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KOCHIA SCOPARIA AS A MODEL PLANT TO EXPLORE THE IMPACT OF WATER DEFICIT ON HALOPHYTIC COMMUNITIES

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Abstract

Most halophyte species experience drought, salinity and high temperature stresses in their growth period, and sensitivity to any of these may affect plant tolerance to others. Among halophytes, *Kochia scoparia* have recently considered as forage and fodder crop in marginal lands. In order to evaluate interaction of saline water application and water deficit effect on growth parameters, water-salinity production function and physiological parameters, a series of experiments were conducted with different levels of saline water (1.5 to 42 dS/m) and different levels of applied water (25 to 125% of the water requirement) in the farm and greenhouse. Results showed that Kochia like other halophytes is sensitive to drought and salinity at the earliest stages of growth. Salinity reduced linear phase of growth and decreased biomass production but salinity tolerance of Kochia was improved by increasing water application. Evaluation of yield response factor under water deficit and salinity showed that there is not any significant difference among water deficit treatments up to 21 dSm^{-1}. There was no significant difference in biomass of medium drought stress and control. Plants showed more tolerance against drought stress, when stress was induced in the whole growth season. In all experiments, ecotypes from the arid regions, revealed a better response to drought and salinity. Under severe drought and salinity, Kochia still could produce up to 16 and 8 t DM ha^{-1} biomass in 2009 and 2008, respectively. Salinity tolerance of Kochia was improved by increasing water application. Results of water depletion from different soil layers showed that Kochia uptakes more water from the 30-60 cm soil depth. The soil salinity (EC_e) of this section was lower in comparison to the 0-30 cm soil depth. Additionally, the water uptake of the 30-60 cm soil depth improved the salt tolerance level of Kochia. At 75% application of water requirement, Kochia produced 90% of biomass in comparison to 100% water application. Therefore, deficit irrigation is a useful management technique for Kochia even under saline conditions. The results of the present study demonstrated that some indices regarding growth of Kochia and probably other halophytes under salinity, drought and their combination should seriously be revised. Kochia also could be considered as a forage crop or biofuel material by using saline water in semi-arid areas.

Introduction

Drought and salinity are the most important environmental factors inhibiting photosynthesis and decreasing growth and productivity of plants in many parts of the world. They are the major causes of crop loss worldwide, reducing average yields for most major crop plants by more than 50% (Ashraf, 2004, Qadir, 2008; Naz *et al.*, 2010). Almost all area of Iran affected by aridity and crop production without irrigation is not possible and about 34 million ha, including 4·1 million ha of the irrigated land, are salt-affected in Iran as the consequence of naturally occurring phenomena and anthropogenic activities. The annual economic losses due to salinisation in the country exceed US$ 1 billion (Qadir *et al.,* 2008).

Conventional water resources and crops do not meet all the requirements of human societies living in dry and saline areas. Using seawater or brackish water and salt tolerant crops may be options to be considered, since there could be a greater focus on developing halophytes as cash crops in the future (Breckle, 2009). Kochia (*Kochia scoparia* L. Schrad) is a rapidly emerging and growing plant with potentially high yield that is widely adapted to many parts of Iran (Kafi *et al*., 2010). The drought and salt tolerance of Kochia indicate that it could be an important forage crop in arid and semiarid areas. It may provide a good source of forage by using saline water for irrigation in dry regions (Al-Ahmadi and Kafi, 2007). The nutritive value of Kochia, harvested at or before full bloom, and alfalfa (*Medicago sativa*), harvested at 20% bloom is quite similar (Knipfel *et al*., 1989). Coxworth & Salmon (1972) reported that Kochia seed might be a useful source of protein (29%), oil (10%) and energy for a variety of domestic animals. Jami Al-ahmadi & Kafi (2007) showed that salinity up to 10 dS m^{-1} did not have considerable effect on seed germination. Extreme reduction of germination occurred at 20 dS m^{-1}, but more than 35% of seeds still germinated. Several studies indicate that tolerance to saline irrigation water do change as the crop develops and matures (Maas *et al*., 1986; Maas & Poss, 1989; Ahmad *et al*., 2010). A better knowledge on how salt tolerance changes during some stages of growth may improve new strategies for the utilization of saline drainage water.

