Pak. J. Bot., 41(4): 1861-1870, 2009.

GROWTH ANALYSIS OF KOCHIA (*KOCHIA SCOPARIA* (L.) SCHRAD) IRRIGATED WITH SALINE WATER IN SUMMER CROPPING

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Abstract

Kochia species has recently attracted the attention of researchers as a forage and fodder crop in marginal lands worldwide. Kochia is drought and salt tolerant and native to Iran. This plant has a potential to grow in saline soils and it can be irrigated with brackish water. To evaluate how salinity stress affects growth parameters, an experiment was conducted wherein plants of *Kochia scoparia* were exposed to six levels of saline waters (1.5, 7, 14, 21, 28 and 35 dS/m). The function method was used for evaluating growth parameters. The results showed that all growth parameters decreased with increasing salinity higher than 7 dS/m. *Kochia scoparia* is a meso-halophyte, thus low salt stress (7 dS/m) improved its dry matter production and leaf area index (LAI). Stem dry weight (SDW) and plant dry weight (PDW) decreased significantly under salt stress, but the salt induced reduction in plant dry weight (PDW) was more than that in the former growth attribute. However, while salt stress improved leaf weight ratio (LWR) in *K. scoparia*. Salinity affected Kochia leaf morphology and increased leaf thickness. Fifty percent yield reduction occurred at 38.8 dS/m salinity. In view of the growth performance of this species under saline conditions, this plant shows a high potential to sustain under irrigation with saline water in summer when good quality water is usually scarce.

Introduction

Salinity is one of the major constrains of production systems in many parts of the world including Iran. Saline sodic waters or soils inhibit the growth of high value cash crops (Duan *et al*., 2004; Ashraf, 2004; Ashraf & Harris, 2004). High temperature, scarce supplies of good-quality water and salinity tend to move upward through capillary rise in the Golestan province. 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). Kochia (*Kochia scoparia*) is native to Eurasia, well spreading in many parts of Iran (Arak, Azarbaijan, Esfahan, Kerman, Kermanshah, Khorasan, Qazvin, Tehran and Golestan) (Akhani, 2005). Field trials indicated that Kochia displays a good tolerance to salinity after establishment, so that increase of irrigation water salinity from 1.5 to 28.2 dS m^{-1} is accompanied with only 36% yield reduction. Kochia can also provide a good source of forage and fodder under water-limited conditions due to less irrigation with good quality water or under saline water irrigation. Due to its high nutritional value, it is an important component of ruminant diets (Jami Al Ahmadi & Kafi, 2007). Kochia offers potential as a crop, which can be grown on saline soils, yielding fodder in quantities approaching that produced by alfalfa (*Medicago sativa* L.) (Steppuhn *et al*., 1993). Kochia has been described as a palatable and nutritious forage (Green *et al*., 1986) possessing crude protein ranging within 10-25% (Knipfel *et al*., 1989). 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 *et al*. (1993) and Ahmadi & Kafi (2008).

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Growth analysis is a useful method for describing plant responses to environmental variations (Radford, 1967; Ashraf, 2004), because growth parameters show differential responses to salinity stress (Shannon, 1997; Duan *et al*., 2004; Gulzar *et al*., 2005). The objective of this study was to evaluate how different levels of salinity stress as saline waters could affect growth parameters in Kochia.

Materials and Methods

Field studies were conducted during the summer 2008 at the Mazrae Nemoneh Research Station of Golestan province. The soil consisted of 24% clay, 14% sand, 62% silt. The area had sub-drainage system. However, the amount of precipitation at this site during the whole growth period has been presented in Fig. 1. Maximum temperature during summer was 42°C on 4^{th} and 10^{th} September, 2008 (Fig. 2). Plants were harvested on 26^{th} October, 2008.

Kochia was sown at 20 plants/m^2 density in the first week of July 2008 after harvesting of wheat. Two irrigations with good quality water were applied for getting the plants established. The experiment was conducted based on randomized completely block design with three replications and six levels of drainage saline waters (1.5, 7, 14, 21, 28 and 35 dS/m). The seeds origin was from Sabzevar city of Khorasan province.

