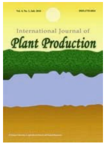

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Effect of irrigation interval and water salinity on growth of vetiver (*Vetiveria zizanioides*)

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Abstract

The purpose of the present study was to investigate the limits of irrigation water salinity and soil water content for growth inhibition of vetiver. Moreover, different models were studied to describe the root water uptake and plant top growth under salinity and water stresses in a pot experiment. Irrigation treatments consisted of three irrigation intervals (3, 6 and 9-day). The salinity levels of the irrigation water were 0.8 (tap water), 10, 20 and 30 dS m^{-1}. It is concluded that by enforcing salinity and increasing its level up to 30 dS m^{-1}, no significant decline in the top dry matter (TDM) has been observed. However, in the salinity level of 30 dS m^{-1} increasing of soil water stress caused TDM to decrease. The maximum amount of leaf area index (LAI) was observed at water salinity level of 0.8 dS m^{-1} and as the salinity increased, it decreased. However, at different water salinity levels, the reduction of LAI was not significant. Moreover, the results showed that the water stress did not have significant effects on reduction of LAI separately, while the water salinity did. The thresholds of water salinity and irrigation intervals for affecting vetiver's root were between 20 and 30 dS m^{-1} and 6 days (80% soil available water depletion), respectively. Moreover, the threshold values of soil salinity were 13.8 dS m^{-1} for top and 19.4 dS m^{-1} for root growth. Then, it can be concluded that the top growth is more sensitive to the water salinity, than the root one. Therefore, in terms of economic, if using root is more substantial, root production would be more beneficial. The growth reduction per unit increase in soil salinity for top growth and root growth are 2% and 3% per dS m^{-1}, respectively. Therefore, top and root growth affected similarly by increasing the soil salinity. Relative yield response factor to water stress was 0.472 that showed the vetiver resistance to soil water stress. It is indicated that the root water uptake coefficient (α) was predicted accurately after considering the results and comparing different models. Furthermore, the estimated values of α predicted the shoot dry weight accurately. However, Homaee and Feddes method is preferred for estimation of TDM.

Keywords: Vetiver deficit irrigation; Irrigation salinity; Vetiver yield modeling; Root-water uptake coefficient.

Introduction

Vetiver grass (*Vetiveria zizanioides*), is a highly efficient, graminaceous plant in absorbing dissolved nutrients and heavy metals in polluted soil and water, native to tropical and subtropical areas. It can tolerate many kinds of extreme environments, such as growing in drought, medium and high in acidity, alkalinity, salinity, sodium and magnesium. It has been successfully used for soil and water conservation practices. Additionally, it is now considered to have future potential as bio-fuel for power generation and cellulosic ethanol. Despite of all of these researches, little is known about its salinity tolerance and soil water limits for growth.

Truong (1996) introduced vetiver as a resistant graminaceous plant toward high soil and water salinity and soil water stress. Many investigations on vetiver in greenhouse have shown its exceptional potential to thrive, being irrigated after 50 days of drought. Moreover, Summerfelt et al. (1999) showed its remarkable ability of absorbing soil and water minerals. Zhou and Yu (2009) expressed that in salinity levels, lower than NaCl=200 mmol L^{-1}, vetiver is able to stay alive through osmotic adjustment. Truong et al. (2002a) mentioned that cropping an especial species of vetiver, named *Monto vetiver*, reduced the soil salinity; however, the crop yield reduction was unavoidable. Furthermore, they determined the soil salinity tolerance threshold for this plant, as EC_e=8 dS m^{-1}. They also mentioned that in soil salinity of 13-17.5 dS m^{-1}, crop yield declined by 50%. Truong et al. (2002b) found that vetiver is resistant to not only water and soil salinity, also to drought and their interaction. Their studies showed that in the salinity levels of 10 dS m^{-1} and 20 dS m^{-1}, respectively 10 and 50% yield reduction has occurred. They also compared this plant with two salt tolerant plants, *Rodesgrass* and *Paspalum* and finally the results showed vetiver's greater resistance to soil salinity level, up to 31.8 dS m^{-1}. They also stated that by supplying the substantial nutrients, such as phosphorus and nitrogen, the plant is capable to flourish in higher salinities expressed and in exchangeable sodium percentage (ESP)=35-48%. Moreover, planting vetiver in contour lines has shown its capability to reduce soil salinity, trap minerals and soil sediments, reduce runoff and increase permeability of the soil. In their observation, vetiver reduced soil salinity from 16 dS m^{-1} to 7-9 dS m^{-1}. Pongvichian et al. (2005) stated that the salinity tolerance threshold would be different in different regions and cultivars. For instance, two species of *Vetiveria zizanioides* and *Vetiveria nemoralis* have more resistance against soil salinity up to 20 dS m^{-1}, than the other ones. They also stated that saline water and soil affect plant growth, dry matter production and root development, directly. Van Du and Truong (2006) stated that planting vetiver in saline soil under the influence of sea water with a salinity of EC_w=8-11, produced 25 Mg ha^{-1} top dry matters (TDM), after 60 days. It also reduced the EC_e, calcium and sodium in the soil. Even after achieving the mentioned purposes, the plant was used to feed the livestock.

In arid and semi-arid regions, plants are encountered by scarce water, which is highly saline. Water stress and salinity, are two complex issues which affect different steps of plant's growth, while little is known about the salinity tolerance of new crops, especially vetiver that there is few information on its water use under varying irrigation water management. Therefore, the objectives of this study were to investigate salinity tolerance and growth of vetiver under different irrigation water management levels in greenhouse. Additionally, different models were studied to describe the root water uptake under different salinities and water stresses to be used for shoot (top) dry matter prediction.