Domestication of salt tolerant plants which grow naturally in saline land could be introduced as new crops cultivated under environmental stresses induced by salinity and aridity. Several researchers showed that *Kochia scoparia* produces high biomass in saline-sodic soils or saline-sodic irrigation water (Green *et al.,* 1986; Qadir & Oster, 2004; Steppuhn *et al*., 2005; Ahmad *et al.*, 2011). In addition to its halotolerant, because of its deep rooting systems, Kochia is exceptionally drought tolerant (Madrid *et al*., 1996).

Despite the negative impacts, irrigation is critical to sustaining and increasing agricultural production. While about 17% of agricultural land worldwide is irrigated, this 17% accounts for about 40% of the total global food harvest (FAO, 2002). Moreover, per capita arable land has decreased over the years, from a worldwide average of 0.38 ha in 1970 to 0.28 ha in 1990, and some analysts project a further decrease to 0.15 ha in 2050 (Ghassemi *et al*., 1995). Hence, increased production must come from increased average yields, increases that will be possible only through high-yielding irrigated agriculture (Skaggs *et al*., 2006).

Optimum soil moisture for plant growth varies with the stage of crop growth. Certain periods of crop growth and development are more sensitive to soil moisture stress compared with others. Inadequate water supply during sensitive periods will irrevocably reduce the yield (Naz *et al.*, 2010b). On the other side this sensitive periods for salinity stress are not necessarily coincide, for instance the reproductive growth stages are more tolerant to salinity while they are more sensitive stages for some crops (panicle initiation, heading, flowering for rice, heading and flowering for pearl millet, flowering, seed formation for soybean and commencement of fruit set for tomato). Hence, the objectives of this study were to determine the sensitivity of Kochia to salinity and drought stress at different growth stages and determine best time to start using saline irrigation water.

Materials and Methods

We have done different experiments in 3 location with different climate, namely Gorgan (semi-humid region), Mashhad (Semi-arid Region) and Birjand (arid region). Two field experiments were arranged to grow Kochia as a summer crop in 2008 and as a spring crop in 2009. The field site was located at Mazrae Nemoneh Research Station of Golestan Province close to the Caspian Sea in northern Iran. The mean annual rainfall in this region averages 330 mm of which more than 80% occurs in autumn and winter from November to April. The accumulated rainfall during the 2008 and 2009 experiments equaled 51 and 165 mm, respectively. The growing season temperatures range from 0 to 40ºC. The relative humidity of this area is 70%. The soil consisted of 24% clay, 14% sand, 62% silt. The field was equipped with a sub-drainage system. Kochia was sown in the first week of July 2008 for summer cropping and in the first week of April 2009 for spring cropping.

The experiment was arranged by a randomized complete block design with split plot layout considering water quality as the main plot and application of water requirement as subplot with three replications in 2008 and 2009. The saline water consisted of six levels of irrigation water salinity 1.5 (S_1), 7 (S_2), 14 (S_3), 21 (S_4), 28 (S_5), and 35 (S_6) dS/m in 2008 and 2009. Water quantity consisted of three levels of irrigation water providing 25 (AW_1), 75 (AW_2), and 125 (AW_3) percent of the calculated water requirement in 2008 and four levels of irrigation water providing 50 (AW_1), 75 (AW_2), 100 (AW_3), and 125 (AW_4) percent in 2009.

The saline waters for the different irrigation salinity levels were got by mixing various ratios of non saline (0.9 dS/m) and drainage (325 dS/m) waters. The seeds received from Sabzevar city of Khorasan province and sown at density of 20 plants/m^2. In order to achieve proper establishment, the first two irrigations applied using good quality water. Total water application (irrigation and rainfall) for each level of drought stress was 266.5, 330 and 489.8 mm, respectively. Sampling was conducted 100 days after planting for leaf dry weight (LDW), lateral stem number (SN), height (H), stem dry weight (SDW) and at ripening stage for seed yield (Y) and biomass (BIO) production.

Soil samples were taken twice a week for monitoring the soil moisture depletion from non stress treatment. Soil samplings were done eight times in soil depths of 0-30 cm, 30-60 cm, and 60-90 cm during the season for evaluating the soil salinity and the water content. At the mid flowering stage, the Kochia plants were harvested from 0.165 m^2 in spring and summer cropping, respectively. The dry weight of the plant materials was measured after drying for three days at 72°C.