Every other week two plants were selected randomly from each plot regularly 30 day after planting until seed ripening. Leaf area was estimated by measuring SLA. Dry weight of plant materials was measured after drying for 3 days at 72°C. The grain yield was adjusted to 12% moisture content.

Estimation of growth analysis components: Function method is a useful way to estimate CGR and NAR because it minimizes harvest to harvest variation in each growth characteristic (Poorter, 1989, Bullock *et al*., 1988). The logistic function (a/[1+b x exp (–ct)]) was used for estimating a, b and c for plant dry weight (Yusuf *et al*., 1999). The means of the primary data were transformed to natural logarithm to obtain heterogeneity of error (Bullock *et al.*, 1993).

Cubic polynomial function was used for LAI, stem dry weight and leaf dry weight. The logistic and polynomial curve was fitted with the proc NLIN and REG procedures using the computer package SAS.

$Ln\ w = fw\ (t)$ Plant Dry Weight Eq.1
$Ln\ l = fL(t)$ Leaf Weight Eq. 2
$Ln\ A = fA(t)$ Leaf Area Eq. 3
$CGR = exp[fw(t)] \times f^1w(t)$ Eq. 4
$NAR = f^1w(t) \times exp[fw(t) - fA(t)]$ Eq. 5
$LWR = exp[f(t)]/exp[w(t)]$ Eq. 6
$SLA = exp[fA(t)]/exp[fL(t)]$ Eq. 7
$$Yr = 1/\left[1 + \left(\frac{c}{c50}\right)^{\exp(sc50)}\right]$$ Eq. 8
C50= salinity at Yr=0.5 s= Steepness parameters (Steppuhn *et al*., 2005)
Salt Index = c50 + sc50 Eq. 9
$GDD = [(Tmax + Tmin/2] - 3.5$ Eq. 10

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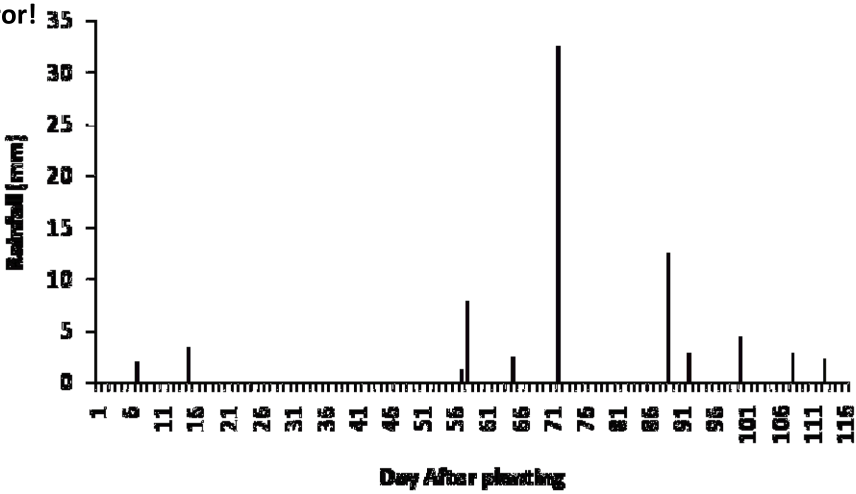

Fig. 1. Total rainfall during the experiment.

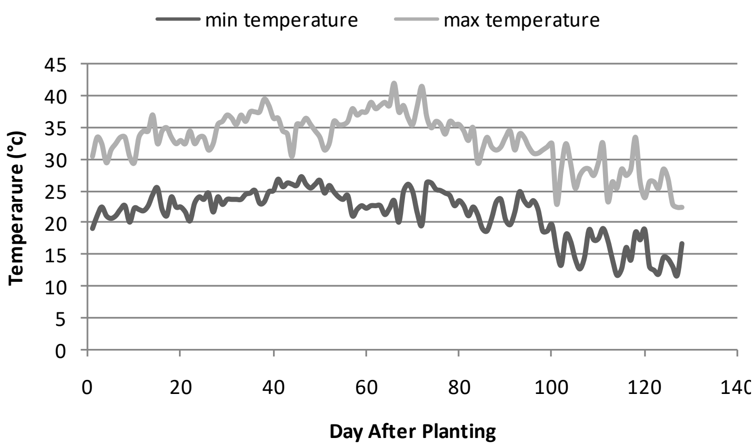

Fig. 2. Max and Min temperatures during the experiment.