Materials and Methods

Field experiment

The present research was conducted in a greenhouse at the Agricultural College, Shiraz University, located at latitude 29.5˚ N, longitude 52.5˚ E and 1810 m above mean sea level in year 2010. The soil was a loam, collected from the top 0-0.20 m layer, air-dried and passed through a 10-mm sieve. Forty eight plastic pots with 0.20 m in height and 0.227 m in diameter were filled by 8.365 kg air-dried soil with a 10 mm layer of 0.745 kg gravel filter (gravel particles with 4 mm in diameter) at bottom. One vetiver plant weighting 0.5 kg was planted in each pot. The soil in each pot was compacted to reach a density of 1.24 g cm^{-3} and finally the soil height was 0.18 m. Some physic-chemical properties of the used soil are shown in Table 1. In order to study the effects of irrigation interval and water salinity levels on growth of vetiver, an experimental design with randomized complete block with three irrigation intervals, four salinity levels and four replications was conducted. Irrigation treatments were (I_1, I_2 and I_3) 3, 6 and 9-day intervals, that was equivalent to 50%, 80% and 100% of depleted soil available water, respectively. The salinity levels of the irrigation water were 0.8 (tap water as control), 10, 20 and 30 dS m^{-1} (S_1, S_2, S_3 and S_4), made by the addition of NaCl and $CaCl_2$ to the tap water with equal proportion. Before treatments, initially, the pots were irrigated with tap water (salinity 0.8 dS m^{-1}), by weighing the pots and raising the soil water content to the field capacity. When using saline water, 15 percent more water was applied as leaching requirement to control the salt accumulation in the pots.

Table 1. Physic-chemical properties of the soil used in the experiment.

Physical property		Chemical property	
Sand (%)	17	EC_e (dS m^{-1})	0.57
Silt (%)	47	pH	7.6
Clay (%)	36	Na (meq L^{-1})	1.5
Bulk density (g cm^{-3})	1.24	K (meq L^{-1})	0.22
$\theta_{v\text{-}FC}$ (cm^3 cm^{-3})	0.35	Ca (meq L^{-1})	3.8
$\theta_{v\text{-}PWP}$ (cm^3 cm^{-3})	0.15	Mg (meq L^{-1})	1.7
		Cl (meq L^{-1})	1.9

The maximum and minimum air temperatures in the greenhouse were 41±7 and 8±5 ˚C respectively.

Soil samples were used to determine the soil water retention curve by hanging water column and pressure plate apparatus. The soil water retention equation is shown as follows (van Genuchten, 1980):

$$h = 66.7\left[\left(\frac{0.41}{\theta - 0.099}\right)^{3.82} - 1\right]^{0.74} \tag{1}$$

Where θ is the soil volumetric water content in cm^3 cm^{-3} and h is the soil water matric head in cm. Before irrigation, soil water contents in pots were measured by weighing the pots. Electrical conductivity was determined in the drainage water during the growing season. Osmotic head of the drainage water as soil solution was estimated by the following equation (Richards, 1954):

$$h_0 = -360 \times EC_{ss} \tag{2}$$

Where h_0 is the osmotic potential in cm and EC_{ss} is the soil solution salinity in dS m^{-1}. Soil water content before each irrigation converted to soil water matric head by using the soil water retention equation [Eq. (1)].

In this study, the mean daily crop evapotranspiration (ET_c) during the growing season was determined by the weight reduction of the control treatment (I_1S_1) for each 3-day periods at four replications. The mean weight reduction of pots for different treatments was considered as the actual evapotranspiration (ET).

At planting, the vetiver plants were cut at a height of 5 cm above soil surface. Then at the end of the growing season, the top of plant at height of 5 cm above the soil surface was harvested and considered as top growth. The harvested plant tops were dried in oven under 65 ˚C for 48 h and weighed. The leaves areas were measured at harvest by *Windias* instrument and the leaf area index was determined for each treatment. Before planting the vetivers, the roots of three of them were cut, washed and dried in oven with 65 ˚C for 48 h and then weighted. The mean of these three values, was used in root growth determination. At harvest the roots in each pot were washed and dried in oven with 65 ˚C for 48 h and weighed. The difference between these two weights was considered as root growth. Also at harvest, soil samples were collected from different depth of the pots with auger for chemical analysis. The results were subjected to statistical analysis and means were compared by the Duncan multiple range test by SAS software.

Water uptake models

Water flow in unsaturated soils described with Richards equation (Richards, 1931). Including the root extraction term *S*, it is as follows:

$$\frac{\partial \theta}{\partial t} = C(h)\frac{\partial h}{\partial t} = \frac{\partial}{\partial Z}\left(K(h)\frac{\partial h}{\partial Z} + K(h)\right) - S \tag{3}$$

Where θ is the volumetric soil water content (L^3 L^{-3}), t is the time (T), C is the differential soil water capacity (L^{-1}) that is equal to the slope of the soil water retention curve ($d\theta/dh$), h is the soil water pressure head (L), Z is the gravitational head, as well as the vertical coordinate (L) taken positive upward, K is the soil hydraulic conductivity (L T^{-1}) and S is the soil water extraction rate by plant roots (L^3 L^{-3} T^{-1}). This is determined as follows:

$$S=\alpha\,(h,\ h_0)\ S_{max} \tag{4}$$

Where S_{max} is the maximum water uptake rate and $\alpha(h,h_0)$ is a dimensionless function of pressure and osmotic head. Mass and Hoffman (1977) proposed the following equation for the macroscopic reduction function:

$$\alpha(h,\ h_0)=\frac{h-h_4}{h_3-h_4}\times\left[1-\frac{a}{360}(h_0^*-h_0)\right] \tag{5}$$

Where h_3 is the soil water pressure head threshold value, h_4 is the soil water pressure head at wilting, h_0^* is the osmotic pressure head at threshold soil salinity, h_0 is the osmotic pressure head and a, is the yield reduction percent per unit salinity (dS m^{-1}). This equation is valid for $h_0 \leq h_0^*$ and $(h_4-h_0) \leq h \leq h_3$, respectively.

