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Possible utilization of high-salinity waters and application of low amounts of water for production of the halophyte *Kochia scoparia* as alternative fodder in saline agroecosystems

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ABSTRACT

Production of halophytes using saline waters and soils and feeding them to livestock is one of the most sustainable methods of conservation in desert ecosystems, in addition to accomplishing food production for the people living in these areas. Therefore, to study the possibility of irrigating Kochia (*Kochia scoparia* L. Schrad) with minimum quantities of highly saline water for use as a fodder crop in arid environments stretching across saline waters, two experiments were carried out in the Research Farm of the Ferdowsi University of Mashhad, Iran. In the salinity experiments, two populations of Kochia, including the Sabzevar and Indian genotypes, were irrigated with ground water having electrical conductivity (EC) of 5, 15, and 20 dS m^{-1}. In the irrigation-treatment experiments, two local populations of Kochia, including Sabzevar and Borujerd, were subjected to four irrigation regimes as follows: complete irrigation (100%), 80%, 60%, and 40% of the water requirements using a saline ground water with EC = 5 dS m^{-1}. Because, the Indian genotype is preferred as an ornamental plant, it is not suitable for increased dry-matter production under high-salinity irrigation water compared to the local genotype (Sabzevar), which is suitable for forage. The Sabzevar genotype produced a large amount of dry matter (7530 kg ha^{-1}), even when irrigated with 20 dS m^{-1} saline water. The best time for harvesting Kochia for fresh feeding is at the end of flowering (88 days after sowing or DAS), when the biomass is relatively high (6500 kg ha^{-1}) and the leaf-to-shoot ratio, as a quality index, is approximately 50%. The highest green-area index was observed at 15 dS m^{-1} and decreased at high levels of salinity. Photosynthesis and transpiration rate did not decline significantly with increasing external salinity four weeks after salinization, but increased in both genotypes at 15 dS m^{-1}, indicating that the salinity-tolerance threshold of Kochia for both photosynthesis and transpiration reduction is above this salinity level. The Indian genotype also showed a very low seed yield (210 kg ha^{-1}) at low levels of salinity, whereas Sabzevar produced 1120 kg ha^{-1} seed under the same conditions. Different irrigation regimes had a significant effect on the biomass and seed production of Kochia. The highest forage yield was obtained from complete irrigation, with 11.1 Mg ha^{-1} dry material. Sabzevar local population represented a better performance in terms of all characteristics, except accumulation of inflorescence dry matter, and no significant effects were recorded. In conclusion, Kochia's high foliage production capacity in the presence of salinity and limited irrigation make this plant suitable for use as an alternative forage crop in harsh environmental conditions. There is a wide range of intraspecific variation in *K. scoparia*, but more investigation is needed to introduce it as a cash crop.

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1. Introduction

In all areas where irrigation is necessary for crop production, salinization of soil is also unavoidable. Therefore, to guarantee the continuation of crop production in such areas, growing crop species with threshold of yield reduction well above the salinity of the irrigation water is needed (Munns and Tester, 2008). Conventional crops are not halophytes; thus, their yield and even their life might be threatened under such saline conditions, and this is the main cause for the destruction of agricultural systems in societies where saline water is used for irrigation (Khan et al., 2009). Recent trends and future projections suggest that the need to produce more food and fiber for the expanding population will lead to an increase in the use of salt-prone water and land

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resources for crop-production systems, and this will be met by using salt-tolerant crops or halophytes (Khan et al., 2009; Yensen and Biel, 2006).

Biosaline agriculture is now becoming a reliable strategy for using saline environment. The first patent for a halophyte crop was issued less than 20 years ago, and at present, crops are being developed by classical breeding, biotechnology, tissue culture, and plant exploration (Yensen and Biel, 2006; Qureshi et al., 2007).

O'Leary et al. (1985) pointed out that halophytes irrigated solely with seawater have great potential as crop plants, in spite of a few problems such as the high salt content of tissues. Miyamoto et al. (1994) in a study of water use and salt-uptake responses of four halophytes, including *Atriplex nummularia* Lindl., *Distichlis palmeri* Fassett, *Batis maritima* L., and *Suaeda esteroa* Ferren & Whitmore, reported that these halophyte species can be grown productively at a leaching fraction of 0.30 or less when the salinity of the irrigation water is less than 10 g l^{-1}.

Kochia (*Kochia scoparia* L. Schrad) is a salt- and drought-tolerant species, an annual plant of the family Chenopodiaceae, which can be a valuable source of fodder grown using saline water (Danesh Mesgaran and Stern, 2005; Riasi et al., 2008). Riasi et al. (2008) reported that *K. scoparia* and *Atriplex dimorphostegia* have more number of beneficial chemical nutritive components and digestible values than *Suaeda arcuata* as forage for ruminants. Steppuhn and Wall (1993) claimed that Kochia offers great potential as a crop that can be grown on saline soils, yielding fodder in quantities approaching that produced by alfalfa (*Medicago sativa* L.). Shamsutdinov et al. (1996) also reported more than 15 Mg ha^{-1} dry-matter production for Kochia under saline conditions and concluded that it is a good candidate for forage hay. Coxworth and Salmon (1972) proposed the use of Kochia seed as a component of the diet of turkey poultry.

Farmers in some arid areas of the world have already begun to cultivate Kochia as a salt-tolerant forage crop on lands where other crops are difficult to grow; accordingly, Kochia has been called "the poor man's alfalfa" (Undersander et al., 1990; Kafi and Jami Al Ahmadi, 2008). The fast vegetative growth and drought- and high-temperature tolerance of Kochia indicate that this plant has a high potential to be adopted as an important forage and fodder crop, especially in desert areas (Jami Al Ahmadi and Kafi, 2008a). The possibility of converting Kochia from a wild pioneer plant to a cultivated annual forage crop has been considered by many workers, including Coxworth et al. (1988), Steppuhn and Wall (1993), and Jami Al Ahmadi and Kafi (2008b).