Results and Discussion

Total plant dry weight (PDW): Total plant dry weight production was fitted with a logistic curve. This function under estimate production at lag phase, may be was due to slow growth rate after emergence (Fig. 4, Table 1).

Salinity shortened duration of linear phase of growth and consequently, sigmoid phase of growth started sooner than that of control plants. Sigmoid phase started at 87 and 95 days after planting in 35 dS/m and 1.5 dS/m, respectively. Linear phase duration was 27 days at 35 dS/m while it prolonged to 35 days at 7 and 1.5 dS/m. The main effect of saline water on total plant dry biomass was on duration of linear phase. Differences among treatments started at 87 days after planting, approximately 50 days after salinity application (Fig. 4). PDW reduced 48% at 35 dS/m compared with that at control or 7 dS/m. These results are in agreement with other reports (Green *et al.*, 1986; Cha-um & Kirdmanee, 2008).

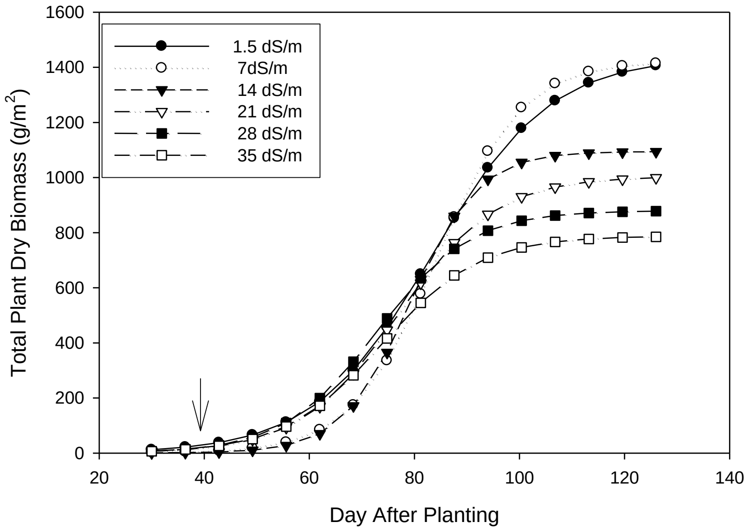

Fig. 3. Total plant dry biomass (g/m^2) of Kochia grown with 6 levels of saline water. The means of the primary data were transformed to natural logarithm to minimize heterogeneity of error. Arrow shows the time of salinity application.

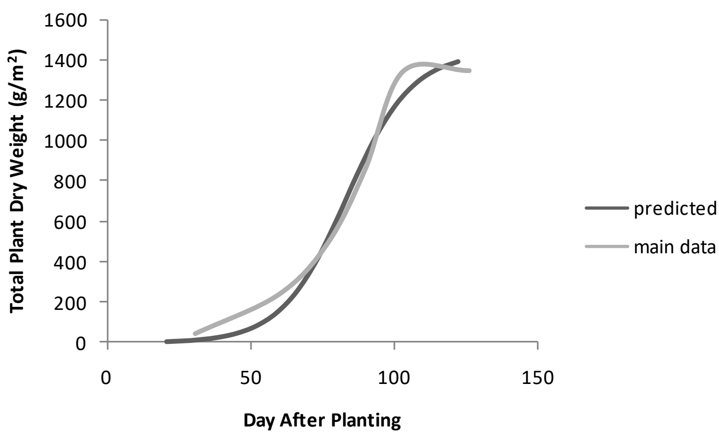

Fig. 4. Predicted and main data of total plant dry weight (g/m^2) at 1.5 dS/m.