Homaee and Feddes (1999) proposed another equation that is a combination of linear and non-linear and differs conceptually from additive and multiplicative theories. Further assumption is that each dS m^{-1} salinity beyond the threshold value (EC^*) shifts the wilting point to the left. In this method, the reduction function for water uptake is as follows:

$$\alpha(h,\ h_0)=\frac{h-(h_4-h_0)}{h_3-(h_4-h_0)}\times\left[1-\frac{a}{360}(h_0^*-h_0)\right] \tag{6}$$

Root-water uptake coefficient (α) is relative transpiration that obtained from ratio of the actual transpiration to the potential transpiration. In this study it is assumed that the relative transpiration is equal the relative evapotranspiration. Therefore, to determine α, the actual evapotranspiration (irrigation intervals of 6 and 9-day) was divided by the potential evapotranspiration (irrigation interval of 3-day) and the results were taken equivalent to the root-water uptake coefficient.

Yield models

Stewart et al. (1977) proposed the equation to obtain yield in water stress as follows:

$$\frac{Y_a}{Y_m} = 1 - K_y \left[1 - \frac{ET_{c-adj}}{ET_c} \right] \tag{7}$$

Where Y_a is the actual crop yield (Mg ha^{-1}), Y_m is the maximum expected crop yield (Mg ha^{-1}), K_y is the relative yield response factor at water stress, ET_c is the crop evapotranspiration for standard condition with no water stress (mm d^{-1}) and ET_{c-adj} is the adjusted crop evapotranspiration (mm d^{-1}) that is calculated as follows:

$$ET_{c\text{-}adj} = ET_c \times K_s \tag{8}$$

In which K_s is the transpiration reduction factor and is dependent on available soil water that is varied between 0-1. This factor under salinity and water stress condition is calculated as follows (Allen et al., 1998):

$$K_s = \left[1 - \frac{b}{K_y 100} \left(EC_e - EC_{e-th} \right) \right] \times \left[\frac{TAW - Dr}{TAW - RAW} \right] \tag{9}$$

Where EC_e is the soil water electrical conductivity (dS m^{-1}) and $EC_{e\text{-}th}$ is the threshold soil water electrical conductivity (dS m^{-1}), b is the growth reduction per unit increase in soil salinity, D_r is the root zone water depletion (mm), TAW is the total available soil water in the root zone (mm), RAW is the readily available water (mm), p is the fraction of TAW that a crop can extract from the root zone without suffering water stress. Therefore, relative crop yield under water and salinity stress is determined as follows:

$$\frac{Y_a}{Y_m} = 1 - K_y \left[1 - \frac{\alpha(h, h_0) ET_c}{ET_c} \right] \tag{10a}$$

$$\frac{Y_a}{Y_m} = 1 - K_y \left[1 - \frac{K_s ET_c}{ET_c} \right] \tag{10b}$$

Application of equation (10b) should usually be restricted to EC_e<$EC_{e\text{-}th}$+50/b and it predicts Y_a=0 at K_s=0. Furthermore, the K_y values are given for only 23 crops by Doorenbos and Kassam (1979) and where K_y is unknown it is suggested to use K_y=1 or may select the K_y for a crop that has similar behavior.

If K_s in Eq. (8) is replaced by $\alpha(h, h_0)$ Eq. (10a) is obtained that is a different method for calculation of $ET_{c\text{-}adj}$. Then, Eq. (10a) is used to estimate relative yield and with knowing the maximum yield, Y_m, the value of actual yield, Y_a, is estimated.

Results and Discussion

Irrigation and salinity effects

Top dry matter

Top dry matter (TDM) has decreased as the result of enforcing irrigation intervals and salinity water levels (Table 2). The maximum of TDM is referred to the water salinity of 0.8 dS m^{-1} and the irrigation interval of 3-days. At this salinity level, increasing of irrigation intervals decreased the TDM; however, it was not significant. Moreover, the increase in water salinity levels, up to 20 dS m^{-1}, did not make any significant reduction in top TDM. At soil salinity of 30 dS m^{-1} and reduction of 80% and 100% of available water (irrigation intervals of 6-and 9-day), 49 and 53% decrease in TDM was observed, respectively, that are not very different.

At each irrigation intervals, higher reduction in TDM was resulted due to increase in water salinity. At water salinity levels up to 20 dS m^{-1} and irrigation intervals up to 9-day, TDM showed small, but not statistically significant reduction. However, at water salinity of 30 dS m^{-1} and irrigation intervals of 6-day and 9-day (80 and 100% depletion of soil available water, respectively), the TDM has decreased significantly. This indicated that the threshold treatments for TDM are between 20 and 30 dS m^{-1} for the water salinity and 6-day irrigation interval. The parallel conclusion was observed in the research, conducted on *Fleawort*, by Safarnejad et al. (2007). It also showed that shoot dry matter decreased, as the water salinity increased. This might be due to the fact that water salinity and drought, make the root to pierce less and as the result, the dry matter is decreased (Frota and Tucker, 1978; Grieve et al., 1999; Yildirim et al., 2006).