Germination tests of Kochia seeds were evaluated under different levels of salinity (0–20, 5 dS m^{-1} intervals) and temperatures (10–40 °C). The results showed that Kochia can adjust its germination to a wide range of temperatures, from 3.4 °C (T_{base}) to 49.7 °C (T_{max}), with the optimum germination temperature of 24 °C (Jami Al Ahmadi and Kafi, 2006, 2007). Steppuhn and Wall (1993) tested the germination of Kochia seeds in saline solutions, with salinities reaching up to 30 dS m^{-1}, and reported that germination of this plant reduced 3.3% per 1 dS m^{-1} increment of salinity between 12 and 30 dS m^{-1}. Khan et al. (2001) reported that a few seeds of this plant germinated even at 1000 mmol/L NaCl. Growth and development of Kochia were tested in the field at three levels of irrigation-water salinity (1.5, 8.6, and 28.2 dS m^{-1}). Salinity negatively influenced most of the morphological and physiological indices of the plant; yet, the dry-matter accumulation under the highest salinity level reached 60% of that in plants grown at lower saline levels, and even moderate salinity caused a small amount of stimulus in the plant's growth and yield performance (Jami Al Ahmadi and Kafi, 2008a,b).

Although Kochia is not grown for seed production, its seeds contain considerable amounts of protein (20–25%) and oil (8–10%). Moreover, in some countries such as Iran, in addition to fodder production, the dried branches of this plant are harvested at the ripening stage for use as a broom for open-space cleaning, for example, cleaning public avenues. Our study aims to evaluate on an experimental basis the effects of different levels of irrigation-water salinity and regulated irrigation regimes on growth, green-area index (GAI), photosynthesis, transpiration, fodder and seed production, and protein content of three genotypes of *K. scoparia*—two local (Iranian) and one Indian populations.

2. Materials and methods

2.1. Plant material and location

The seeds of the Indian genotype were obtained from Khan Seed Store, New Delhi, and the Sabzevar and Brujerd genotypes were collected, respectively, from Mashkan village and Brujerd, Iran, and were stored in paper bags at 6 °C at a seed store until sowing. 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 2007. This station, located at latitude 36°18′11″N and longitude 59° and 46′19″E, has a geographical altitude of 985 m above sea level. The climate of the experiment site is dry, with annual precipitation of 259 mm and annual reference-crop evapotranspiration of more than 1300 mm (Dinpashoh, 2006). The average relative humidity of the location during the growth period of Kochia (June to September) was 34%. During the course of the experiment, rainfall did not exceed 2 mm, and the soil–water reserve was ignorable. Therefore, the total water requirement of the plants was matched by the irrigation water. The soil had a loamy–silty–clay texture, with reasonable water-holding capacity. The results of soil analysis are presented in Table 1. The clay, silt, and sand contents of the soil were 39%, 46%, and 15%, respectively, and the acidity and electrical conductivity (EC) of the soil extract were 7.7 and 12.4 dS m^{-1}, respectively. The source of irrigation water for both irrigation-treatment experiment and low-level salinity experiment was the water pumped from a deep well near the site (Table 1). For the remaining two higher levels of salinity, water was transferred by tankers from ground sources in the same basin, within a distance of 5 km. Chemical analysis of the water resources in terms of the three levels of salinity was carried out, and the main difference was in the chloride and sodium contents of the samples (Table 1). Low salinity level (EC = 5 dS m^{-1}) played the role of control because previous experiments have shown that Kochia showed a better performance under moderate salinity (8.6 dS m^{-1}) compared to that in fresh water (1.5 dS m^{-1}) (Jami Al Ahmadi and Kafi, 2008a,b).

2.2. Experimental design and treatments

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, Iran, were allocated to the subplots. In the salinity experiment, irrigation with water having EC of 5, 15, and 20 dS m^{-1} were allocated to the main plots and two populations of Kochia, namely, Sabzevar and Indian genotypes, were arranged as subplots. Each plot (2.5 m × 5.0 m) consisted of five rows with distances of 50 cm between the rows and 10 cm between the plants in the row; therefore, the density was 20 plants m^{-2}. Low-salinity water was used for sowing, and the first irrigation and treatments started three weeks after sowing when the plants were in the 6-leaf stage. Seeds were sown on 30th May, and the final harvesting was on the 27th of September 2007. The plants were watered 12 times during the experiment from sowing up to the

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Table 1
Main chemical properties of soil (0–30 cm), and applied irrigation waters at the study site.

Water source	Na (meq l^{-1})	Ca (meq l^{-1})	Mg (meq l^{-1})	K (meq l^{-1})	SO_4 (meq l^{-1})	CO_3 (meq l^{-1})	HCO_3 (meq l^{-1})	Cl (meq l^{-1})	EC (dS m^{-1})
Low saline water	32.50	8.60	9.20	0.23	15.00	0.40	2.40	34.40	5.0
Medium saline water	67.10	16.4	22.2	0.38	35.00	0.00	3.00	75.60	15.0
High saline water	129.80	27.00	46.80	0.31	35.00	0.20	2.60	176.80	20.1

physiological ripening, and the method of irrigation was furrow irrigation. The irrigation interval was 8–12 days based on the growth stage and potential evapotranspiration. To avoid osmotic shock of salinity, saline treatment was imposed incrementally, starting at 5.0 dS m^{-1} at sowing then to 10 dS m^{-1} at 14 days, to 15 dS m^{-1} at 14 days and finally to 20 dS m^{-1} at 21 days after sowing.

The reference-crop evapotranspiration (represented by ET_o) was calculated based on the Hargreave's method (see Allen et al., 1998; Villalobos et al., 2002). The Hargreave's method was developed in 1985 for use when the climatic data was not easily accessible. This method provides reasonable ET_o results with a global validity between empirical models and is also authorized by the Food and Agriculture Organization (FAO) (Allen et al., 1998):

$$ET_o\,(\text{mm day}^{-1}) = 9.388 \times 10^{-6} \times RA\,(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5}, \qquad (1)$$

where T_{max}, T_{min}, and T_{mean} are the maximum, minimum, and mean daily temperatures, respectively, and RA is the extraterrestrial radiation (MJ m^{-2} day^{-1}).