Flowering of Kochia started at 53 days after planting in summer cropping and day length at this time was 12.8 h in Gorgan. Plant color changed from green to red 110 days after planting which coincided with ripening. Cumulative growing degree days (GDD) until flowering and ripening were 1795, and 3022, respectively. It seems likely that Kochia is sensitive to photoperiod and GDD requirement, hence, flowering time could be predicted precisely based on photoperiod and GDD (Ahmadi & Kafi, 2008). Increase in salinity level from 1.5 to 7 dS m^{-1} increased the plant dry weight slightly but with salinity over 7 dS/m and up to 35 dS m^{-1}, plant dry weight decreased significantly. These findings are in agreement with those of Ashour *et al*., (1997) and Ashraf (2004), who underlined stimulating effect of moderate salinity on growth and yield of halophytic grasses.

Leaf area index: LAI fitted with logistic function was similar to total plant dry production, while Bullock *et al*., (1991) and Yusuf *et al*., (1999) used cubic function. Cubic function underestimates LAI at lag phase (Table 1, Fig. 5).

The lowest and highest LAI was observed at 35 and 7 dS/m, respectively. Kochia is a meso-halophyte (Choukr *et al*., 1995) therefore, low salt stress (7 dS/m) improved its dry matter production and LAI. LAI decreased 47.5% at 35dS/m compared with 7 dS/m. Over days in salinity stress, reductions in cell elongation and also cell division led to slower leaf appearance and smaller final size analogous to what has been reported elsewhere (Ashraf, 2004; Munns & Tester, 2008). The reduction in leaf growth must be regulated by long distance signals in the form of hormones or their precursors, because the reduced leaf growth rate is independent of carbohydrate supply (Ashraf & Harris, 2004; Munns *et al.*, 2000) and water status (Munns *et al*., 2000; Fricke & Peters, 2002).

Leaf dry weight (LDW): LDW was fitted with cubic function and the highest LDW production observed 109 days after planting (Table 2, Fig. 6). Significant differences among treatments started 96 days after planting. LDW was significantly higher at 7 and 1.5 dS/m than the other treatments and LDW decreased 43% at 35 dS/m in relation to that at 7 dS/m.

Crop growth rate (CGR) and net assimilation rate (NAR): Calculation of CGR, NAR, SLA and LWR started 60 days after planting. NAR and CGR decreased with increasing salinity of water. Salinity firstly affected LAI and consequently, CGR and NAR were also reduced (Fig. 7). Likewise Shannon (1997) reported that net assimilation rate of sunflower decreased with higher levels of NaCl salinity in the soil.

Leaf weight ratio (LWR) and Specific leaf area (SLA): LWR is leaf weight in relation to PDW. The highest LWR (0.61) during the growth period was observed at 21 dS/m. At 35dS/m salinity, stem dry weight decreased 50.5% but LDW decreased 43%, therefore, the salinity effect on SDW was higher than that on LDW, but in contrast, salt stress improved LWR (Fig. 8a). Increasing salinity improved forage digestibility of Kochia to some extent by restricting stem growth and increasing partitioning to leaves (Ahmadi & Kafi, 2008). Salinity affected on Kochia leaf morphology by increasing leaf thickness and consequently decreasing SLA at 35 dS/m (Fig. 8b). Under salt stress cell dimensions change, with more reduction in area than depth, so the leaves were smaller and thicker. Such reduction is largely attributed to the osmotic effect of the salt (Cha-um & Kirdmanee, 2008; Munns & Tester, 2008).

Stem dry weight (SDW) and lateral stem number (LSN): SDW was fitted with cubic curve. SDW of control plants and those grown at low salinity level was significantly higher than that at the other treatments (Table 2, Fig. 9a). Ayers *et al*., (1952) found that in barley and wheat, seed production was decreased less than shoot dry weight by salinity. LSN was fitted with logistic function and the highest LSN was observed at 1.5 dS/m, but at 35 dS/m it decreased 24% (Table 1, Fig. 9b). When salt concentration around the roots increases to a threshold level, the rate of growing leaves expansion is reduced, new leaves emerge more slowly, and lateral buds develop more slowly or remain quiescent, so fewer branches or lateral shoots are formed (Ashraf, 2004; Munns & Tester, 2008). The maximum plant height was achieved at 77 days after planting. Plant height decreased significantly with increasing salinity (over 7 dS/m). At 35 dS/m, plant height decreased 26% in relation to that at 1.5 dS/m (Fig. 10). Khatoon *et al*., (2000) evaluated growth parameters of sunflower under salt stress and reported that relative growth rate, relative increase in leaf area and plant height were suppressed by salinity levels (3, 4.5 and 6 dS/m).