Table 2. Growth parameters in different levels of salinity and irrigation intervals.

Growth parameter	Irrigation water salinity (dS m^{-1})	Available water reduction, % 50 (I_1)	80 (I_2)	100 (I_3)
Top dry matter (g pot^{-1})	0.8 (S_1)	9.65^{a*}	7.37^{abcd}	8.05^{abc}
	10 (S_2)	6.65^{bcde}	5.2^{def}	5.57^{cdef}
	20 (S_3)	5.87^{cdef}	3.42^{f}	5.8^{cdef}
	30 (S_4)	8.42^{ab}	4.32^{ef}	3.93^{f}
Root dry matter (g pot^{-1})	0.8 (S_1)	20.76^{b}	18.15^{b}	28.72^{a}
	10 (S_2)	7.85^{de}	11.57^{cde}	10.07^{cde}
	20 (S_3)	7.85^{de}	12.25^{cd}	11.55^{cde}
	30 (S_4)	13.32^{c}	7.42^{e}	12.77^{c}
Leaf area index	0.8 (S_1)	1.29^{a}	0.9^{bc}	1.16^{ab}
	10 (S_2)	0.75^{cde}	0.77^{cd}	0.6^{cdef}
	20 (S_3)	0.43^{defg}	0.38^{efg}	0.64^{cdef}
	30 (S_4)	0.5^{efg}	0.19^{g}	0.36^{fg}

[*] Means followed by the same letters in each column and rows are not significantly different at 5% level of probability by Duncan multiple range test.

Root dry matter

Similar results to TDM were obtained for root dry matter (RDM), due to enforcing irrigation intervals and salinity water levels (Table 2). However, at salinity level of 0.8 dS m^{-1}, higher reduction in available water i. e., 100% (the irrigation interval of 9-day), caused 38% increasing in RDM. Root growth, as one of the drought tolerance mechanisms in plants, might happen to encounter with drought (Alizadeh, 1999). The increase of water salinity from 10 to 20 dS m^{-1} did not make any statistically significant reduction in RDM. Like TDM, at each irrigation intervals, the maximum of RDM was referred to the water salinity of 0.8 dS m^{-1}. As the same as TDM, increasing in water salinity levels, up to 20 dS m^{-1} did not make any significant changes in RDM. While, at water salinity of 30 dS m^{-1} and reduction of 80% of available water (irrigation intervals of 6-day), 44% decrease in RDM was observed. Therefore, the critical values of water salinity and irrigation interval would be elicited easily, which are between 20 and 30 dS m^{-1} and 6-day irrigation intervals (80% reduction in soil available water), respectively. All of these results indicated that the RDM is affected by both salinity and water stress. When soil moisture is highly reduced, the salt concentration between soil and plant root severely increased and when these two stresses are interacted simultaneously, they intensify each other (Brown et al., 2006).

Pessarakli and Tucker (1985) showed that the enforcement of salt stress decreased the root-water uptake, plant's growth and the dry matter production. Similarly, Brown et al. (2006) indicated that enforcement of soil salinity and water stress would definitely decrease both TDM and RDM.

Leaf area index

The maximum leaf area index (LAI) was observed for treatment S_1 of water salinity levels (0.8 dS m^{-1}) and as the salinity increased, it was decreased (Table 2). However, at different water salinity levels, the reduction of this parameter was not significant. Results showed that water stress did not have significant effects on reduction in LAI, while the water salinity reduced it. Plants used different mechanisms in drought avoidance, which encompass leaf area reduction, leaf thickness increasing and transpiration reduction (Alizadeh, 1999). Abbasi and Koocheki (2008) showed the reduction of leaf area in *Aeluropus logopoides* and *Aeluropus litttoralis* as the result of enforcement of water salinity. Many researches have shown that salinity plays more important role in leaf area reduction than soil water stress and since the water salinity influences osmotic pressure, proteins molecules' structure and plants growth, the obtained results are expected (Shibles and Weber, 1966; Premachandra et al. 1992; Tanji, 1996; Basra, 1997). Wignarajah (1974) reported that bean's leaves area decreased in high (NaCl=24-72 mmol L^{-1}) saline conditions. In saline situation, plant available water is decreased and cells division is stoped. That is why the leaf area is decreased (Wang et al., 2001; Nielen and Nelson, 1998). Marani et al. (1985) also observed similar results for cotton.

Drainage water salinity

It is well known that saline irrigation water increases the salinity in soil and drainage water. In this experiment, by increasing irrigation intervals in S_1 (0.8 dS m^{-1}), the increase in drainage water salinity was not significant (Table 3). However, in irrigation water salinity levels of S_2, S_3 and S_4 (10.0, 20.0 and 30.0 dS m^{-1}, respectively), this increase was statistically significant. Results showed that the interaction of irrigation water salinity and soil water stress intensified the salinity of drainage water. This is due to the fact that increasing irrigation intervals can increase the leaching of salt and other soil minerals (Alizadeh, 1999). According to Figure 1, the salinity of drainage water has decreased during the growing season. The reason might be related to soil physical changes during the growing season, which resulted in cracks and crevices in soil that gradually reduced the leaching efficiency and finally the drainage water salinity.