The initial crop coefficient ($K_{C\,ini}$) was calculated as a function of the irrigation frequency and reference-crop evapotranspiration (Villalobos et al., 2002):

$$K_{C\,ini} = 2(IL)^{-0.49} \exp[(-0.02 - 0.04 \ln IL) ET_{o1}], \qquad (2)$$

where IL is the irrigation interval (day), and ET_{o1} is the average reference-crop evapotranspiration during the initial period. Calculating the K_C for other growth stages was carried out based on the method recommended by the FAO (Allen et al., 1998). The total water application was 8000 m^3/ha, which was applied 12 times during the growth season and was the same for all salinity treatments. In the irrigation experiments, water application was reduced based on the percentage of reduction in water requirement; this amount was reduced from the volume of 100% irrigation for each irrigation step, but the number of irrigation processes was fixed. The volume of water applied for each irrigation protocol was measured by a volumetric counter (Jami Al Ahmadi and Kafi, 2008b).

2.3. Measurement of plant growth

Sampling started at 14 days after salt application (35 DAS) and continued up to the ripening stage, conducted at two-week intervals. Three plants were cut from the ground surface and, after measurement of the fresh weight of the shoots, were separated into leaves, stems, and inflorescences (if applicable) precisely. The GAI (leaf + stem + florescence) was measured thrice—two weeks after salinization (preflowering; inflorescence with well-developed flower buds, but no open flower), at flowering, and two weeks after flowering. After measurement of the green area using a leaf area meter (Model LI-31 DOC, LI-COR, Lincoln, Nebraska), the samples were oven-dried at 75 °C for 72 h and then weighed using an electronic balance. In the last sampling that coincided with the ripening of seeds, the seed yield was also determined. Data of shoot, leaf, and stem dry matter, in addition to the protein yield in limited irrigation experiments was collected at the time of full flowering, during which period high-quality fodder could be harvested, whereas the data related to seed-yield measurement was collected at ripening (50% of the area of each plot was reserved for seed-yield measurement). Forage protein was determined by the Kjeldahl method of nitrogen measurement, and the nitrogen content was multiplied by 6.25 to change it to protein content.

2.4. Photosynthesis parameters

Gas exchange and relative parameters were measured thrice—49 (preflowering), 63 (flowering), and 88 (postflowering) DAS-using a portable leaf chamber analyzer (model LCA4, Analytical Development Company, England) at photosynthesis photon-flux density (PPFD) > 950 μmol m^{-2} s^{-1} between 10 a.m. to 12 noon. All measurements were carried out on the intact and youngest fully developed leaf, maintaining the chamber constantly vertical to solar radiation, until gas exchange in the leaf chamber was stabilized. At least 10 readings were obtained for each leaf after it reached the steady state. The chlorophyll content of the leaves was representatively estimated using a chlorophyll-content meter (Minolta, Model SPAD 502, Japan) simultaneously with the photosynthesis measurement, and the data for three points in the youngest fully expanded leaves of two plants were recorded.

2.5. Statistical analysis

Statistical analysis was carried out using the one-way analysis of variance or ANOVA; P values ≤ 0.05 were considered significant. Statistical significance, where indicated, is at least at the 5% level as determined by the analysis of variance and the Fisher's least-significant difference test.

3. Results and discussion

3.1. Salinity experiment

3.1.1. Biomass production

Because the main application of Kochia is as animal feed and the biomass above the ground is considered yield, the shoot biomass production is economically important. Although the sampling of dry-matter accumulation was carried out every other week, starting 35 DAS (two weeks after salinization), the harvesting at 88 DAS at the full-flowering stage, which coincides with the beginning of seed-setting, and at ripening (120 DAS) are more important for fodder and seed production, respectively. Fig. 1a and b shows the trend of biomass accumulation during the growth season. In all measurements conducted from 35 DAS (two weeks after salt application by the first irrigation with saline water) up to ripening, the Sabzevar genotype significantly produced higher dry-matter (biological) yield than the Indian genotype. No significant differences were found in the biomass production of the Sabzevar genotype at any stage of growth between salinities of 5 and 15 dS m^{-1}, which indicates the high salt tolerance of this genotype. These findings are in agreement with those of Ashour et al. (1997) and Ashraf and Harris (2004), who underlined the stimulating effect of moderate salinity on the growth and yield of halophytic grasses. Flowers et al. (1986) also reported that dicotyledonous halophytes show optimal growth at concentrations of 50–250 mM NaCl. The value 15 dS m^{-1} is present within this range. Ungar (1991) pointed out that lower dry-mass accumulation in the

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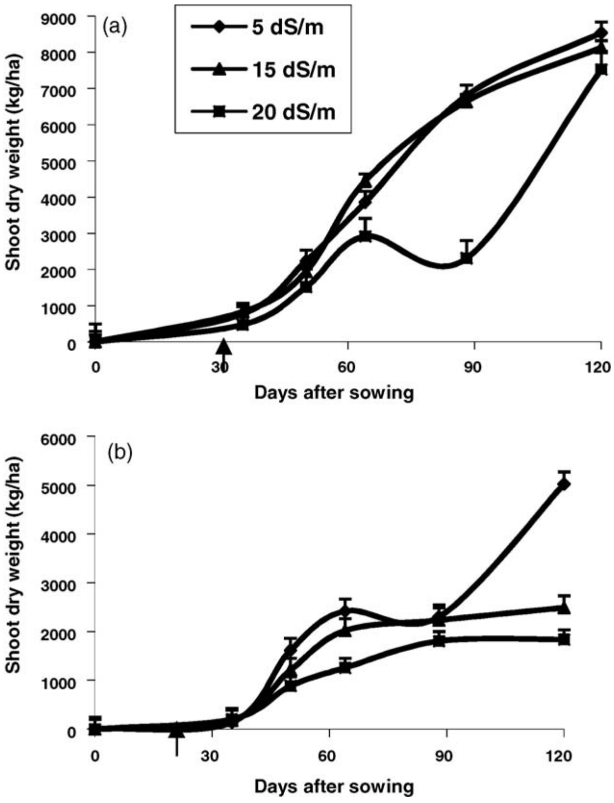

Fig. 1. Trend of shoot dry matter accumulation (kg ha^{-1}) of two genotypes of Kochia (a = Sabzevar and b = Indian) irrigated with three levels of saline waters (5, 15, and 20 dS m^{-1}) from 35 days after sowing (14 days after salinization) up to the ripening (120 days after sowing). Values represent mean ± s.e. and each point is the average of 3 measurements. Arrow indicates time of salt application (21 days after sowing).

absence of enough salt for halophyte growth may reflect a greater energy loss through respiration or a shift from anabolic to catabolic processes, and this might be the probable reason why Kochia could not produce more biomass in low levels of salinity compared to that at high levels.