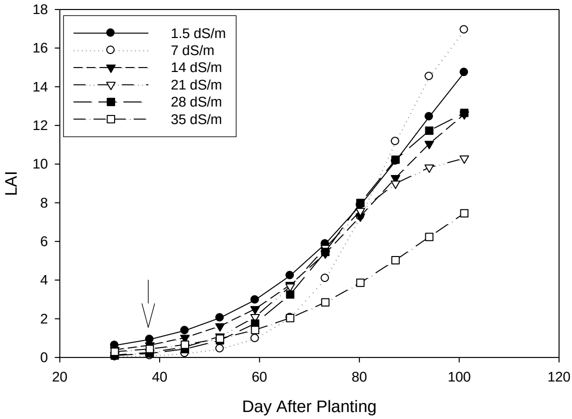

Fig. 5. Leaf area iindex (LAI) of Kochia grown at 6 levels of salinity. Arrow shows the time of salinity application.

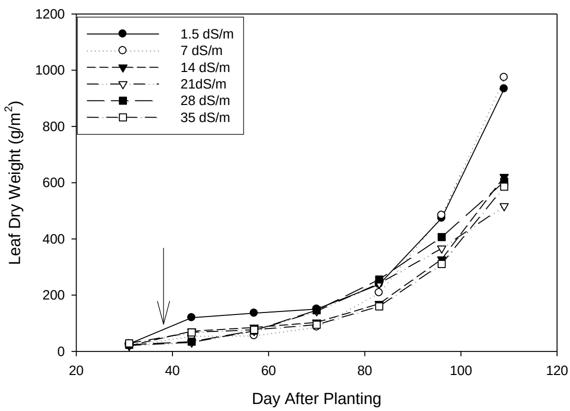

Fig. 6. Leaf dry weight (g/m^2) of Kochia grown at 6 levels of saline water. Arrow shows the time of salinity application.

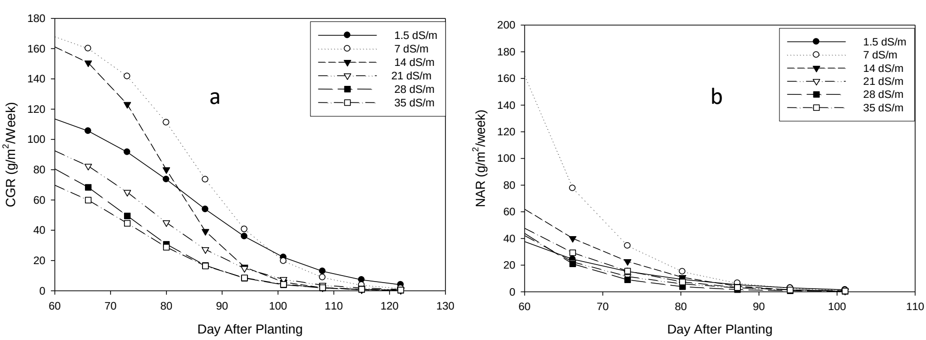

Fig. 7. Net assimilation rate (NAR) and crop growth rate (CGR) of Kochia grown at 6 levels of saline water.