Soil saturation extract salinity

As the same as drainage water salinity, the maximum value of soil saturation extract salinity (EC_e) is referred to S_3 and S_4 and by increasing the irrigation intervals at S_1, the increase in EC_e was not significant (Table 3). It seems that at S_3 and S_4, soil water stress did not increase the EC_e as it is presented in Table 3. Therefore, it can be concluded that soil water stress does not influence the EC_e in high water salinities. According to the results of EC_e at the end of the growing season and the measured drainage water salinity, it is observed that the drainage water salinity is lower than the soil EC_e. The reason is that because of soil physical changes during the growing season, cracks and crevices are produced and because of soil texture, crust formation on soil surface lead the saline water to be exited with less mixing with soil water. Therefore, the drainage water salinity cannot be considered as soil salinity criteria.

Table 3. Seasonal soil saturation extract and drainage water salinity (dS m^{-1}) in different levels of salinity and irrigation intervals.

Salinity parameter	Irrigation water salinity	Available water reduction, %		
	(dS m^{-1})	50 (I_1)	80 (I_2)	100 (I_3)
Drainage water salinity (dS m^{-1})	0.8 (S_1)	0.86[h*]	0.93[h]	1.72[h]
	10 (S_2)	12.85[g]	17.56[f]	20.07[e]
	20 (S_3)	22.17[d]	28.6[c]	31.27[b]
	30 (S_4)	26.9[c]	32.32[b]	38.05[a]
Soil saturation extract salinity (dS m^{-1})	0.8 (S_1)	1.83[d]	2.55[d]	2.62[d]
	10 (S_2)	24.22[c]	30.56[b]	31.7[b]
	20 (S_3)	34.66[ab]	38[a]	39.96[a]
	30 (S_4)	39.77[a]	40.22[a]	36.13[ab]

[*] Means followed by the same letters in each column and rows are not significantly different at 5% level of probability by Duncan multiple range test.

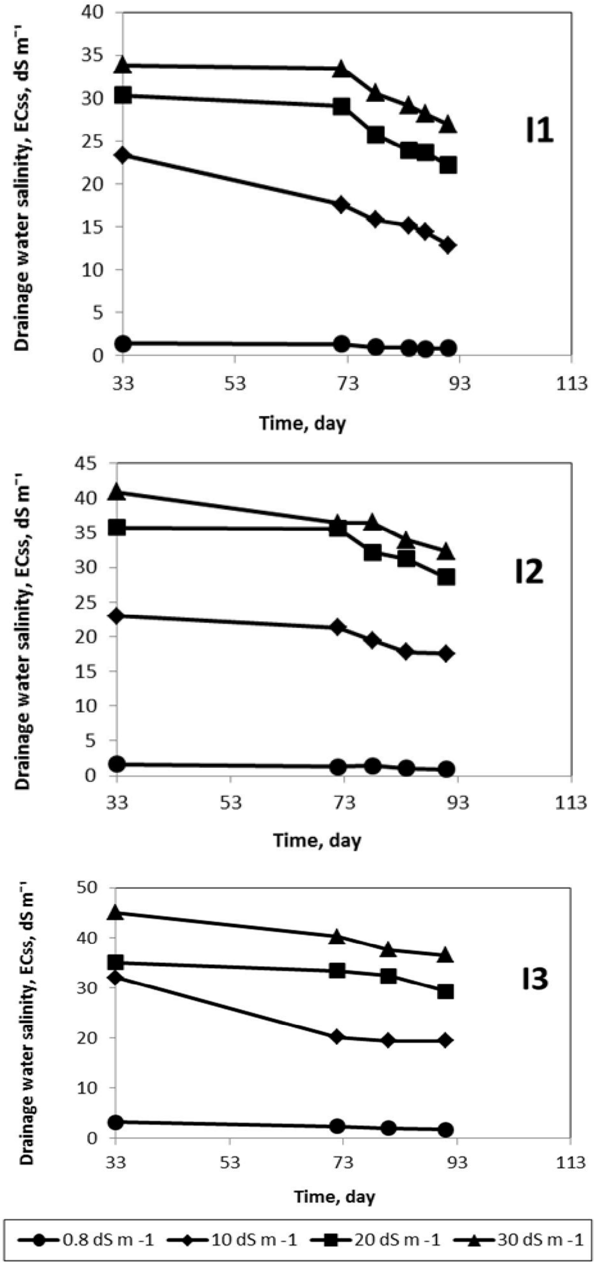

Figure 1. Drainage water salinities during the growth period, for different irrigation intervals: 50% (I_1), 80% (I_2) and 100% (I_3) reduction of available water.

Seasonal evapotranspiration

According to Table 4, water salinity and different irrigation intervals has influenced the seasonal evapotranspiration. However, no significant interaction between intervals of irrigation and water salinity levels was observed.

Relationship between the relative TDM (relative to those obtained at irrigation interval of 3-day) for water salinity level of 0.8 dS m^{-1} and relative evapotranspiration was determined by regression analysis as follows:

$$1-\frac{Y_a}{Y_m}=0.472\left(1-\frac{ET_a}{ET_m}\right), \qquad R^2=0.691 \tag{11}$$

Where $(1-\frac{Y_a}{Y_m})$ is the relative TDM reduction and $(1-\frac{ET_a}{ET_m})$ is the relative evapotranspiration reduction. Coefficient of Eq. (11) is the growth response factor to water for TDM which is 0.472 in this equation and this value showed that the reduction of a unit of evapotranspiration leads a decrease of 0.472 unit of top dry matter. Sepaskhah and Yarami (2010) found this coefficient as 1.79 for saffron. This coefficient was found 1.14 for rice, by Sepaskhah and Falakdehi (2009). It was 1.25, 0.98 and 1.5 for corn, sorghum and red bean (Alizadeh, 1999). Actually the growth response factor reveals plant sensitivity or its resistance to water stress. Therefore, vetiver can be considered as a drought resistant plants compared with other mentioned plants.

