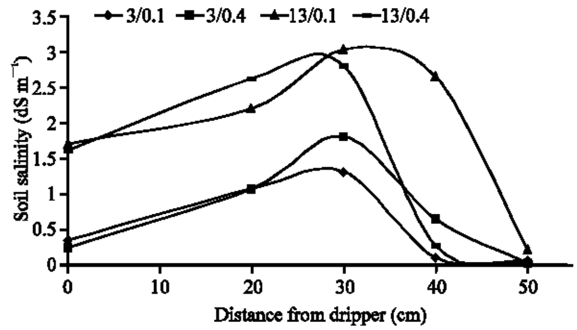

Fig. 3: Salt distribution under drip irrigation as affected by saline irrigation and leaching fraction

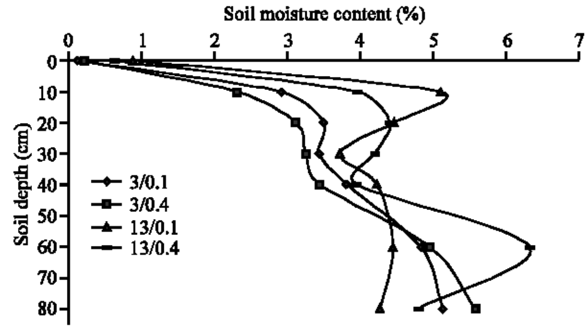

Fig. 4: Water distribution in the soil profile as affected by saline irrigation and leaching fraction

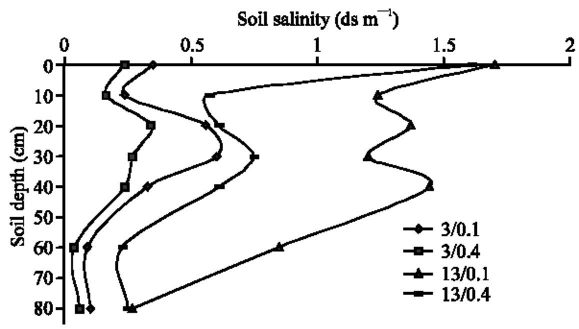

Fig. 5: Salt distribution in the soil profile as affected by saline irrigation and leaching fraction

higher salinity. Petersen (1996) reported low soil salinity with increased volume of irrigation water due to salt transportation below the root zone.

Stress factor (Ks) is an additional parameter for the determination of crop evapo-transpiration. Stress factor is an indicator of unusual stress exerted on plants through salinity, drought, disease or deficiency of nutrient etc. For soil salinity it is predicted by electrical conductivity of saturation extract (Ec_e). As expected there was a higher

EC_e value under higher saline water (Table 2). The Ks values greatly decreased under high level of salinity.

Soils irrigated with saline water are usually required to reduce salts accumulations through leaching\drainage practices. Water salinity (EC_w) detected by TDR system represented the actual salinity stress of root zone i.e., 20 and 40 cm depth (Table 2). The less salts were found under enhanced leaching fraction. Oron *et al*. (2002) reported that high saline water has an agricultural potential with proper irrigation management. By increasing the volume of irrigation water, the soil salinity may be reduced due to water percolation below the root zone (Petersen, 1996). Higher salts were found in soil with less diluted seawater. Al-Busaidi and Cookson (2005) found that the most efficient leaching occurred in sandy soil with the application of seawater equal in amount to the depth of the soil to be leached.

The infiltration rate of soil was not affected by the saline percolating water (Fig. 6). The rate of infiltration reduced with passage of time after irrigation. Plant roots provided favorable environment for infiltration. The infiltration was highly correlated with the magnitude of water applied. The hydraulic conductivity was also statistically similar among the treatments with an average value of 0.045 cm sec^{-1}. Al-Busaidi and Cookson (2005) reported insignificant changes in soil physical parameters of saline sandy soil with leaching salts using fresh and seawater.