In Mashhad experiments seeds were directly sown in the soil at the Research Farm of the Center of Excellence for Special Crops of the Ferdowsi University, located 20 km east of Mashhad, Iran, in May 2008. The climate of the experiment site is semi-dry, with annual precipitation of 259 mm. The average relative humidity of the location during the growth period of Kochia (June to September) was 34%. Both experiments were arranged in a split plot based on a completely randomized block design, with 3 replications. In the irrigation regime experiment, the main plots underwent four irrigation regimes, which included complete irrigation (100%), 80%, 60%, and 40% of water requirements; two local populations of Kochia, namely, Sabzevar and Borujerd, were allocated to the subplots. In the salinity experiment, irrigation with water having EC of 5, 15, and 20 dSm^{-1} were allocated to the main plots and two populations of Kochia, namely, Sabzevar and Indian genotypes, were arranged as subplots.

In another series of experiments in order to investigate the method and time of salinity application and maximum tolerant of Kochia, three experiments was arranged with salinity levels (0, 10, 20, 30, 40, 50 and 60 $dS.m^{-1}$) gradually applied (2 $dS.m^{-1}day^{-1}$) at different growth stages (planting and early seedling) in Mashhad Area.

Result and Discussion

Ameliorative interactions of drought and salinity: Saline water imposed a significant effect on main stem height (H), stem dry weight (SDW), biomass (BIO), seed yield (Seed Y), leaf dry weight (LDW) and Total dry weight (PDW). Drought stress had significant effect on LDW and PDW. Interaction effect of salinity and drought stress was not significant (Table 1).

With increasing salinity higher than 7 dS/m significant reduction was observed in all measured traits. Deficit irrigation caused a significant reduction on LDW and TDW. At 35 dS/m salinity seed yield and TDW showed 50% and 47% reduction compared to control, respectively. The highest dry matter production was achieved at 7 dS/m but it was not significantly different compared to control. Plant height had 74% reduction at 35 dS/m compared to control (Table 1).

Effect of drought stress caused a significant reduction only on LDW and TDW (Table 1). In another experiment increase of irrigation interval from 7 to 14 days caused only 25 percent yield reduction in arid climate of Birjand (Kafi & Al-Ahmadi, 2008).

Table 1. Effect of different water application and salt stress on height (H), lateral stem number (SN), stem dry weight (SDW), seed yield (seed Y), leaf dry weight (LDW) and plant dry weight (PDW) in summer cropping of Kochia.

Saline water	H (cm)	SDW (g/m^2)	Seed Y (g/m^2)	LDW (g/m^2)	TDW (g/m^2)
1.5	123 a	1101.8 a	333.34 a	678.21 a	1342.1 a
7	117.5 ab	965.81 a	306.49 ab	770.58 a	1393.9 a
14	113.7 bc	702.96 b	252.66 bc	567.87 bc	1193.9 ab
21	109 c	693.21 b	249.26 bc	504.27 c	1017.4 bc
28	107.1 c	612.71 b	207.95 dc	445.62 c	1013.9 bc
35	91.1 d	546.01 b	167.5 d	441.56 c	883.1 c
deficit irrigation					
25%	108.3a	796.85 a	246.4 a	507.2 b	1098.4 b
75%	111.8 a	759.12 a	260.9 a	498.9 b	1053.2 b
125%	110.8 a	755.32 a	251.2 a	697.9 a	1270.4 a

Interaction effect of salinity and drought stress was not significant. The highest seed yield measured at 1.5 dSm^{-1} and 75% of irrigation requirement and the highest plant dry weight harvested at 7 $dS^{-1}$and 125% water application. At highest level of salinity (35 dSm^{-1}) increasing water consumption had no effect on seed yield production but at 14, and 28 dSm^{-1}, seed yield increased with increasing water use. As the salinity of irrigation water increase, the effectiveness of quantity of water decreases, but the degree to which the quantity is diminished is dependent on the crop to be irrigated and the relative yield to be achieved (Letey, 1993). It seems that effect of additional water use on reducing negative effects of salt stress is depending on crop salt tolerance. Kochia is so salt tolerant that only 50% seed yield reduction occurred at 35 dS/m of irrigation water (Salehi *et al*., 2009) and 50% reduction of plant dry weight was calculated at 38.16 ± 3.53 dSm^{-1}. Using 7 dS/m of saline water and 50% of water requirement application will cause only 13% reduction in seed yield.