Table 4. Seasonal evapotranspiration (mm) in different levels of salinity and irrigation intervals.

Irrigation water salinity	Available water reduction, %		
(dS m^{-1})	50 (I_1)	80 (I_2)	100 (I_3)
0.8 (S_1)	562[a*]	228[d]	188[f]
10 (S_2)	517[b]	215[de]	147[g]
20 (S_3)	506[b]	201[def]	141[g]
30 (S_4)	477[c]	193[ef]	140[g]

[*] Means followed by the same letters in each column and rows are not significantly different at 5% level of probability by Duncan multiple range test.

Plant growth-soil solution salinity function

The relationship between salinity of the irrigation water and the growth factors was not statistically significant (data not shown). In other words, the irrigation water salinity did not affect the growth factors directly. However, it affected the soil water salinity. Therefore, the soil water salinity influenced the plant growth parameters. Relationship between the relative evapotranspiration, top and root dry matter and soil water salinity determined by regression analysis as follows:

$$(ET_a/ET_m)=1\text{-}0.003(EC_{ss} - 13), \quad R^2=0.512, \quad P=0.04 \tag{12}$$

$$(Y_a/Y_m)_{Top}=1\text{- }0.02(EC_{ss} - 13.8), \quad R^2=0.78, \quad P=0.02 \tag{13}$$

$$(Y_a/Y_m)_{Root}=1\text{- }0.03(EC_{ss} - 19.36), \quad R^2=0.75, \quad P=0.005 \tag{14}$$

Where (ET_a/ET_m), $(Ya/Ym)_{Top}$ and $(Ya/Ym)_{Root}$ are the relative evapotranspiration, relative top and root dry weights and EC_{ss} is the salinity of the soil solution in dS m^{-1}. The threshold of EC_{ss} and the growth reduction coefficient for evapotranspiration's reduction is 13 dS m^{-1} and 0.3% per unit salinity increase, respectively. These values for TDM were 13.8 dS m^{-1} and 2% per unit salinity increase, respectively. Similar equations to Eq. (13) were obtained for each irrigation treatments; however, their threshold values for EC_{ss} and growth reduction coefficients were not different. Therefore, they were combined in one equation as Eq. (13). The value of osmotic head equivalent to the threshold EC_{ss} is -4968 cm according to Eq. (2). According to Eq. (13), the salinity of soil water for zero relative TDM is 63.8 dS m^{-1} and the equivalent osmotic head is -22968 cm.

The threshold of EC_{ss} for RDM is 19.36 dS m^{-1} and it is higher than that obtained for TDM. The growth reduction coefficient for RDM is 3% per unit increase in soil salinity and it is about similar to that obtained for TDM. Based on Eq. (2), the value of osmotic head equivalent to the threshold EC_{ss} is -6969.6 cm for RDM. According to Eq. (14), the salinity of soil water for zero relative RDM is 52.7 dS m^{-1} and the equivalent osmotic head for this value, is -18969.6 cm. The growth reduction coefficients for TDM and RDM did not differ a lot; however, according to the thresholds of EC_{ss} for top and root, it can be inferred that top growth is more sensitive to salinity, than root. Truong et al. (2002a) represented the *Monto vetiver*'s EC_{ss} threshold about 8 dS m^{-1} which is different from our results. As Pongvichian et al. (2005) mentioned, the thresholds for different species of this plant might differ and it depends on location and growth conditions. In general, vetiver can be considered as a salinity resistant plant.

Root-water uptake coefficient

The root-water uptake coefficients (α) were estimated by Eqs. (5) and (6). In these estimations, the corresponding values of soil matric and osmotic heads were used as presented in Table 5. After statistical analysis for measured uptake coefficients, results showed that the highest values are referred to S_1 (Table 6). Applying various water salinity levels at different irrigation intervals caused significant decrease in the measured uptake coefficients. However, between the salinity levels of S_2, S_3 and S_4 the reduction was not significant. It seems that the reduction has started at irrigation water salinity of EC=10 dS m^{-1}. Moreover, at I_1 and I_2, no significant decrease in uptake coefficient was observed, while at I_3 this value was significantly decreased. In other words, in different soil salinities, the soil water reduction up to 80% would not affect water uptake coefficient; however, increasing the irrigation interval intensifies the salinity effects on water uptake reduction.

Table 5. Soil matric and osmotic potentials at different points in the range of their variations.

Parameter	Different points	Parameter value
Matric water potential, cm	h_3	-2419
	h_{max}	-22105
Osmotic water potential, cm	h_0^*	-4968
	h_{0max}	-22968
Growth reduction coefficient (% per dS m^{-1})	a	2.0

Table 6. Measured water uptake coefficients in different levels of irrigation water salinity and irrigation intervals.

Irrigation water salinity	Available water reduction, %		
(dS m^{-1})	50 (I_1)	80 (I_2)	100 (I_3)
0.8 (S_1)	1.0^{a*}	1.0^{a}	1.0^{a}
10 (S_2)	0.92^{b}	0.9075^{b}	0.785^{cd}
20 (S_3)	0.9025^{b}	0.885^{b}	0.75^{d}
30 (S_4)	0.85^{bc}	0.85^{bc}	0.7475^{d}

* Means followed by the same letters in each column and rows are not significantly different at 5% level of probability by Duncan multiple range test.