Although, in the mid-growth season, the dry-matter production of the Sabzevar genotype decreased significantly at 20 dS m^{-1}, at harvest, this treatment also produced 7530 kg ha^{-1} biomass, which is only 12% less than the biomass production at 5 dS m^{-1} salinity (Fig. 1a). Dry-matter accumulation of Indian Kochia was reduced by moderate and high external salinities, and it was nearly half the value of that at low level of salinity (Fig. 1b). In this experiment, the growth season of Kochia was 120 days, but the bulk of the dry matter accumulated during the linear phase of growth, which was between 40 and 100 DAS.

The highest biomass production of the Sabzevar and Indian genotypes was 8543 and 5027 kg ha^{-1}, respectively, at low salinity level and at maturity (Fig. 2). In low levels of salinity, the biological yield of the Indian genotype was 58.8% that of Sabzevar, whereas at higher levels of salinity, the Sabzevar genotype produced four times more biomass than the Indian genotype (Fig. 2). The biomass production of Kochia in this experiment was lower than the biological yield reported by Shamsutdinov et al. (1996), who reported more than 15 Mg ha^{-1}, and Jami Al Ahmadi and Kafi (2008a), who reported 10,000 kg ha^{-1} dry-matter production for Kochia under saline conditions ranging from 1.5 to 28.2 dS m^{-1} in the arid areas of Birjand, Iran. This biomass production of Kochia could be comparable with the biomass production of conventional forage crops, such as alfalfa, in saline and dry areas, with conditions such as those in this experiment. O'Leary et al. (1985) pointed out that the growth rates of dicotyledonous halophytes can match those of glycophytes, with the annual dry-matter production obtained from field experiments on saline soils ranging between 0.08 and 18 t ha^{-1} yr^{-1}, although they applied energy for the accumulation and compartmentalization of ions required for osmotic adjustment (Yeo, 1983).

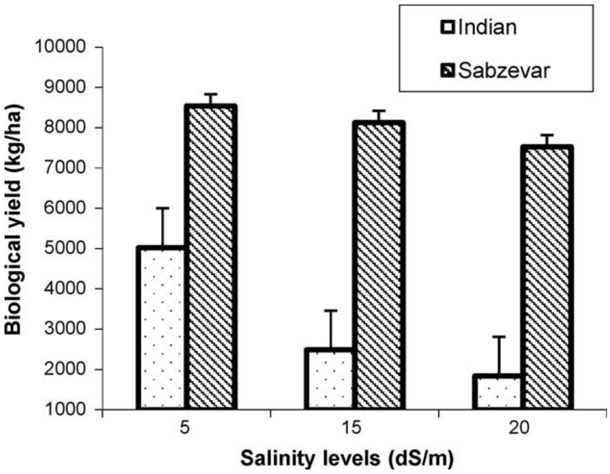

Fig. 2. Biological yield (kg ha^{-1}) of two genotypes of Kochia, irrigated with three levels of saline waters (5, 15, and 20 dS m^{-1}) from 21 days after sowing up to the ripening (120 days after sowing). Values represent mean ± s.e. and each point is the average of 3 measurements.

A pattern of response similar to that of shoot dry-matter accumulation was followed by leaf dry mass (Fig. 3). The quality of the shoots is determined by the leaves, and higher leaf production not only indicates higher economical yield, but also higher quality

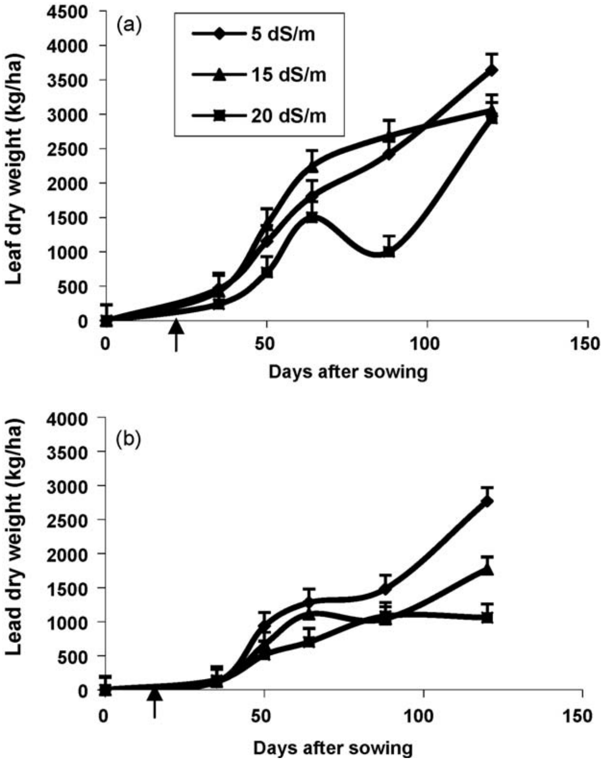

Fig. 3. Trend of leaf dry matter accumulation (kg ha^{-1}) of two genotypes of Kochia (a = Sabzevar and b = Indian) irrigated with three levels of saline waters (5, 15, and 20 dS m^{-1}) from 21 days after sowing up to the ripening (120 days after sowing). Values represent mean ± s.e. and each point is the average of 3 measurements. Arrow indicates time of salt application.

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of the fodder. Low and moderate salinities did not impose significant effects on the leaf production of Kochia shortly after salinization, but in the long term, a reduction occurs at moderate and high salinity levels (Fig. 3). The Indian genotype produced relatively higher leaf mass compared to that of the shoot, but it was still significantly lower than that of the Sabzevar genotype (Fig. 3), because the former genotype being grown mostly as an ornamental plant, needs more energy to manage salt compartmentalization and osmotic adjustment to overcome the salt stress; the increased leaf mass might be due to this demand (Flowers and Colmer, 2008). The energy demands of processes essential to salt tolerance in halophytes might be substantial (Yeo, 1983); energy would be consumed during ion transport to regulate net uptake and cellular compartmentation of Na^+ and Cl^-, in addition to being consumed for the synthesis of compatible solutes.