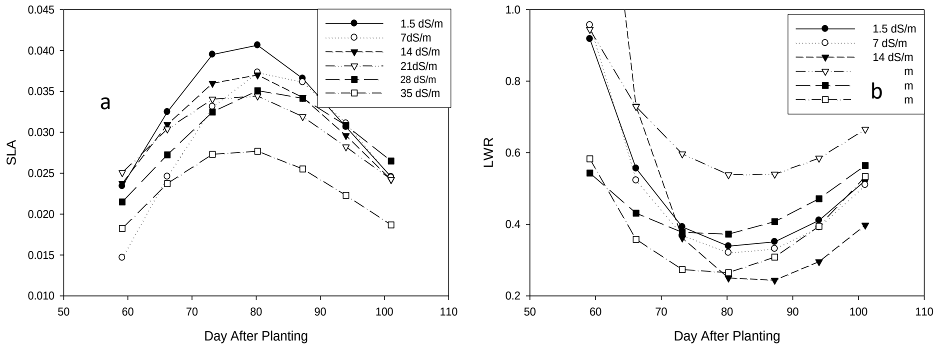

Fig. 8. Specific leaf area (SLA (m^2/g)) and leaf weight ratio (LWR) of Kochia grown at 6 levels of saline water.

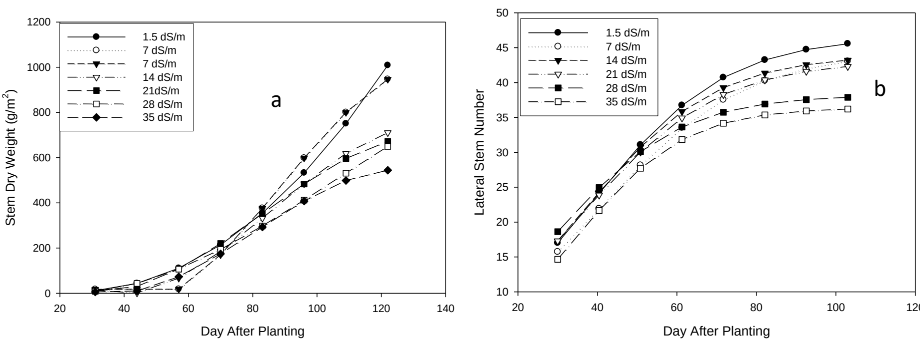

Fig. 9. Actual and predicted stem dry weight (g/m^2) and lateral stem number (LSN) of Kochia grown at 6 levels of saline water. Arrow shows the time of salinity application.

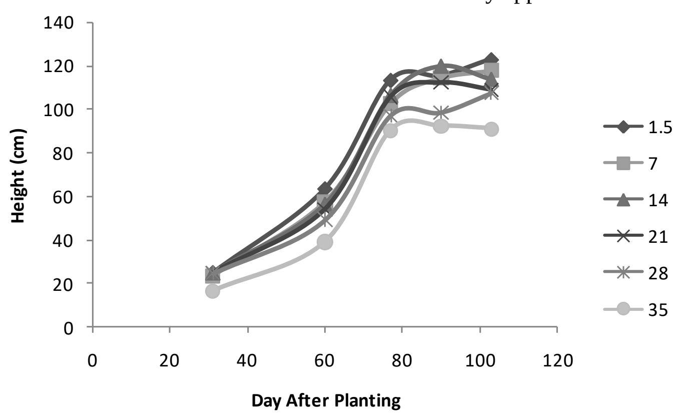

Fig. 10. Salinity effect on plant height of Kochia grown at 6 levels of saline water.

Evaluation of salinity effects on biomass production was fitted with equation 8 (Steppuhn *et al.*, 2005). Fifty percent yield reduction was observed at 35 dS/m based on Eq. 8 (Fig. 11). Steepness was 0.0105 and salt index 39.21 for relative PDW. Steppuhn *et al.*, (2005) reported values, 0.055 and 21.5, for steepness and salt index of Kochia based on stem dry weight and EC of saturated soil, respectively. These data show that Kochia is much more salt tolerant than other conventional salt tolerant crops.

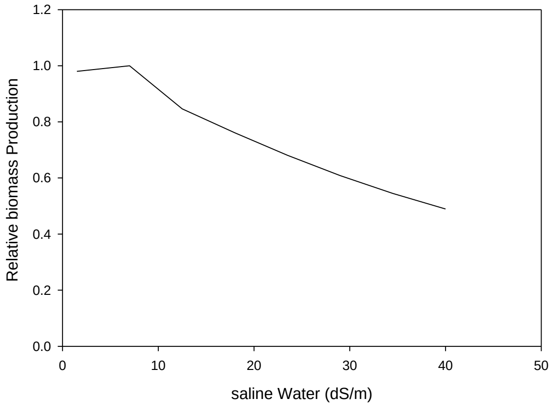

Fig. 11. Relative biomass production as a function of water salinity in Kochia grown at 6 levels of saline water.