The interaction effects of salinity and drought might not be additive or multiplicative and it might be even ameliorative. Plants under salinity stress will produce less transpirative area (leaves), so plant can manage drought more efficient. Drought might limit the water in the surface layer of the soil so that plants will send their roots to the deeper soil layers and the salt concentration at that layer might be lower than upper layers.

Compatibility of soil and irrigation water salinity: Evaluation of salt accumulation in soil profile showed that the highest salt accumulation observed at 0-30 cm of top soil at all levels of salinity (Fig. 1). Results of water depletion from different soil layers showed that Kochia uptakes more water from the 30-60 cm soil depth. The soil salinity (EC_e) of this section was lower in comparison to the 0-30 cm soil depth. As shown in Fig. 3, when an experiment arranged in a non saline or low saline soil, application of saline water accumulate in the soil until equilibrium is achieved and plants receive lower salinity than applied water salinity Therefore, field experiments should be continued for more than a season to adjust soil salinity with irrigation salinity.

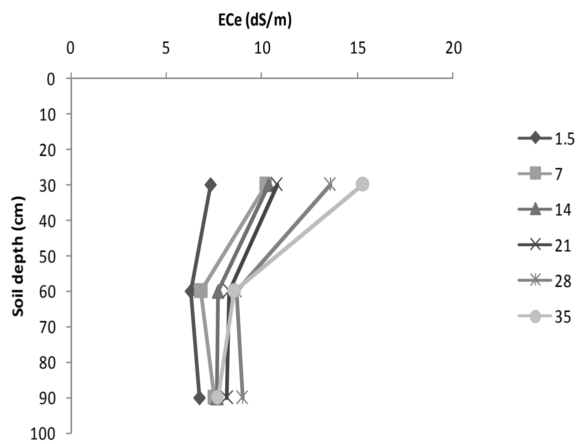

Fig. 1. Salt distribution in soil profile under cultivation of Kochia.

Kochia water productivity increased as the application of irrigation water decreased. In the same salinity level, the highest water productivity was observed at 50% water use. In non saline and drought stress, water productivity was 13.04 kg mm^{-1}. The lowest WP observed at 35 dS/m salinity and 125% water use, and it was 3.21 kg mm^{-1} (Fig. 2).

Salinity reduced water productivity and crop coefficient. Evaluation of yield response factor under water deficit and salinity showed that up to 21 dS/m there were no any significant differences among water deficit treatments, and then water deficit management can be used in Kochia.

Revision of water requirement calculation: Water requirement for stressed plants are different from normal plants, one might calculate leaching requirement to keep the salinity of soil solution at a fix level, on the other side growth duration and volume of the stressed canopy that transpire are quite lower than normal condition. Both transpiration rate and transpiration area in Kochia decreased by salt stress, in all growth stages higher salinity caused a lower transpiration rate in Kochia.

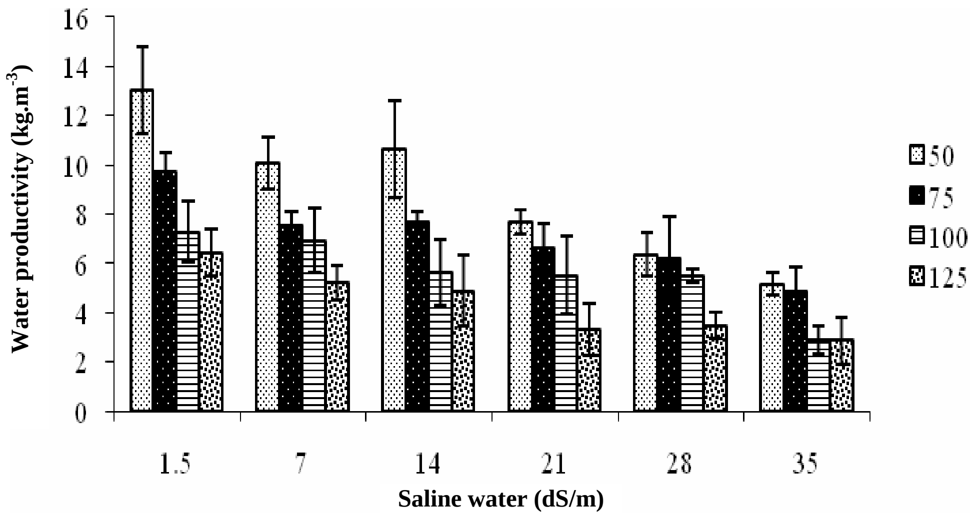

Fig. 2. Water productivity of Kochia at different salinity and water application in spring cropping.

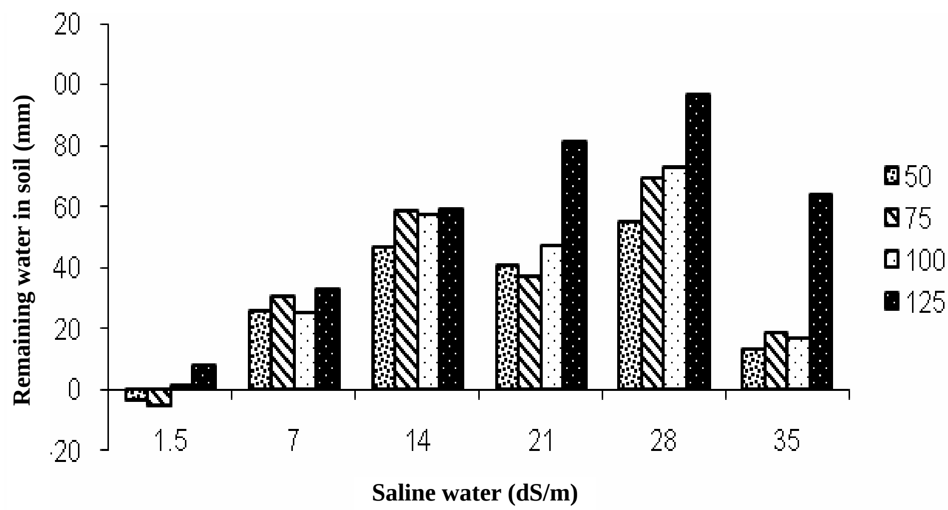

Fig. 3. Remaining water in soil at different saline water and water deficient (Data are average of three soil layers, 0-30, 30-60, 60-90) in spring cropping.

Decreased leaf production due to limited irrigation caused lower photosynthetic area and consequently decreased dry-matter production correspondingly, but there was no significant difference between control and 80% limited irrigation of Kochia (Kafi *et al*., 2010). Fresh weight and dry-mass production of *K. scoparia* were greater when they were grown under complete irrigation than those under reduced irrigation conditions (Table 2). Deficit irrigation treatment of 60% and 40% produced only 66.6% and 44.6% of the shoot dry matter of the control plants; in water-limited conditions, it is still acceptable to record 5895 kg ha^{-1} fodder by application of only 40% water requirement.

Therefore, a revision is needed for calculation of crop coefficient of halophytes and glycophytes under stress. Soil water content after crop harvesting shows that how much water was extra than crop requirement. As shown in Fig 3 considerable amount of water remained in the soil which indicates this water was not necessary for its growth and even it mat cause some water lodging as well. Therefore it is possible to apply less water to the soil.

Effect of climate on stress tolerance: As mentioned by other researchers climate is an important factor to salinity and drought tolerance, the negative impacts of salinity and drought increase by decreasing the humidity of the environment. We have done a work in Mashhad which is a semi-dry area and in Gorgan which is relatively a humid area and observed higher biomass production in Gorgan in the same levels of salinity.

Season of stress application and time of sowing: The effects of salinity and drought are directly related to the time of sowing. In the condition of Gorgan, one or two irrigations are needed for establishment of plants in summer cropping and after establishment of plants the 10-15 cm plant height stage is suitable for starting irrigation with high saline water (Salehi *et al*., 2009). But in spring cropping it is possible to directly start irrigation with saline water because the winter and spring precipitation lowered the salinity of the soil below the germination threshold of Kochia. As shown in table 2, as much as the growth of kochia overlapped with spring weather the biomass production will be higher.

Table 2. Shoot dry biomass of Kochia irrigated with 6 levels of saline water and 4 and 3 levels of water application in 2009 and 2008, respectively. Each point is the average of 12 data for salinity and 18 data for irrigation treatments.

Salinity (dSm^{-1})	Gorgan		Mashhad
	Summer 2008	Spring 2009	Spring and summer 2008
	Shoot dry biomass (g/m^2)		
1.5	1342.1 a	3439.6 a	
7.0 (5)†	1393.9 a	2955.1 ab	854.3a
14.0 (15)	1193.8 ab	2701.2 bc	830.0a
21.0 (20)	1013.9 bc	2321.4 c	753.0b
28.0	1017.4 bc	2199.6 c	
35.0	883.1 c	1592.0 d	
% of water requirement application			
125(100)	1098.41 B	2572.4 A	1322.0
100(80)	1053.26 B	2714.2 A	1242.0
50(60)	1270.48 A	2573.6 A	874.3
25(40)		2279.1 A	589.5

† Numbers in parenthesis are electrical conductivity and % of water requirement application of Mashhad

Method and stage of stress application: To evaluate the effects of abiotic stresses solely or in combination the plant growth stage and the method of salt application is important in the response of plant to that stress. For instance, if salinity applies gradually, Kochia could tolerate up to 60 dSm^{-1} salinity.

Increasing salinity gradually at early seedling growth stage and at sowing caused a reduction in plant height, and shoots fresh and dry weight, but even in 60 dSm^{-1} plants could survive and produced some dry matter. Generally, seedling establishment improved by gradual increase of salinity and increase salinity at sowing time had negative effete on Kochia growth compared with early seedling stage so that Kochia be able to tolerate salinity up to 60 dSm^{-1} with increase salinity gradually at early seedling stage (Table 3). The results showed that increasing salinity gradually at planting and early seedling decreased plant height, branch number, shoot fresh and dry weight, digestible dry matter, digestive value, and crude protein yield. Generally, seedling establishment improved by gradual increase of salinity and increase salinity at planting stage had negative effete on Kochia growth compared with early seedling stage. Kochia can tolerate salinity up to 128 dSm^{-1} with increase salinity gradually at early seedling stage.

Table 3. Plant height and shoot dry weight of gradual salinity application from sowing and from seedling growth stages up to flowering stage.

From sowing to harvest	Salinity (dS/m)						
Trait	**Control**	**10**	**20**	**30**	**40**	**50**	**60**
Height (cm)	103.5	84.0	66.0	78.1	69.0	62.0	49.0
Shoot dry weight (g/P)	51.2	39.7	17.8	17.4	15.5	13.8	9.9
From seedling to harvest							
Height (cm)	91.5	79.3	69.8	56.5	61.0	54.0	54.3
Shoot dry weight (g/P)	57.8	34.3	34.7	22.4	19.8	21.1	19.3

Distinguish between glycophytes and halophytes: Judgment about negative effects of salinity and drought in halophytes should be different from glycophytes. The levels of salinity and drought that may be injurious in glycophytes, they might be normal for halophytes. In the case of Kochia cutting up to 50% water requirement and increasing salinity up to 20 dSm^{-1} will reduce the yield less that 25%.

Conclusion

Salinity stress beyond 7 dS/m imposed a significant negative effect on seed yield and dry matter production of Kochia but effect of drought stress was not significant on dry matter production up to 50% reduction of water application. Water productivity decreased with increasing salinity and but increased with deficit irrigation. The highest WP observed at 7 dSm^{-1} and 25% water use, in this treatment 13% reduction of seed yield observed compare to control. This approach is so useful for poor farmers who access to low quantity and quality soils and waters. Increasing water consumption at high salinity (35 dSm^{-1}) did not have any compensative effect on seed yield but increasing water use at lower salinity increased yield to some extent. Using saline water (28 and 35 dSm^{-1}) increased soil salinity after harvest and reduced emergence rate of Kochia for next season, in addition extra water application washed out the accumulated salts from root environment. Although Kochia can tolerate high saline water but sustainable use of soil resources should be considered.

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