The leaf-to-shoot ratio shows the leafiness of the plant under different treatments; this parameter is shown in Fig. 4 for both genotypes. On the basis of our results at full flowering, which was the best time for harvesting Kochia for fresh feeding, the leaf-to-shoot ratio of the Sabzevar genotype is approximately 50%, and salinity did not cause a significant difference in this parameter, but at the ripening stage, it was reduced to less than 35%. This reduction might be mostly because of leaf senescence, defoliation, and translocation of assimilates from the leaves to the seeds (Koyro, 2006; Munns and Tester, 2008). In the Indian genotype, this ratio was significantly higher than that of Sabzevar, and even at the end of the growing season, it did not change significantly, because this genotype did not produce enough seeds to change the pattern of allometry from leaves to seeds. According to the results of Jami Al Ahmadi and Kafi (2008a), increasing salinity improved the forage quality of Kochia to some extent by restricting the stem growth and increasing assimilate partitioning to the leaves.

The Indian genotype did not produce enough seeds under any level of salinity, with the highest seed yield (210 kg ha) of this genotype being obtained at 5 dS m^{-1}, whereas under the same conditions, Sabzevar produced five times higher quantity of seed (1120 kg ha^{-1}) (Fig. 5), which indicates the potential of the Sabzevar genotype for seed production. Salinity caused a significant reduction in the seed yield of Sabzevar, but even at high levels of salinity, this genotype yielded 890 kg ha^{-1} seed, which is nearly 80% of the seed yield at 5 dS m^{-1} (Fig. 5). The seed yield of the Indian genotype dramatically decreased with increasing salinity and, at 20 dS m^{-1}, it produced only 40 kg ha^{-1}, 1, which is only 19% of the seed yield of this genotype at 5 dS m^{-1} (Fig. 5). This might be because, in India, this plant is selected as an ornamental plant; the leafier plants were selected by growers, and small amount of seed production was enough for plant propagation.

3.1.2. GAI comparison

Results showed that the Sabzevar genotype produced significantly higher green area than the Indian genotype (Fig. 6), and this plant continued leaf production after flowering by production of branches. The green area of the Sabzevar genotype increased with plant age, apart from the salinity level, and there were no significant differences in the GAI between the 5 and 15 dS m^{-1} levels in this genotype at any particular growth stage. Interestingly, the maximum GAI was observed at 15 dS m^{-1} and was decreased at high levels of salinity treatment (Fig. 6). Difference in the leaf areas between salinity treatments was mainly due to the differences in the numbers of leaves per plant. GAI of the Indian genotype reduced significantly under high salinity, which indicates the salt-stress susceptibility of this genotype (Fig. 6). When the salt concentration around the roots increases to a threshold level, the rate of leaf growth is reduced, new leaves emerge, and lateral buds develop more slowly or remain quiescent; thus, fewer branches or lateral shoots are formed (Munns and Tester, 2008).

3.1.3. Photosynthesis and transpiration rate

Net photosynthesis rate did not decline significantly with increasing external salinity after two weeks of treatment (preflowering), but it increased in both genotypes at 15 dS m^{-1} (Fig. 7). At the preflowering stage (49 DAS), there was a clear peak in the

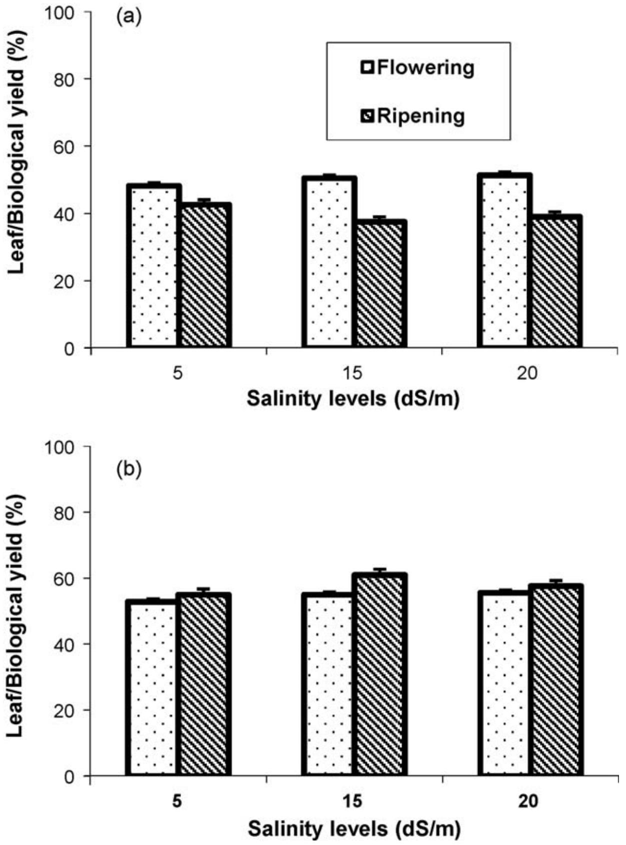

Fig. 4. Leaf to shoot dry matter ratio (%) of two genotypes of Kochia (a = Sabzevar and b = Indian) at the time of flowering and harvesting, irrigated with three levels of saline waters (5, 15, and 20 dS m^{-1}) from 21 days after sowing up to the ripening (120 days after sowing). Values represent mean ± s.e. and each point is the average of 3 replications.

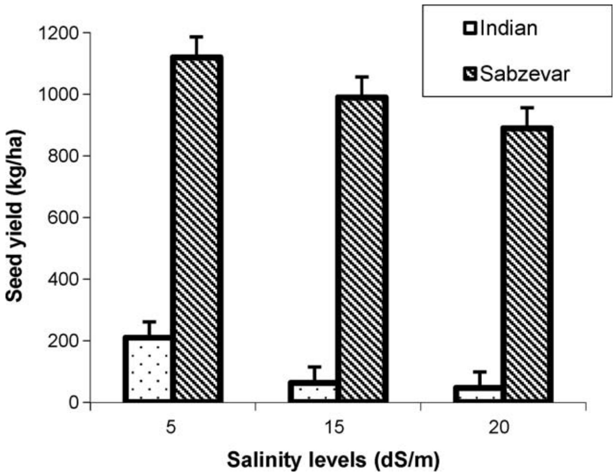

Fig. 5. Seed yield (kg ha^{-2}) of two genotypes of Kochia irrigated with three levels of saline waters (5, 15, and 20 dS m^{-1}) from 21 days after sowing up to the ripening (120 days after sowing). Values represent mean ± s.e. and each point is the average of 3 replicationd.