Conclusion

Growth parameters of Kochia decreased significantly with increasing salinity higher than 7 dS/m. Growth parameters of Kochia decreased in the following order in response to salinity: LSN> H> LDW> LAI> PDW> SDW. Although both SDW and PDWof Kochia decreased significantly under salt stress, the effect of salt on PDW was more severe. Since salinity causes a reduction in linear phase of growth, the harvesting of Kochia for forage under salt stress should be done sooner. Increasing LWR may improve forage digestibility under salt stress. Kochia is so salt tolerant that only 50% yield reduction occurred at 35 dS/m of irrigation water. 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 is also suitable for reducing salt accumulation during summer because of upward movement of shallow saline water.

References

Akhani, H. 2005. *The illustrated flora of Golestan National Park, Iran*. University of Tehran Press.

Ashraf, M. 2004. Some important physiological selection criteria for salt tolerance in plants. *Flora*, 199: 361-376.

Ashraf, M. and P.J.C. Harris. 2004. Potential biochemical indicators of salinity tolerance in plants. *Plant Sci*., 166: 3-16.

Ashour, N.I., M.S. Serag, A.K. Abd El-Haleem and B.B. Mekki. 1997. Forage production from three grass species under saline irrigation in Egypt. *Journal of Arid Environments*, 37: 299-307.

Ayers, A.D., J.W. Brown and L.Wadleigh, 1952. Salt tolerance of barley and wheat in soil plots receiving several salination regimes. *Agron. J*., 44: 307-3 10.

Bullock, D.G., F.W. Simmons, I.M. Chung and G.I. Johnson. 1993. Growth analysis of corn with or without starter fertilizer. *Crop Sci*., 33: 112- 117.

Bullock, D.G., R.L. Nielsen, and W.E. Nyquist. 1988. A growth analysis comparison of corn grown in conventional and agusedistant plant spacing. *Crop Sci*., 28: 254-258.

Cha-um, S. and Ch. Kirdmanee. 2008. Effects of osmotic stress on proline accumulation, photosynthetic abilities and growth of Sugarcane plantlets (*Sacchrum officinarum* L.). *Pak. J. Bot*., 40(6): 2541-2552.

Choukr Allah, R., C.V. Malcolm and A. Hamdy. 1995. *Halophytes and biosaline agriculture*. CRC Press. 400 pages.

Coxworth, E., D. Green, and J.A. Kernan. 1988. Improving the agronomics and feed value of Kochia. Saskatchewan Research Council, Saskatoon, SK. Report R- 814-4-B-88, 38pp.

Duan, D., X. Liu, M. Ajmal Khan and B. Gul. 2004. Germination of *Chenopodium glaucum* L. seed. *Pak. J. Bot*., 36(4): 793-800.

Fricke, W. and W.S. Peters. 2002. The biophysics of leaf growth in salt-stressed barley. A study at the cell level. *Plant Physiol*., 129: 374-88.

Gulzar, S., M. Ajmal Khan, I.A. Ungar and Xiaojing Liu. 2005. Influence of salinity on growth and osmotic relation of *Sporobolus loclados*. *Pak. J. Bot*., 37(1): 119-129.

Green, D., J. Knipfel, J. Kernan and E. Cox-worth, 1986. Evaluation of Kochia as a high yielding forage crop for saline soils. Pages 433-461. In: *Proc. Sask. Soils and Crops Workshop*. Ext. Div., University of Saskatchewan, Saskatoon, SK.

Jami Al Ahmadi, M. and M. Kafi. 2008. Kochia (*Kochia scoparia*): To be or not to be? In: *Crop and Forage Production using Saline Waters*. (Eds.): M. Kafi and M.A. Khan. NAM S&T Centre. Daya Publisher, New Delhi.

Khatoon, A., M.K. