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The Impact of Seawater Salinity on Evapotranspiration and Plant Growth Under Different Meteorological Conditions

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1. Introduction

Conventional water resources of good quality are scarce especially in arid and semiarid regions. The salinization of soils and water places is a substantial constraint of crop productivity. The mixed application of fresh water along with seawater is becoming a common practice by the farmers near sea sides in the developing countries. Seawaters contain beneficial nutrients that can be useful for plants. The use of saline water has shown a considerable importance for crop production in the recent years. Unfortunately, the misuse of saline water for irrigation may increase soil salinity to a level higher than the tolerance of crops. The proper use of brackish water appeared to be reasonable with certain conditions. Hamdy et al. (2005) found that freshwater can be substituted to some extent with saline water without any loss in production especially in water deficit areas. Moreover, Oron et al. (2002) reported that high saline water has an agricultural potential with proper irrigation management. Petersen (1996) observed that the higher volume of irrigation water reduced soil salinity and transported salts below the root zone. Whereas, Ghadiri et al. (2005) noticed restricted water uptake by salinity due to the high osmotic potential in the soil and high concentrations of specific ions that may cause physiological disorders in the plant tissues and reduce yields.

Irrigation water, drainage salinity and evaporation are interconnected terms. Any increase or decrease in one of them will affect others. More irrigation water enhances leaching of salts, decreasing soil salinity and increasing drainage water salinity. Furthermore, evaporation and salt accumulation are also positively connected, hence increasing salinity of applied water and high evaporation lead to high concentration of salts in drainage water. Soil evaporation is mostly affected by environment factors, which includes mainly two aspects: climate aspect (net radiation, wind speed, air temperature, etc) and soil aspect (soil types, soil water content and temperature, hydrological properties, soil salinity, etc). In general, the soil water is considered as a direct factor affecting evaporation process. In fact, the surface temperature may be considered as the indirect factor on soil evaporation (Zhu & Takeo, 2010).

Under elevated temperature, plant could be water stressed due to the higher evapotranspiration. High temperatures cause an array of morpho-anatomical, physiological and biochemical changes in plants, which affect plant growth and development and may lead to a drastic reduction in economic yield. Major impact of high temperatures on shoot growth is a severe reduction in the first internode length resulting in premature death of plants (Hall, 1992). However, heat stress is a complex function of intensity, duration and rate of increase in temperature. The extent to which it occurs in specific climatic zones depends on the probability and period of high temperatures occurring during the day and/or the night. Higher air and leaf temperatures as a result of changes in climate will mean higher potential transpiration for the same stomatal conductance. Increased evaporative demand will tend to increase transpirational volume flow which will tend to increase salt damage. Any simple way out of this is confounded by the positive relationship between yield and the total quantity of water transpired (Pessarakli, 1999).

Barley (Hordeum vulgare L.) is regarded an important cereal grown in many countries of the world. It is the main cereal of arid and semiarid climates due to its lower water demand when compared to other crops. However, barley yield is also impaired by water and heat stress conditions. The productivity of barley is reported to be limited by terminal water stress and high temperatures during grain filling (Agueda et al., 1999). Matin et al. (1989) found a positive correlation between diffusion resistance in barley leaves and drought tolerance. From other side, barley is a cereal crop of salt-affected soils and has been rated as salt tolerant (Maas & Hoffman, 1977; Shannon, 1984). A considerable depression in barley grain yield after irrigation with high salinity waters was observed (Curtin et al. 1993).

There is a general consensus that productivity of plant is strongly influenced by environmental conditions. The yield potential of crops is limited by several abiotic stresses. Salinity and extreme temperatures are considered to be the most important factors (Atienza et al., 2004). Barley is widely grown in arid and semiarid areas of the Mediterranean regions for grain or forage purpose. It is well adapted to the cool and short growing season. Sharratt (1999) reported differences in growth parameters as affected by sowing date of barley due to day length and temperature. Therefore, the fundamental understanding on the effects of growth condition and seawater salinity could be useful for the quality production of barley crop in arid and semi arid countries. Moreover, evapotranspiration process is one of the main factors that is involved in irrigation scheduling, salt accumulation and other stresses. Therefore, this study was aimed to evaluate the effects of different meteorological conditions and seawater salinity on the evapotranspiration process and barley growth.

2. Materials and methods

Soil samples were collected from Sand Dune of Tottori-Japan. The samples were air-dried, and sieved (< 2 mm). Soil texture was determined by the pipette method (Gee & Bauder, 1986). Exchangeable cations were leached from the soil with neutral ammonium acetate. Their contents were determined using atomic absorption spectrophotometer (Model Z-2300 Hitachi Corp, Japan). Electrical conductivity (EC) and pH of the soil: water suspensions (1: 5) were also measured with pH and EC meters (Accumut M-10 and Horiba DS-14). Other physicochemical properties of the soil were analyzed following Klute (1986) methods (Table 1).

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	1.50 g cm^{-3}
Infiltration rate (intake rate)	30.00 mm min^{-1}
Saturated hydraulic conductivity	0.007 cm sec^{-1}
Field capacity (pF1.8)	6 %
Permanent wilting point (pF4.2)	2 %
Texture	Sand

Table 1. Selected physicochemical characteristics of soil

Pot experiments were compared for evapotranspiration of barley and salt accumulation in soils under the effects of similar saline irrigation treatments at the Arid Land Research Center, Tottori University, Japan in the following three environments: i) a glasshouse (Gl. H.) condition from Feb to Apr, 2005; ii) a controlled growth chamber (Gr. Ch.) condition where the day / night temperature was 20 / 18 ^oC, relative humidity was 60 % and light intensity was 80000 lux; and iii) a greenhouse (Gr. H.) condition ranged from May to Jun, 2005. For each condition, air temperature and relative humidity were measured continuously by relative humidity and temperature meter (HOBO, Pro Series, onset, Japan) and Pyranometer (EKO, MS-601F) for solar radiation (Kw m^{-2}). Ten barley seeds were sown in each plastic pot (size- depth: 20 cm, diameter: 16 cm) filled with sand dune soil. After 18 days of sowing, plants were irrigated at a depth of 1.1 mm ET_c (crop evapotranspiration) with diluted seawater treatments of 3, 8 and 13 dS m^{-1}. The required amount of water was given daily depending on the loss of water, which was estimated by weighing the pots. Extra 10 % water was also applied as a leaching fraction. Evaporation was also monitored by placing the evaporation pans (class A) among pots. A basal dose of liquid fertilizer of NPK was added to plant in the irrigation water. The EC of drainage water was measured by a calibrated conductivity meter (Horiba DS-14). Occasionally, the pots were rotated randomly and spacing was provided in accordance with the growth of plants. Plant height and leaf area (by portable area meter LI-3000A) were monitored during the experiments. Two months old plants were harvested and their fresh and dry biomass was weighed. Stress factor, crop coefficient factor and plant water deficit were also calculated by using the formula:

$$\text{Stress factor } (K_s) = 1 - [(b / 100\ Ky)\ (EC_e - EC\ \text{threshold})]$$

where b is the percentage reduction in crop yield per 1 dS m^{-1} which is equal to 5, Ky is the yield response factor equal to 1, EC_e is the soil salinity. The threshold EC value for barley is considered as 8 dS m^{-1} (FAO, 1998).

$$\text{Crop coefficient factor } (K_c) = ET_c / ET_o$$

where ET_c is the crop evapotranspiration and ET_o is the potential evapotranspiration (FAO, 1998).

$$\text{Plant water deficit (\%)} = [\{(FWc-DWc) / FWc\} - \{(FWt-DWt) / FWt\}]\ 100$$

where FWc and DWc indicate fresh and dry weights for control whereas FWt and DWt indicate fresh and dry weights for saline irrigation treatment respectively.
Soil water storage was also calculated with each irrigation by the formula:

$$\text{Water storage} = \text{initial water} + (\text{irrigation} - \text{drainage} - \text{evapotranspiration})$$

Statistical analysis of data was carried out and the means were compared by LSD test at 5 % probability level.

3. Results and discussion

3.1 Irrigation water quality

Irrigation water is the most important parameter controlling plant life. Water shortage problem could stress plant and reduce its productivity. In the world, different irrigation waters were used for agriculture purposes but applications depend on soil, plant and quality of the irrigation water. Table 2 demonstrates some irrigation waters that were used by different researchers (FAO, 1998; Daoud et al., 2001; Yamamoto et al., 1988). Since fresh water is the best option for optimum plant growth but the shortage of fresh water is compelling researchers toward the use of saline irrigation. Using saline water for agriculture could add soil salinity. Whereas, under sodic conditions, saline water may improve soil physical conditions. Saline waters especially seawater could also contain some beneficial plant nutrients (Table 2). The disability of sandy soil to hold much salt as compared to clayey soil supports the idea of saline irrigation. The plant response to salt stress is complex, since it varies with the salt concentration, the type of ions, other environmental factors, and the stage of plant development depending on the growth conditions. Nutrient availability and uptake by plants in saline environments is related to i) the activity of nutrient ion in the solution, which depends upon pH, pE, concentration and 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 (Pessarakli, 1999).

Water type	pH	EC	Na^+	Cl^-	K^+	Ca^{2+}	Mg^{2+}	NO^{3-}	P
		dS m^{-1}				mg L^{-1}			
Fresh water 1	7.6	0.6	22.0	21.3	5.0	58.2	20.7	0.3	-
Fresh water 2	8.1	0.7	39.9	540.0	3.5	95.6	11.2	traces	1.4
Saline water 1	8.0	4.5	1150.0	560.9	3.9	48.0	21.6	-	-
Saline water 2	7.7	5.8	828.0	1366.8	15.6	720.0	108.0	-	-
Seawater	7.5	38.5	11211.0	18834.0	377.0	266.0	1976.0	0.2	2.1

Table 2. Chemical properties of different waters

3.2 Soil parameters

The meteorological data recorded during the experiment are given in Figure 1. The plants were grown during the winter season (Feb–Apr) in the glasshouse whereas greenhouse experiment was conducted in the summer season (May-Jun). The values of temperature, humidity and solar radiations remarkably differed among the places in the order of greenhouse > growth chamber > glasshouse. The greenhouse also showed the highest weather variations.

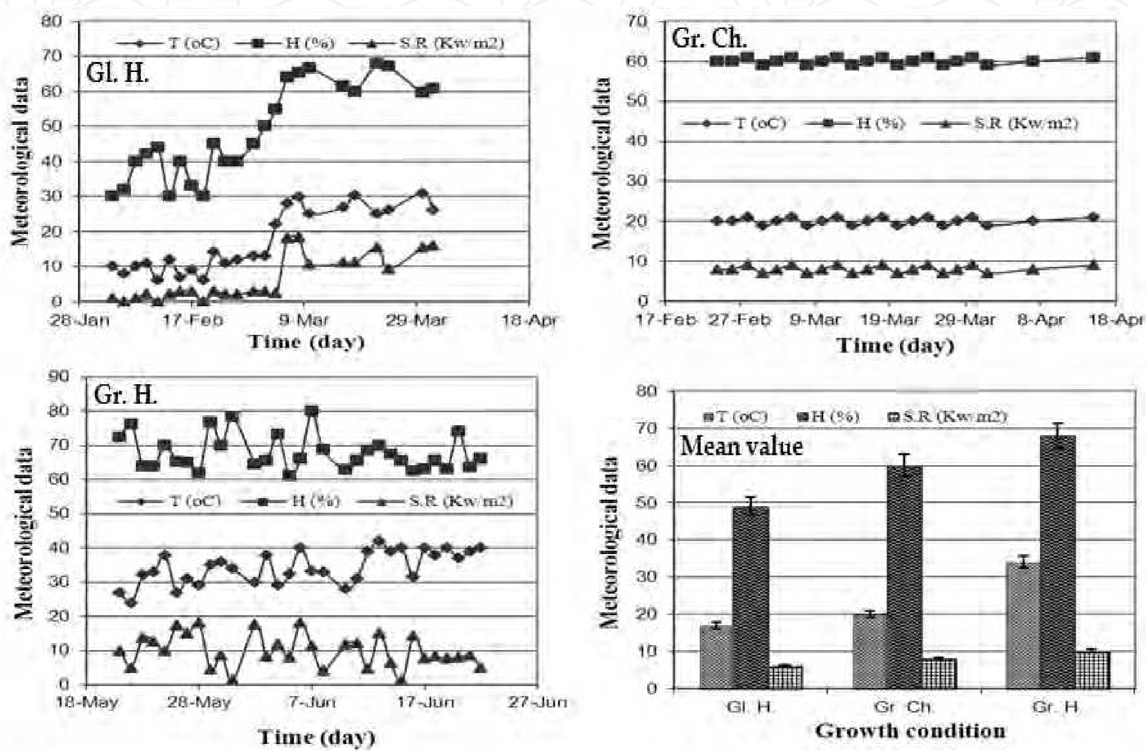

Fig. 1. Meteorological data of three experimental places

Evapotranspiration was remained the function of growing conditions and salinity treatments. Growth chamber significantly showed the highest evapotranspiration followed by the greenhouse and glasshouse (Fig. 2). This could be due to the constant temperature conditions in the growth chamber. The winter temperature of glasshouse was unable to expedite evapotranspiration rate. The weather considerably fluctuated during the day / night within the greenhouse. An averaged day temperature was recorded as 34 °C in the greenhouse. The evapotranspiration and other soils parameters were differentiated mainly due to climatic differences of the experimental sites. Plant substantially enhanced the evapotranspiration at the peak growth stage. Moreover, heating intensity along with the growing stage of plants tremendously affected the evapotranspiration and salt accumulation in the soils irrespective of the salt treatments. Plants tend to maintain stable tissue water status regardless of temperature when moisture is ample; however, high temperatures severely impair this tendency when water is limited (Machado & Paulsen, 2001).

Salts in the soil water solution can reduce evapotranspiration by making soil water less available for plant root extraction. Salts have an affinity for water and hence additional force is required for the crop to extract water from a saline soil. The presence of salts in the soil water solution reduces the total potential energy of the soil water solution. In addition, some salts cause toxic effects in plants and can reduce plant metabolism and growth (FAO, 1998).

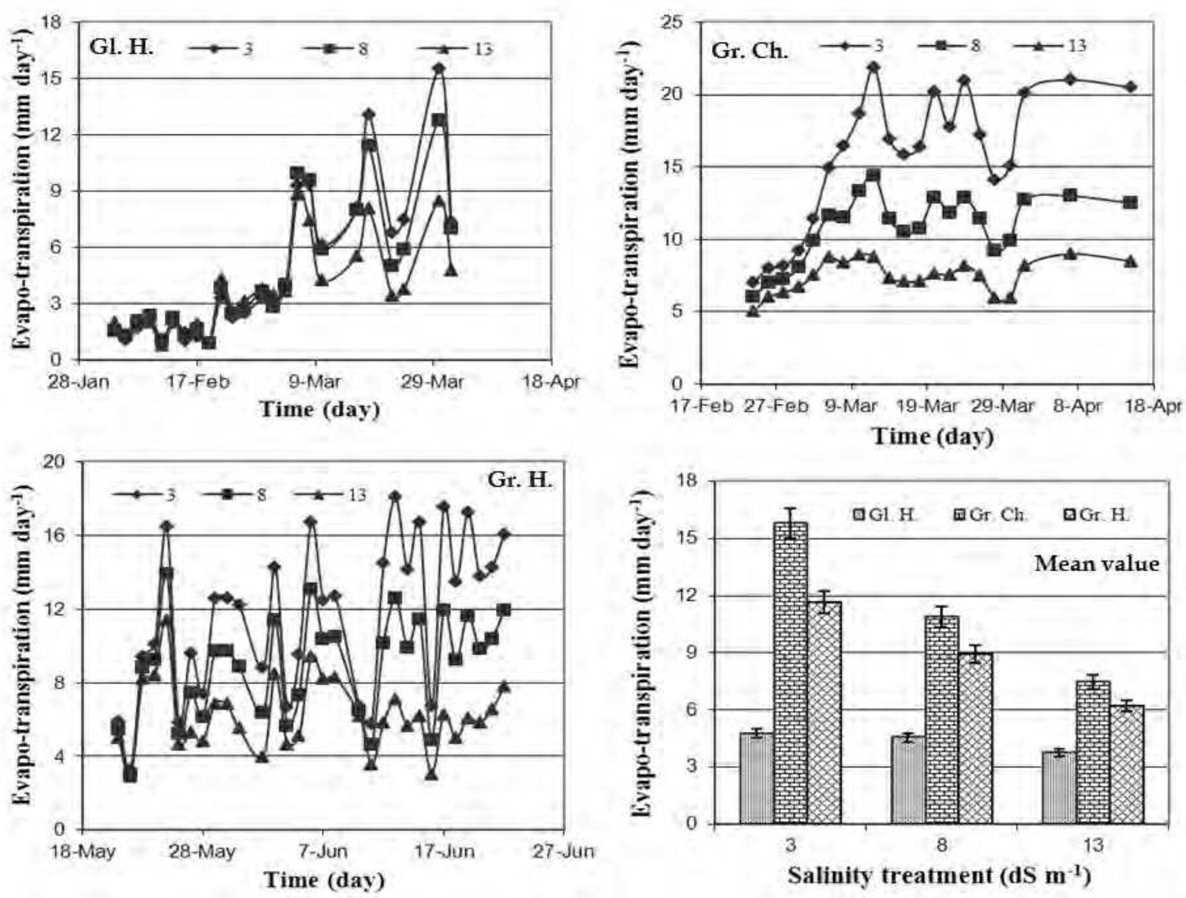

Fig. 2. Evapotranspiration as affected by temperature and salinity treatments

The evapotranspiration values were generally higher under low salt treatment regardless to the weather conditions (Fig. 3). In other words, evapotranspiration was positively related to the quality of irrigation water. A reduced water loss under high saline treatment was measured as compared to low saline water. Reduced bioavailability of water and retarded plant growth under saline irrigation produced a poor evapotranspiration in the system. The depressing effects of salinity on plant growth have been reported by various researchers (Heakal et al., 1990; Abdul et al., 1988; Koszanski & Karczmarczyk, 1985). Saline soils inhibit plant growth through reduced water absorption, reduced metabolic activities due to salt toxicity and nutrient deficiency caused by ionic interferences (Yeo, 1983). Salt concentrations in irrigation water inhibited evaporation from the soil surface (Fig. 3). 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. Abu-Awwad (2001) found that high salt concentration at the soil surface is due to high evaporation from wetted areas and the nature of soil water distribution associated with irrigation system. Moreover, Al-Busaidi & Cookson (2005) observed salt crust formation on the soil surface due to saline irrigation, which inhibited evaporation and reduced leaching efficiency.

The data showed that soil water was apparently affected by the quality of irrigation water under all conditions (Fig 4). The water lost by the drainage and evapotranspiration was

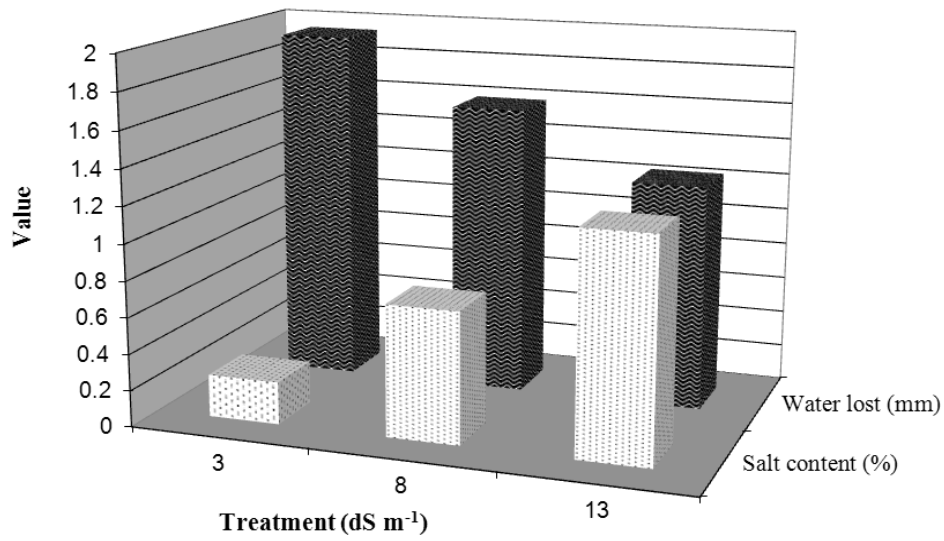

Fig. 3. Salts concentration and water loss as affected by saline water treatments

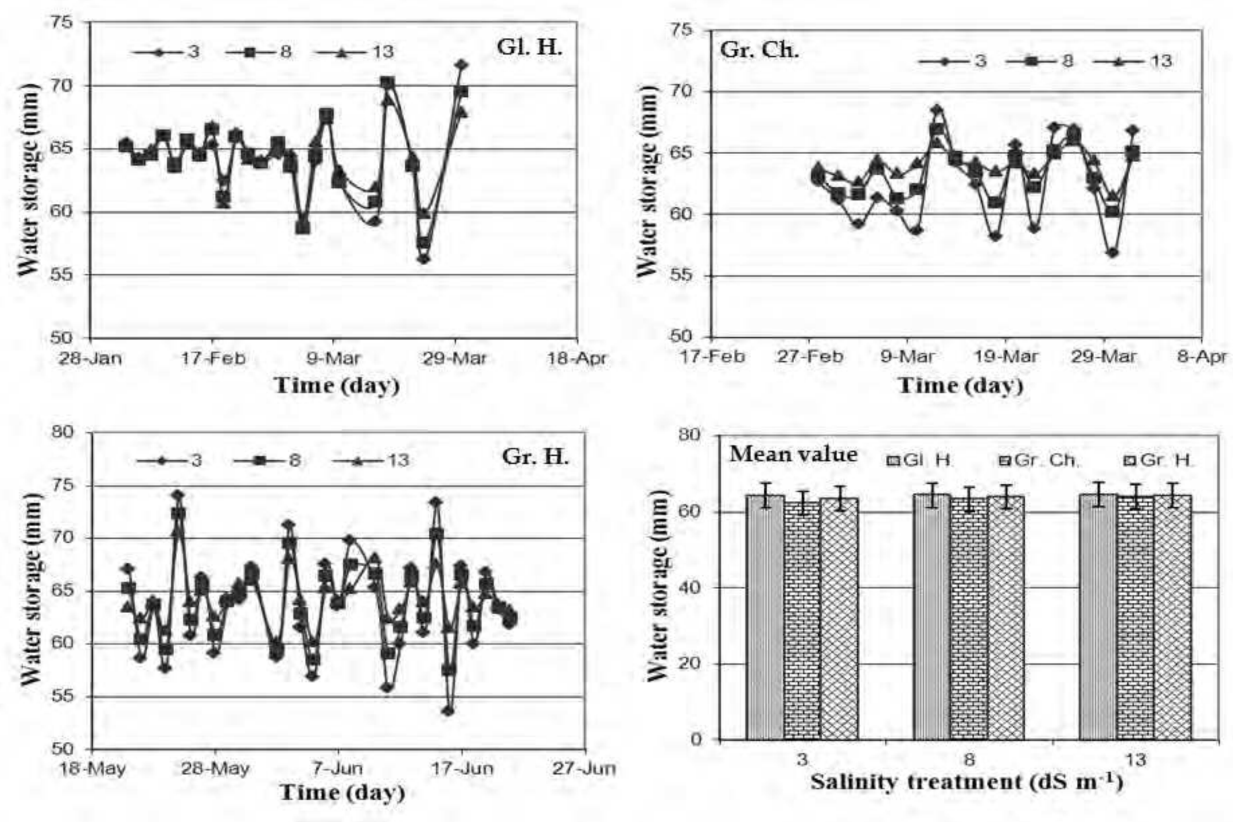

Fig. 4. Water storage as affected by different experimental conditions and saline treatments

counted to determine the water left behind in the soil. The soil water storage remained stable through out the experiment in the glasshouse. However, slight fluctuations during the last days of experiment were observed. The constant temperature of growth chamber exhibited similar trend of water contents under all salinity treatments. Water storage ranged from 54 -74 mm under greenhouse due to high variations in the air temperature and plant growth. There was a high fluctuation of soil water with low salts. The glasshouse upheld the highest magnitude of water in the pots across all saline treatments. In general the saline irrigation water, drainage water salinity and evaporation were appeared interrelated factors. Soil evaporation was positively associated to salt accumulation. High evaporation produced high concentration of salts in the drainage water under increasing salinity of water (Fig. 5). Glasshouse gave little salts increments whereas growth chamber and greenhouse induced severe salinity in drained water. The intensive temperature expedited water evaporation and accumulation salts processes under greenhouse environments. Higher plant biomass and increased evapotranspiration rate in growth chamber salinized drainage water relatively less than greenhouse. Higher drainage salinity in the salt treated pots also signified higher salts concentrations in the root zone.

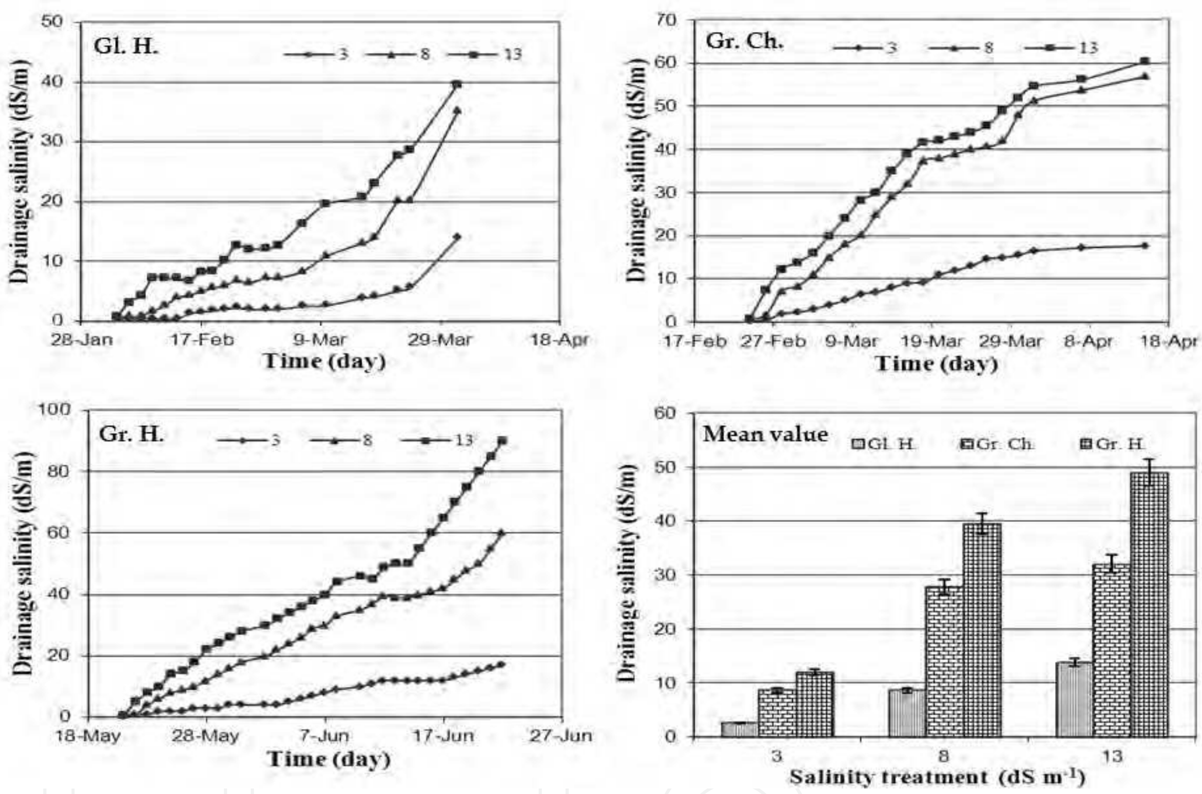

Fig. 5. Salinity status of drainage water as affected by environmental conditions and saline water

Salts accumulation in soil was highly affected by the saline irrigation water (Fig. 6). The accumulation of salts in the soils were varied in the order of glasshouse < growth chamber < greenhouse. Water uptake by plants and evaporation from the soil surface were reported the main factors for salts accumulation in the root zone (Ben-Hur et al., 2001; Bresler et al., 1982). Blanco and Folegatti (2002) found linear soil salinity with the application of saline water down the soil profile with higher salts contents near the surface. Petersen (1996) reported low soil salinity with increased volume of irrigation water due to salt transportation below the root zone.

The sustainable use of saline water in irrigated agriculture controls soil salinity in the field and make a good drainage management that may not pollute the downstream water resources (Beltran, 1999). In this experiment the leaching fraction was too low to produce sufficient drainage water. Therefore, salts were accumulated in higher strength in the soils especially under higher temperature.

3.3 Plant parameters

Soil salinity is one of the principal abiotic factors affecting crop yields in the arid and semi-arid irrigated areas. Plant growth was significantly affected by growth conditions as well as saline irrigation (Table 3). Treatment of less salinity gave the higher biomass production as compared to the high salinity. This finding was also reported by Heakal et al. (1990), Greenway & Munns (1980) and Abdul et al. (1988) when they found that dry matter yield of plant shoots decreased with increasing salinity of water. Koszanski and Karczmarczyk (1985) observed that diluted or undiluted seawater reduced plant height, grain and straw yield of barley and oats. Generally, the soils salinity affects the plants growth by producing an ionic imbalance or water deficit state in the expanded leaves. Shani and Dudley (2001) related the yield loss to reduced photosynthesis, high energy and carbohydrate expenses in osmoregulation and interference with cell functions in saline conditions.

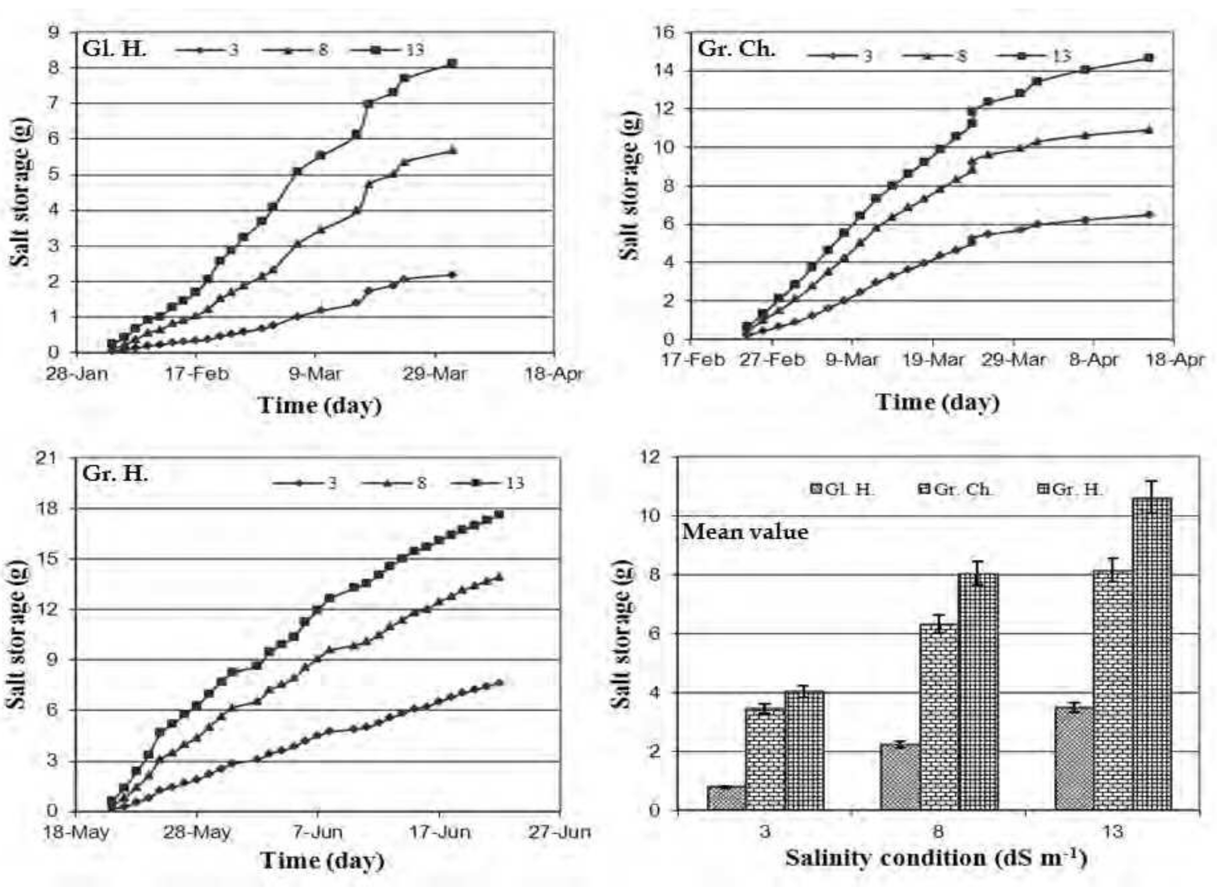

Fig. 6. Salt accumulation as affected by different environments under saline irrigation

Among growing conditions, glasshouse grown barley was the tallest and highest in biomass but relatively less in leaf area. Growth chamber produced a moderate biomass yield than other places. The biomass yield was reduced typically due to higher amount of salt depositions in the hot environment. High temperature was the major stress for plant growth. Sule et al. (2004) reported severe effects of heat stress on cereals in several countries.

The application of saline water in the presence of high temperature conditions exacerbated the process of salt accumulation and plant growth reduction. There have been several reports regarding the reduced and enhanced plant growth in various environments (Marmiroli et al., 1989; Saarikko & Carter, 1996; Sharratt, 1999).

Growing condition	Salinity	Height	Leaf area	Fresh weight	Dry weight
	dS m^{-1}	cm	cm^2	g	g
Glasshouse	3	65.5a	35.8a	401.3a	75.6a
	8	61.3b	32.0b	313.0b	61.4b
	13	52.2c	26.4c	210.9c	42.8c
Growth chamber					
	3	50.3d	31.6d	373.2d	71.9d
	8	44.5e	20.4e	253.4e	52.0e
	13	40.5f	12.6f	137.6f	33.1f
Greenhouse					
	3	54.0g	50.3g	353.0g	59.5g
	8	47.5h	43.7h	248.5h	44.5h
	13	40.0i	36.2i	144.0i	29.5i

*Means in the column with same letter indicate no difference at Duncan's Multiple Range Test at $P < 0.05$

Table 3. Plant growth parameters as affected by three experimental conditions*

Interactions between salinity and temperature were significant ($p < 0.05$) for the number of tillers, growth of tops and roots. Maximum number of tillers and the highest dry matter were produced when the root temperature was at the intermediate levels of 15 to 20 °C. Effect of salinity on most parameters tested strongly depended on the prevailing root temperature (Mozafar & Oertli, 1992). Moreover, heat stress, singly or in combination with drought, is a common constraint during anthesis and grain filling stages in many cereal crops of temperate regions (Guilioni et al., 2003). Sule et al. (2004) reported that high temperature is one of the environmental stress factors that can affect the growth and quality characteristics of barley. Moreover, it was found by Macnicol et al. (1993) that both water and heat stress reduced yield and grain size of barley. Our experiment also confirmed that growth environments differentiated the performance of barley under the same type of irrigation water. The incorporation of some salts with high temperature could lead to higher loss of plant production (Daoud et al., 2001).

The low temperature in the glasshouse exerted the lowest water deficit as compared to greenhouse and growth chamber (Fig. 7). Extended canopy and large number of tillers per plant apparently caused high transpiration rate in growth chamber. Since plants were irrigated daily at field capacity considering water loss due to evapotranspiration. The water deficit conditions under high salinity treatments could be directly attributed to the impaired water flow from soil to plant. Yeo (1999) reported that root selectivity and transpirational water flow provide the net uptake of salts whereas the salt concentration develops with the growth rate. The greater mass flow of solution through the soil-root interface or higher magnitude of evapotranspiration would increase the salt transport in plants. Thus there is a potential risk of higher salt damages in hot climate.

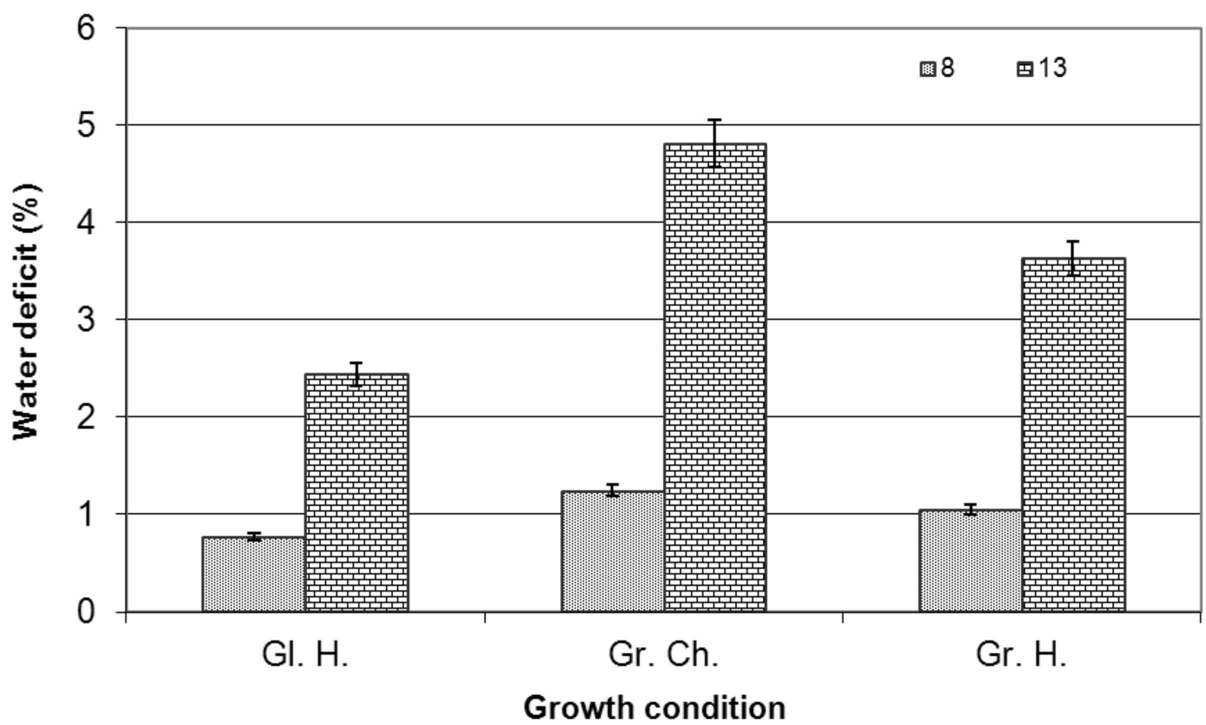

Fig. 7. Plant water deficit as affected by growth conditions

Stress factor (K_s) is an additional parameter to determine crop evapotranspiration. It is an indicator of unusual plants stress such as salinity, deficit water, disease or nutrient imbalance. It implies when its value decreases by less than 1 and smaller K_s value means higher stress. The stress co-efficient was found in the order of greenhouse > growth chamber > glasshouse (Fig. 8). The K_s values greatly decreased under high level of salinity and heat conditions. Pots irrigated with low saline water produced more biomass which did not decline K_s values. The lower K_s values depicted higher accumulation of salts in the pots under the accelerated evapotranspiration due to hot environment. Stress factor (K_s) is an indicator of salt stress problem. It can be seen from Table 4, that low salinity treatment (3 dS m^{-1}) was giving the weakest relationship between K_s and salt storage (ST). Whereas, a very strong relationship (0.90 - 0.98) was observed with high salinity treatments (8 and 13 dS m^{-1}). Table 4 is an extension of Fig. 8 and it is clearly explain how K_s value was changing as soil salinity change.

The crop coefficient factor (K_c) as affected by different conditions and salinity treatments is shown in Figure 9. The approximate standard value reported by FAO (1998) for K_c was 1.15. The K_c values obtained during our experiment were higher than FAO value. This could be attributed to the growth conditions and crop variety. There was a similar trend between K_c and ET_c under all environmental conditions. The level of K_c decreased with increasing level of salts in the water. It was reported that increased evaporation from the soil surface can counteract the reductions in K_c caused by high EC_e of the root zone (FAO, 1998). Letey et al. (1985) and Shalhevet (1994) reported that the effects of soil salinity and water stress were interactive to crop evapotranspiration.

Evapotranspiration data are needed for project planning or designing irrigation scheduling. A large number of empirical methods have been developed by several scientists over the last 50 years to estimate evapotranspiration in different climates. Relationships were often subjected to rigorous local calibrations and were proved to have certain limitations. Usually testing the accuracy of the methods under new conditions is laborious, time-consuming and costly.

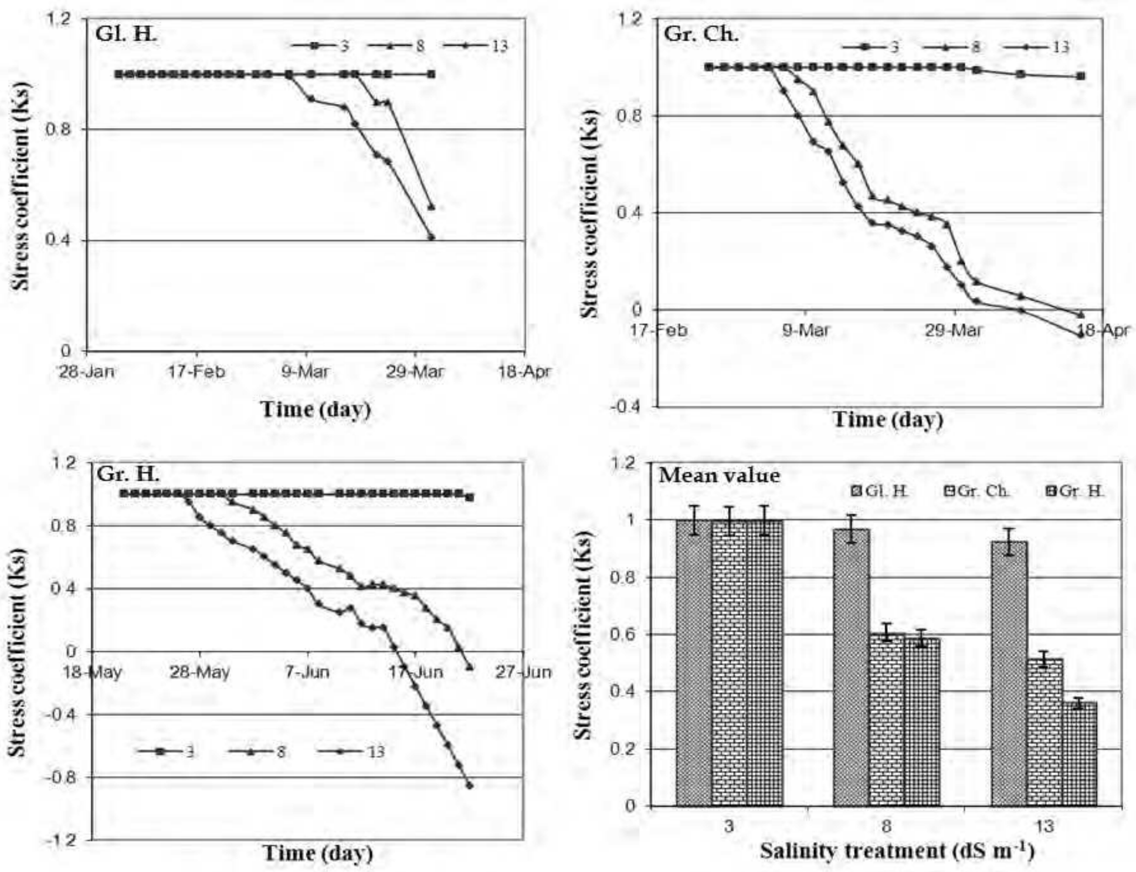

Fig. 8. Stress coefficient as affected by different environments and saline treatments

Growth condition	Salinity treatment (dS m^{-1})	Equation	R^2
Glass house	3	$K_s = 1$	-
	8	$K_s = -0.02(ST)^2 + 0.08ST + 0.95$	0.60
	13	$K_s = -0.02(ST)^2 + 0.08ST + 0.94$	0.90
Growth chamber	3	$K_s = -0.002(ST)^2 + 0.01ST + 0.99$	0.59
	8	$K_s = -0.01(ST)^2 + 0.01ST + 1.02$	0.98
	13	$K_s = -0.002(ST)^2 - 0.05ST + 1.11$	0.98
Green house	3	$K_s = -0.0003(ST)^2 + 0.002ST + 1$	0.21
	8	$K_s = -0.007(ST)^2 + 0.03ST + 0.99$	0.98
	13	$K_s = -0.007(ST)^2 + 0.04ST + 0.92$	0.96

Table 4. Salt storage (ST) relationship with stress coefficient (Ks)

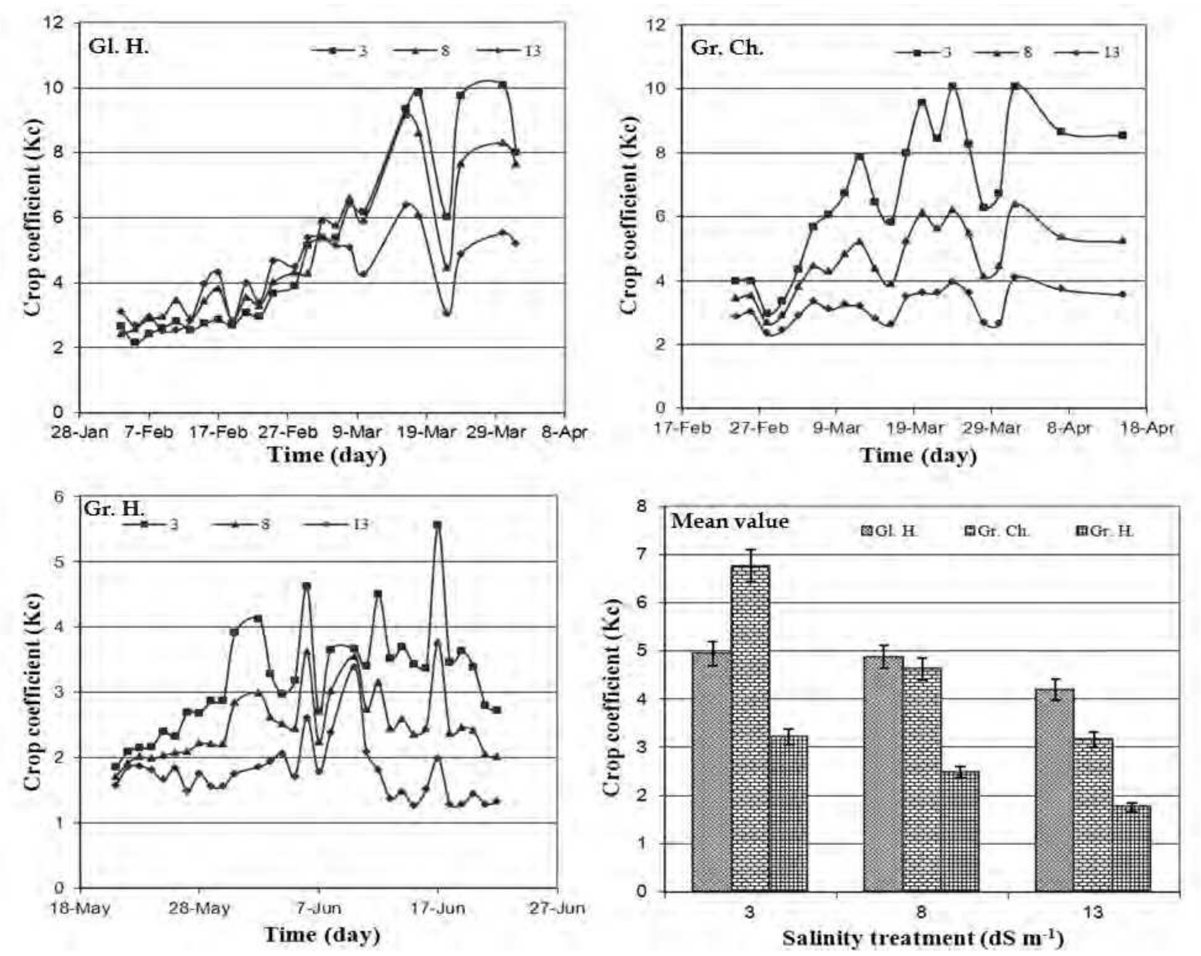

Fig. 9. Crop coefficient value as affected by different growing conditions

Crop evapotranspiration can be calculated from climatic data and crop parameters by using Blaney-Criddle, radiation, Penman and pan evaporation methods (FAO, 1998). The factors like soil salinity, soil water quality and quantity can also affect evapotranspiration value. Since evapotranspiration and crop coefficient factor (K_c) are interconnected parameters indicating plant growth statues. It can be seen that crop coefficient factor was apparently affected by interactions of soil and plant parameters (Table 5). Changes in plant development under glasshouse and growth chamber gave high values of correlation coefficient (0.80 - 0.93) for measured parameters whereas the unstable condition of greenhouse highly reduced the relationship of various parameters (0.31 - 0.60). In general, the increment in water salinity negatively impacted the correlation coefficient values. Temperature, evapotranspiration and stress coefficient controlled the value of crop coefficient factor depending on the growth conditions. It is also reported elsewhere that soil salinity, land fertility, soil management, fertilizers, soil physical condition, diseases and pests were affected crop development and evapotranspiration (FAO, 1998). In FAO report, it was mentioned that increased evaporation under high frequency irrigation of the soil surface can counteract reductions in K_c caused by high EC_e of the root zone. Under these conditions, the total K_c and ET_c are not very different from the non-saline, standard conditions under less frequent irrigation, even though crop yields and crop transpiration are reduced. Because of this, under saline conditions, the K_s reducing factor should only be applied with the dual K_c approach (FAO, 1998). In reviewed articles on impacts of salinity on crop production, Letey et al. (1985) and Shalhevet (1994) concluded that the effect of soil salinity and water stress are generally additive in their impacts on crop evapotranspiration. Therefore, the same yield-ET functions may hold for both water shortage induced stress and for salinity induced stress. Moreover, some equations used to calculate K_c or K_s are not expected to be accurate for predicting ET_c for specific days (FAO, 1998).

Growth condition	Salinity treatment (dS m^{-1})	Dependent variable				Intersection point	Multiple correlation coefficient
		Temp (°C)	ET (mm)	WS (mm)	Ks (-)		
Glass-house	3	0.04	0.41	-0.11	1.00	8.02	0.93
		(15.29%)	(68.03%)	(16.70%)	(-%)		
	8	0.02	0.35	-0.01	-2.96	10.90	0.91
		(10.74%)	(56.63%)	(15.36%)	(17.25%)		
	13	0.05	0.13	-0.0004	0.16	1.41	0.80
		(60.53%)	(36.10%)	(0.11%)	(3.25%)		
Growth-chamber	3	0.37	0.24	0.02	-5.43	-1.60	0.92
		(27.58%)	(65.52%)	(3.44%)	(3.41%)		
	8	0.32	0.09	0.04	-0.79	-5.25	0.92
		(42.56%)	(20.74%)	(6.57%)	(29.82%)		
	13	0.11	0.10	0.07	-0.33	-4.79	0.81
		(29.91%)	(25.47%)	(16.80%)	(27.86%)		
Green-house	3	-0.01	0.13	-0.04	45.03	-40.86	0.57
		(6.40%)	(52.59%)	(20.73%)	(20.29%)		
	8	0.01	-0.02	0.03	-0.28	0.32	0.31
		(18.60%)	(19.45%)	(30.57%)	(31.43%)		
	13	-0.06	0.08	0.04	-0.17	0.19	0.60
		(45.39%)	(22.62%)	(16.42%)	(15.56%)		

Table 5. Multiple regression analysis for crop coefficient (K_c) data

4. Conclusions

In agricultural systems, evapotranspiration process and plant productivity are strongly influenced by environmental conditions. Therefore, this study concludes that the growth conditions had profound effects on the evapotranspiration process, soil salinity and barley growth. Salt concentrations in irrigation water inhibited evaporation from the soil surface. Therefore, soil water was negatively related to the quality of irrigation water. Salt status of soils was highly increased by high temperature and evapotranspiration especially in the greenhouse and growth chamber. The barley grew well in high saline water under a favorable climate of glasshouse. Under low salinity treatment plants showed no stress as compared to high salinity treatment especially under greenhouse and growth chamber conditions. High temperature in the greenhouse and continuous heating in the growth chamber lowered the plant growth and water stress coefficient (K_s). Crop coefficient (K_c) also differed in all growing conditions with salinity treatments. The level of K_c decreased with increasing level of salts in the water and its value was controlled by temperature, evapotranspiration and stress coefficient. This experiment indicated that when saline water is used for irrigation due attention should be given to minimize root-zone salinity. However, a good management of soil and water could be a viable option for sustainable agriculture in salt affected soils. There is further need to evaluate poor water quality on different crops in arid and semi arid fields' conditions.

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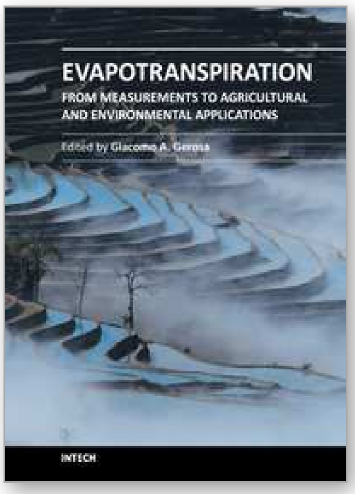

Evapotranspiration - From Measurements to Agricultural and Environmental Applications

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This book represents an overview of the direct measurement techniques of evapotranspiration with related applications to the water use optimization in the agricultural practice and to the ecosystems study. Different measuring techniques at leaf level (porometry), plant-level (sap-flow, lysimetry) and agro-ecosystem level (Surface Renewal, Eddy Covariance, Multi layer BREB), are presented with detailed explanations and examples. For the optimization of the water use in agriculture, detailed measurements on transpiration demands of crops and different cultivars, as well as results of different irrigation schemes and techniques (i.e. subsurface drip) in semi-arid areas for open-field, greenhouse and potted grown plants are presented. Aspects on ET of crops in saline environments, effects of ET on groundwater quality in xeric environments as well as the application of ET to climatic classification are also depicted. The book provides an excellent overview for both, researchers and student,s who intend to address these issues.