Plant growth was significantly affected by the level of salts in the irrigation water as well as leaching fraction (Table 3). Fresh and dry biomass of plants significantly increased by increasing leaching fraction regardless to saline waters. On the other hand, under less salinity and high leaching fraction, barley gave substantial biomass yield. Abu-Awwad (2001) reported that saline soils with considerable soluble salts interfered the growth of crop species. Crop response to salinity usually depends on plant species, soil texture, water holding capacity and composition of the salts. During the experiment low salts enhanced tillering, leaf area and leaf area index as compared to higher saline water. Certainly higher salinity profoundly impaired plant growth parameters. Heakal *et al.* (1990) reported that dry matter yield of plants decreased with increasing salinity of irrigation water. Al-Tahir *et al.* (1997) found that barley grain and straw yields were significantly decreased by drainage water (EC_e: I0.7~16.7 dS m^{-1}). Pal *et al.* (1984) concluded that barley could be grown economically with irrigation water up to EC 16 dS m^{-1}. The greater application of water positively affected plant growth by accumulating the toxic level of salts in the lower soil horizons. The use of diluted seawater for barley irrigation is only possible if the leaching of excess salt from root zone is implemented. Ghulam *et al.* (1997) obtained a reasonable barley yield with irrigation water (EC_w) up to 9.3 dS m^{-1} under 15% excess water as leaching requirement. Thus the conjunctive use of irrigation water (EC 6.8~9.9 dS m^{-1}) produced higher vegetative growth followed by higher grain and straw yields. However, soil and plant data found in this study was in the same line of many published data. Moreover, using seawater or diluted seawater for irrigation is one of the challenges in saline agriculture in which it will provide more food for the whole world and release pressure in using freshwater.

Table 2: Average soil and water salinities with stress factor as affected by saline irrigation and leaching fraction

Treatment EC_w/LF	Ec_e (dS m^{-1})	Ks -	EC_w (20 cm) (dS m^{-1})	EC_w (40 cm) (dS m^{-1})
3/0.1	9.15	0.95	14.61	11.96
3/0.4	5.50	1.00	11.32	9.96
13/0.1	23.36	0.25	25.28	49.08
13/0.4	11.03	0.85	15.41	15.93

Table 3: Plant growth as affected by saline irrigation water and leaching fraction

Treatment EC_w/LF	Height (cm)*	Leaf area (cm^2)	Leaf area index	Fresh weight (g)	Dry weight (g)
3/0.1	66.4a	62.6a	0.2a	356.7a	47.3a
3/0.4	71.4b	60.9a	0.2a	495.6b	61.9b
13/0.1	41.6c	37.1b	0.1b	94.7c	19.3c
13/0.4	39.4c	35.0b	0.1b	107.2c	21.1c

*Means in the column with same letter indicate no difference at Duncan's Multiple Range Test

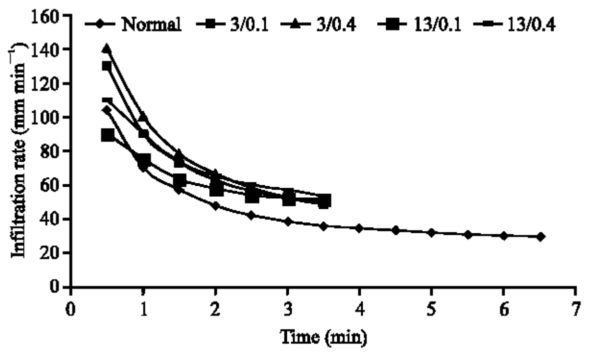

Fig. 6: Infiltration rate as affected by saline irrigation and leaching fraction

CONCLUSIONS

The adoption of appropriate irrigation management to minimize the secondary salinization of lands and the impacts of salinity on crops' productivity is of paramount importance. Present study concludes that saline waters along with the given leaching fraction remarkably affected the evapo-transpiration rate, soil moisture, salts accumulation/distribution and plant biomass production. Low saline water treatment with higher leaching fraction produced substantially higher plant biomass. The salinity of post-harvest soil had inverse relationship with leaching fraction. Salts were accumulated significantly near the soil surface. Salinity of soil varied with soil profile with maximum salts within transitional horizon of 20~40 cm. High salt concentrations inhibited evaporation. Lower salts were noticed in the immediate vicinity of emitter. Physical parameters of sandy soil did not differ among treatments. There is a need to control the salinity of soils through sustainable use of saline water. These results confirmed that saline water could have greater agricultural potential when used with rational fraction of leaching.

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