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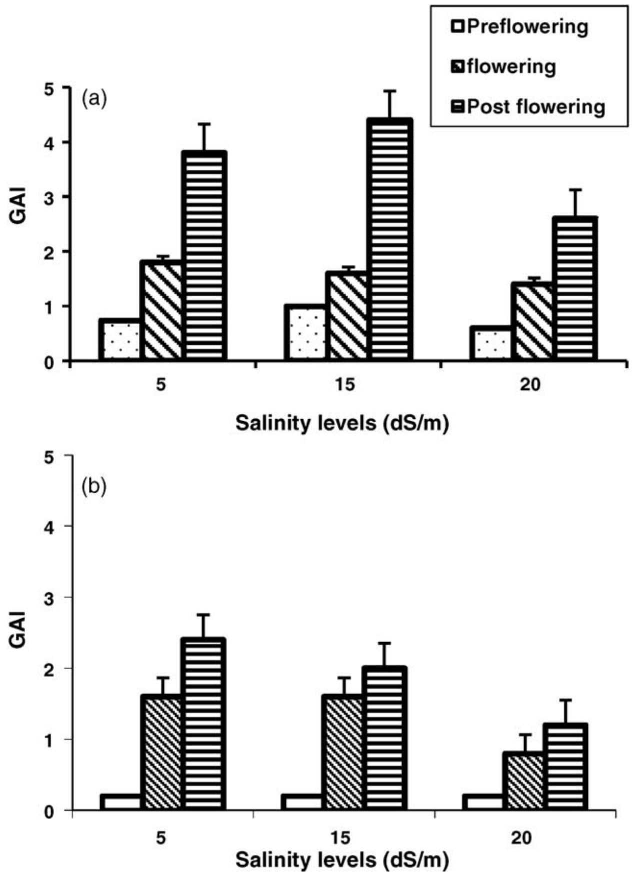

Fig. 6. Green area index at pre-flowering, flowering and post flowering stage, of two genotypes of Kochia (a = sabzevar and b = Indian) irrigated with three levels of saline waters (5, 15, and 20 dS m^{-1}) from 21 days after sowing up to the ripening (120 days after sowing). Values represent mean ± s.e. and each point is the average of 3 measurements.

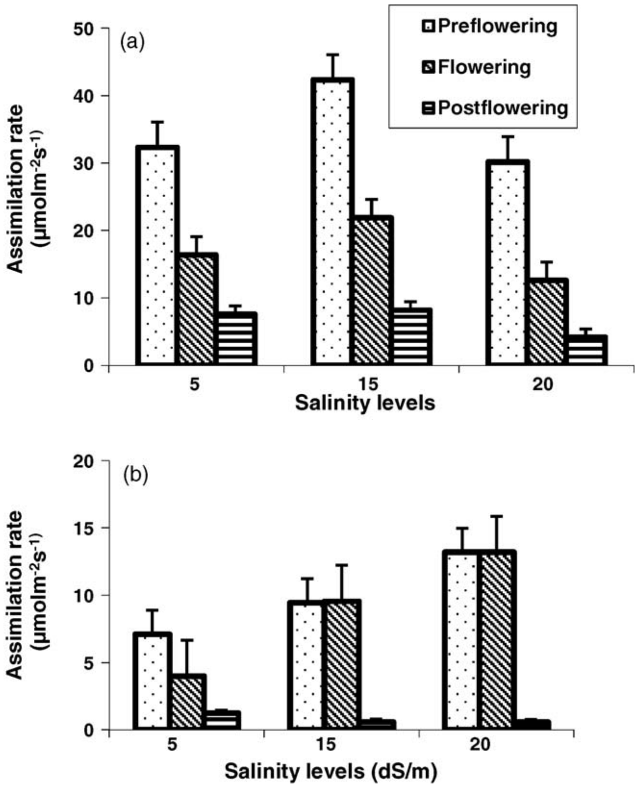

Fig. 7. Assimilation rate (μmol m^{-2} s^{-1}) of two genotypes of Kochia (a = Sabzevar and b = Indian) at three growth stages (pre flowering, flowering and after flowering) irrigated with three levels of saline waters (5, 15, and 20 dS m^{-1}) from 21 days after sowing up to the ripening (120 days after sowing). Values represent mean ± s.e. and each point is the average of 30 measurements.

photosynthesis rate at 5 and 15 dS m^{-1} NaCl, but it declined with further increases in salinity (at 20 dS m^{-1}) in all three growth stages (Fig. 7). The rate of photosynthesis under high levels of salt treatments at the postflowering stage declined significantly with increasing external salinity in both genotypes (Fig. 7). However, photosynthesis tended to decrease during the course of the experiment across the whole range of external salinities. Lower photosynthesis at higher salinity tends to reduce the loading of salt into the leaves and helps to increase the longevity by maintaining salts at subtoxic levels longer than it would occur if the transpiration rates were not diminished (Koyro, 2006).

Rates of leaf-gas exchange of the Indian genotype were similar to the 5 and 15 dS m^{-1} salinized plants, and they were in the same range as those reported for *Plantago coronopus* (Koyro, 2006), but photosynthesis for the Sabzevar genotype was rather higher than this range. The data of photosynthesis was not similar to biomass accumulation (Figs. 2 and 7), and this lack of a positive correlation between the photosynthetic rate and dry-matter production has been reported in several other halophytes grown under increasing salt concentrations, as shown in *Avicennia marina* (Ball and Farquhar, 1984). These results are consistent with those reported for *P. coronopus* (Koyro, 2006) and *Salicornia europea* (Ungar, 1991).

The chlorophyll measurements were carried out in the youngest fully developed leaf in all genotypes, and the chlorophyll content decreased in both genotypes with plant age (Fig. 8). Therefore, the highest value of chlorophyll in both genotypes and at all salinity levels was observed in the first measurement before flowering. Salinity treatment did not significantly disturb the chlorophyll contents in both genotypes. The Indian genotype shows a markedly lower value of chlorophyll content at all levels of salinity when compared with Sabzevar, and this might be the main reason for the low photosynthesis rate and low seed production (Munns and Tester, 2008).

The transpiration rate did not decline significantly with increasing external salinity at the preflowering (49 DAS) stage, but increased in both genotypes at higher levels of salinity (Fig. 9). It declined with further increases in salinity at the postflowering (88 DAS) stage (Fig. 9). The rate of transpiration at high levels of salt treatment at the postflowering stage declined significantly with increasing external salinity in both genotypes (Fig. 9). However, the transpiration rate tended to decrease during the course of the experiment across the whole range of external salinities. The Indian genotype also showed a lower transpiration rate than Sabzevar at all levels of salinity and at all growth stages (Fig. 9). We suggest that the severe salt stress in the medium does not impose toxicity to the plant cells, and only its osmotic potential caused a reduction in water absorption by the root and consequently reduction of the transpiration rate (Clarke et al., 1999). The ability of *K. scoparia* to cope with severe salt stress is a result of the integration of energy-demanding mechanisms that limit plant growth. The control system includes decreases in both stomatal conductance and transpiration rate, which finally results in constant water-use efficiency.

3.2. Low levels of water application

3.2.1. Fodder production

Reduced irrigation (RI) imposed a significant effect on the photosynthesis apparatus of Kochia by decreasing the GAI; however, there was no significant difference between 80% and

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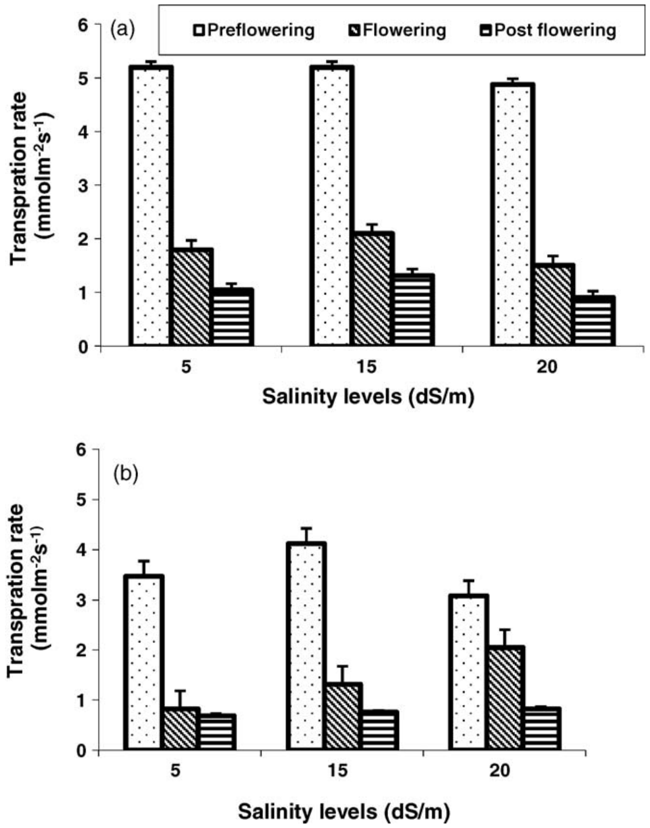

Fig. 8. Transpiration rate (mmol $\mathrm{m}^{-2}\,\mathrm{s}^{-1}$) of two genotypes of Kochia (a = Sabzevar and b = Indian) at three growth stages (pre flowering, flowering and post flowering) irrigated with three levels of saline waters (5, 15, and 20 dS m^{-1}) from 21 days after sowing up to the ripening (120 days after sowing). Values represent mean ± s.e. and each point is the average of 30 measurements.

60% water reduction, whereas limited irrigation by 40% of water requirement led to reduced GAI from 4.67 to 1.57 (Table 2). 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 (Table 2). Fresh weight and dry-mass production of *K. scoparia* were greater when they were grown under complete irrigation than those under RI conditions (Table 2). RI 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. Water-use efficiency under higher water-stress treatment was also increased (data not shown).

There is some debate regarding the use of crude protein as a factor for deciding the forage/fodder quality in halophytes, because a part of the nitrogen content of halophytes is not digestible for animals (Khan et al., 2009); nevertheless, if the protein content is considered a quality index for fodder, results show that up to 60% water supplement, there is no significant reduction in protein yield and that the leaf dry-matter accumulation does not change significantly up to this level of limited irrigation (Table 2). Inflorescence dry matter showed a different trend compared to the other parameters, which could be due to the effect of limited irrigation on the phenological stages of Kochia plants (Table 2). Drought stress might accelerate the phenological stages of plants.

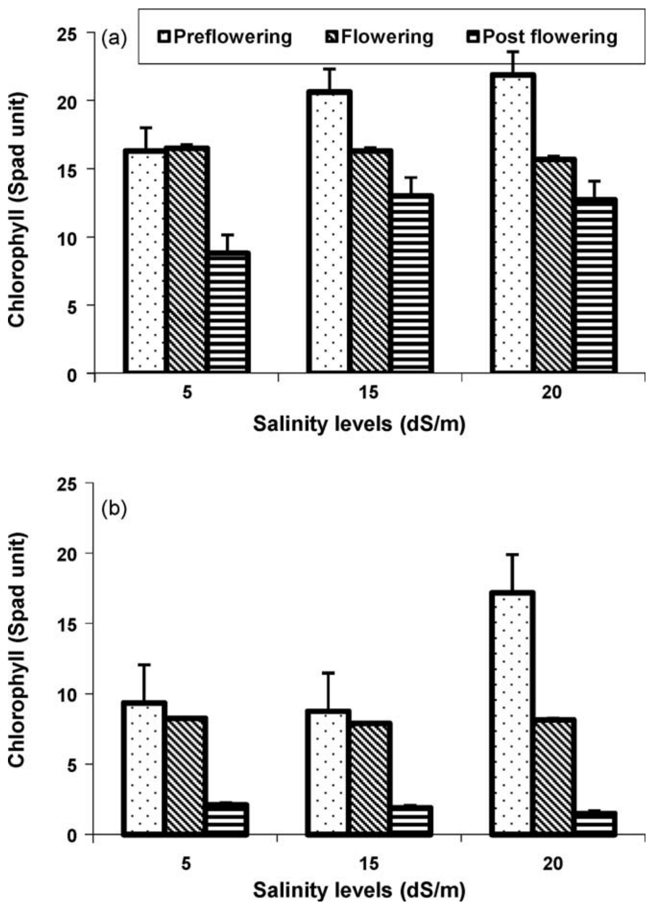

Fig. 9. Leaf chlorophyll (SPAD relative unit) of two genotypes of Kochia (a = Sabzevar and b = Indian) at three growth stages (pre flowering, flowering and post flowering) irrigated with three levels of saline waters (5, 15, and 20 dS m^{-1}) from 21 days after sowing up to the ripening (120 days after sowing). Values represent mean ± s.e. and each point is the average of 9 measurements.