The estimated values of α by Homaee and Feddes (1999) [Eq. (5)] are closed to those of measured values (Figure 2). Relationship between the predicted and measured values of α was determined by linear regression analysis. The slope of linear relationship between the estimated $\alpha(h,h_0)$, by a combination function (Homaee and Feddes, 1999) and the measured values are statistically close to 1.0 and their intercepts were statistically zero. Therefore, this function is appropriate for estimation of $\alpha(h,h_0)$. The relationship between measured (α_m) and predicted (α_p), from Eq. (5) for water uptake coefficients was shown as follows (Figure 2):

$$\alpha_p=0.93\alpha_m+0.038, \quad R^2=0.6, \quad n=27, \quad SE=0.08, \quad P<0.0001 \qquad (15)$$

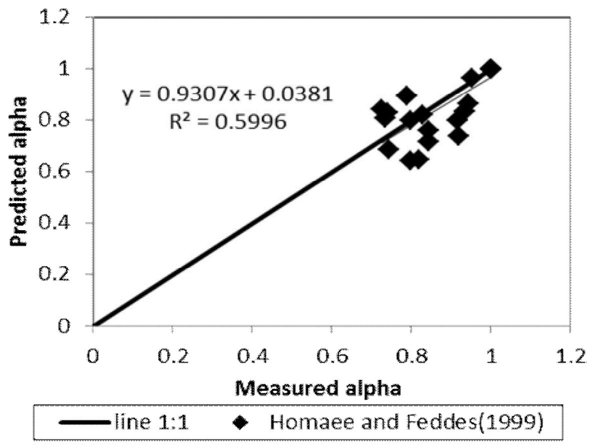

Figure 2. Relationship between measured and predicted values of water reduction coefficient (α) by Homaee and Feddes (1999) (Bold line) and 1:1 line (thin line).

Top dry matter prediction by root-water uptake coefficient

The relative TDM was predicted by using Eqs. (10a) and (10b). The relationships between the predicted relative TDM by Eqs. (10b) and (10a) and the measured values are shown in Figures 3 and 4, respectively. The values of α used in Eq. (10a) are those obtained by Homaee and Feddes (1999). The FAO method [Eq. (10b)] used the values of K_s calculated by Eq. (8). Relationships between the predicted and measured relative TDM was determined by regression analysis. Results presented in Eqs. (16) to (19). The

Homaee and Feddes (1999) method [Eq. (10a)] and the FAO method [Eq. (10b)] resulted in good estimation of relative TDM. However, the predictions resulted by using (10a) was more rational. Higher value of R^2 was obtained for Homaee and Feddes (1999), since FAO's method cannot handle high salinity levels, which are more than the threshold values. This method is not appropriate at high water stress, neither, because K_s might be negative, which is not physically logical. Therefore, it is indicated that Homaee and Feddes (1999) method is preferred for relative TDM estimation.

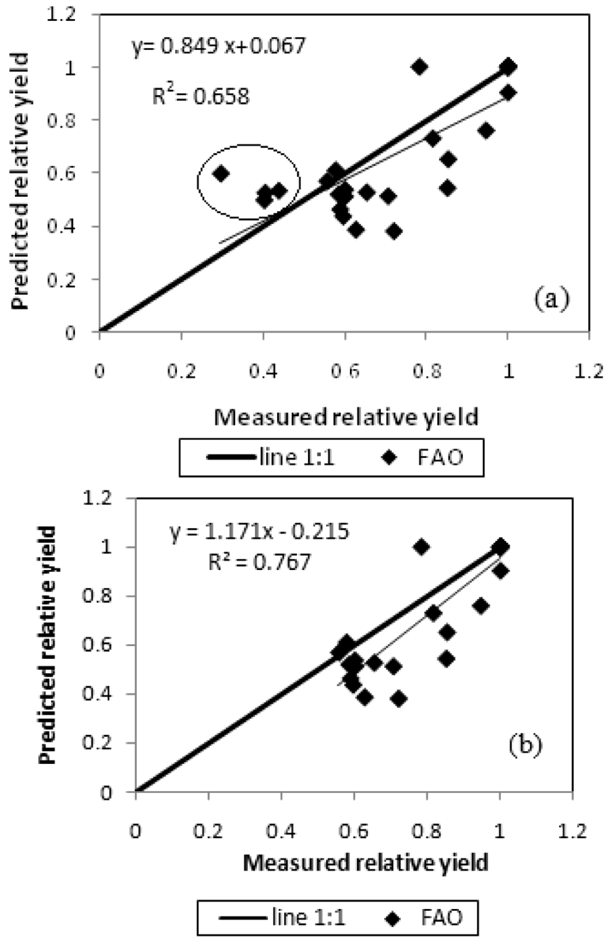

Figure 3. Relationship between the predicted and measured top dry weight by FAO method, [Eq. (10b)], a) before eliminating the irrelevant data, b) after eliminating irrelevant data.

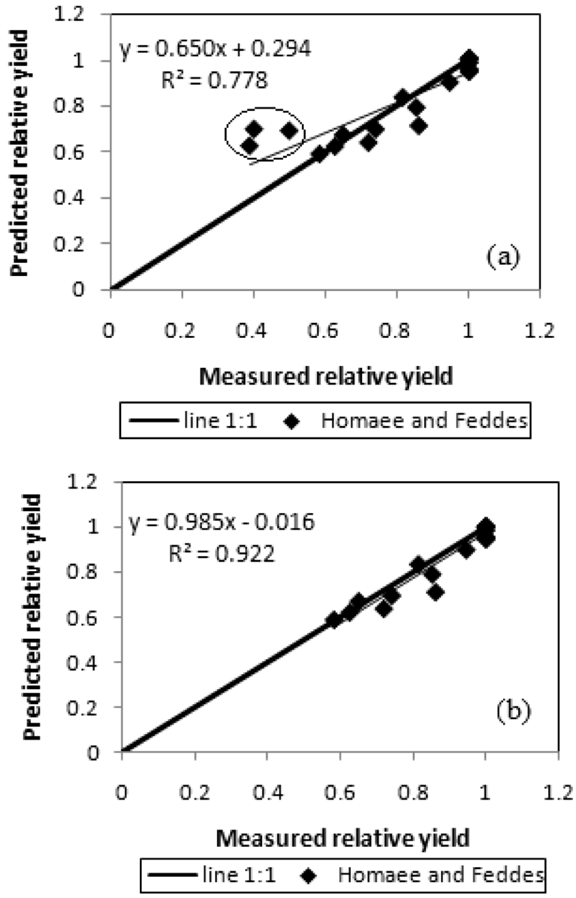

Figure 4. Relationship between the predicted and measured top dry weight by Homaee and Feddes (1999) [Eq. (10a)], a) before eliminating the irrelevant data, b) after eliminating irrelevant data.

Relationship between the measured and predicted yield, resulted from FAO theory was shown as follows (Figure 3):

DM_p=0.849 DM_m+0.067, R^2=0.658 for Eq. (10b) (16)

In this equation DM_p and DM_m, are the predicted and measured relative TDM. It is shown that the measured yields are close to the predicted ones; however, the equation represented the low accuracy of this method (R^2=0.658).

The relationship between the estimated and measured relative dry matter of the equation (10a) is as follows (Figure 4):

$$DM_p=0.650\ DM_m+0.294, \quad R^2=0.778 \quad \text{for Eq. (10a)} \tag{17}$$

In this equation the accuracy is somewhat higher than Eq. (16) because of the higher value of R^2; however, the predicted and measured values are not close to each other. After reviewing the results in Figures 3a and 4a, it became clear that circled data referred to high irrigation intervals and high water salinity levels. The mentioned equations, (Eq. (10a) and (10b)) are not appropriate for high salinity levels, high irrigation intervals and relative yields less than 0.5 (Doorenbos and Kassam, 1979). Therefore, these values were eliminated and new results were shown as follows (Figures 3b and 4b):

$$DM_p=1.171\ DM_m-0.215, \quad R^2=0.767 \quad \text{for Eq. (10b)} \tag{18}$$

$$DM_p=0.985\ DM_m+0.016, \quad R^2=0.922 \quad \text{for Eq. (10a)} \tag{19}$$

Equations (18) and (19) showed good estimation of relative TDM. However, it is shown that Eq. (19) has a higher accuracy (R^2=0.922) and the slope is very close to 1.0. This indicated a high accuracy for Homaee and Feddes (1999) equation.

Shahidi et al. (2010) indicated the Homaee and Feddes (1999) equation is accurate for predicting wheat dry matter. They also stated that with increasing salinity, the wilting point occurred at a lower soil water pressure. However, by increasing salinity in the soil profile, plant water uptake decreased and therefore, more water remained in the soil. That is the reason why this method is appropriate for the soil water pressure head at wilting. Sepaskhah and Yaramy (2010) also demonstrated that Homaee and Feddes (1999) method is appropriate for estimating root water uptake for saffron.

Conclusions

In this research the effects of interaction between the levels of irrigation water salinity and soil water content on the growth of vetiver was investigated. The results showed that irrigating vetiver with water salinity up to 20 dS m^{-1} and 100% reduction of soil available water, did not decrease the top and root dry matters, significantly. Therefore, vetiver is able to be planted in high saline soil or drought conditions. Root dry matter increase was observed by water salinity of 20 dS m^{-1} and soil water reduction of 100%. However, at water salinity of 30 dS m^{-1} and irrigation intervals of 6-day and 9-day (water reduction of 80% and 100%), the top and root growth decreased significantly, which showed that the thresholds for top and root dry matter are between 20 and 30 dS m^{-1} for the water salinity and 80% reduction in soil available water. It is shown that evapotranspiration was reduced by water salinity and different irrigation intervals. However, no significant interaction effect between the intervals of irrigation and water salinity levels was observed. The maximum leaf area index was observed at water salinity level of 0.8 dS m^{-1} and as the salinity increased, LAI decreased. However, at different water salinity levels, the reduction of LAI was not significant. Moreover, the results have shown that the water stress did not have significant effects on reduction of LAI, while it was reduced by the water salinity. The thresholds of water salinity and irrigation intervals for affecting vetiver root were 30 dS m^{-1} and 80% soil water reduction, respectively. Moreover, the threshold values of soil salinity were 13.8 dS m^{-1} for top and 19.4 dS m^{-1} for root growth, respectively. Therefore, it was concluded that the top growth is more sensitive to the water salinity than root growth. Therefore, if root is an economical production, its production is more beneficial in saline conditions. The growth reduction per unit increase in soil salinity for top growth was 2% per dS m^{-1}. This value was, 3% per dS m^{-1} for root growth. Therefore, top and root growth were affected similarly by increasing the soil salinity. Relative yield response factor at water stress was 0.472, which showed that the vetiver is resistant to soil water stress. It is indicated that the root water uptake coefficient (α) was predicted accurately by Homaee and Feddes (1999) model. Furthermore, the estimated values of α by Homaee and Feddes (1999) accurately predicted the shoot dry matter.

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