3.2.2. *Seed production*

Kochia is capable of producing acceptable seed yield, with relatively high oil and protein contents. The highest seed yield was obtained from the complete irrigation treatment (2895 kg ha^{-1}), and it decreased significantly by RI. The percentage of seed-yield reduction was more than the percentage of RI; for example, 78.4%,

Table 2
Green area index, shoot, leaf, stem and inflorescence dry matter accumulation (g m^{-2}) and protein yield of two Kochia genotypes irrigated with saline water (5 dS m−1) under limited irrigation of 80%, 60% and 40% of water requirement. Each point is the average of 6 measurements for irrigation treatments and 12 measurements for genotypes. Similar letters in each column indicate no significant difference between treatments, capital letters are for comparing two genotypes, and they should compare separately.

Percent of full irrigation	Green area index	Shoot fresh weight (kg ha^{-1})	Shoot dry weight (kg ha^{-1})	Leaf dry weight (kg ha^{-1})	Stem dry weight (kg ha^{-1})	Inflorescence (kg ha^{-1})	Protein yield (kg ha^{-1})
(100%)	4.67a	31,810a	13,220a	5976a	5673a	1571b	522a
80%	3.06b	23,270b	12,420a	5443a	4326b	2651a	489a
60%	2.89b	17,990b	8,743b	3664b	3704b	1375b	427a
40%	1.57c	8,938c	5,895c	2436c	2657c	802c	248c
Sadzevar	3.38A	23,638A	11,100A	5020A	4281A	3919A	485A
Broujerd	2.71B	17,362B	9,080B	3739B	3944B	3737A	358B

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Table 3
Seed yield, seed weight and number, oil and protein content of two Kochia genotypes irrigated with saline water (5 dS m^{-1}) under limited irrigation of 80%, 60% and 40% of water requirement. Each point is the average of 6 measurements for irrigation treatments and 12 measurements for genotypes. Similar letters in each column indicate no significant difference between treatments, capital letters are for comparing two genotypes, and they should compare separately.

Percent of full irrigation	Seed yield (kg ha^{-1})	Seed weight (g/1000)	Seed number per plant	Oil content (%)	Protein content (%)
(100%)	2895a	0.72a	20,100a	8.15a	17.93c
80%	2271b	0.71a	15,992b	7.43a	21.35b
60%	1070c	0.58b	9,224c	6.36b	25.97a
40%	876c	0.47c	9,319c	5.39c	28.76a
Sadzevar	2139A	0.67A	15,962A	7.47A	24.30A
Broujerd	1725B	0.57B	15,131B	6.20B	22.71A

37% and 30% of the seed yield of the control under 80%, 60%, and 40% of water limitation, respectively. Seed yield is much more susceptible to RI than biomass accumulation in Kochia, and it is recommended that if the aim of growing it is seed production, irrigation water should not be reduced to more than 80%.

Kochia's seed is too small in comparison with many conventional crops, and the weight of 1000 seeds rarely exceeds 0.75 g. Limited irrigation lower than 80% caused a significant effect on seed weight and at 40% RI, the 1000-seed weight was reduced to 0.47 g; but, to preserve the germination capacity, the seed weight should not be lower than a specific threshold; therefore, the main yield component that was affected by RI was the seed number per plant (Table 3).

The oil content of Kochia seeds was between 8.15% in the control and 5.39% under 40% RI. However, there was no significant difference in the seed-oil content between the control and 80% RI plants.

In this experiment, the Sabzevar genotype showed a better performance compared to the Brujerd genotype in all measured parameters (Table 2), except the inflorescence biomass, which is very dependent on the phenological behavior of the genotypes. However, this study only investigated the effect of different water-deficit treatments and did not consider salt deposition in the root medium. Excess accumulated salts in the soil, due to lack of leaching-fraction application, should be removed from the soil when a reliable source of water such as rain or ground water is available (Sharma and Rao, 1998). Because Kochia is a halophyte, it is possible to drain the soil using ground water with the same salinity of irrigation water to wash out the accumulated salts in the winter when there is no water requirement for crops. More research is also needed to be carried out in the future with reference to salt accumulation in different soil textures, the most sensitive and most tolerant growth stages of Kochia under water stress, and the interaction of water and salt stresses of Kochia.

4. Conclusions

The results suggest that *K. scoparia* may be a candidate species for cultivation in areas where salinity cannot be restricted within acceptable limits by leaching or other salinity-management techniques (Rhoades et al., 1992). The observed growth stimulation by 15 dS m^{-1} salinity suggests that longer term field trials would be justified to evaluate the growth potential of Kochia in areas where it may be conceivable to reuse second-generation drainage water, saline and shallow ground waters, and even seawater for irrigation. This plant has a high potential to grow on soil under irrigation with saline water in summer, when good-quality water is limited for producing forage corn or alfalfa. Kochia can produce considerable dry mass under RI, and up to 20% reduction in its water requirement has no significant effect on its fodder production. There is a wide range of intraspecific variation amongst the local populations of Kochia, and their salt tolerance may vary from one location to another. In this work, the Sabzevar local population showed better performance in terms of all growth and other physiological parameters than the Indian and Brujerd genotypes. Therefore, initial experimental production of Kochia in new areas using all available populations is required before full-scale cultivation. If some agrotechnical requirement of Kochia is discovered, it could contribute significantly in applying currently unused saline wastewaters and land for providing fodder to arid areas that have abundant saline-water resources. The farmers along the desert areas, for example, two big deserts in the center of Iran, are in extreme need of fodder for their animals, and the introduction of this species would provide an impressive economic benefit.

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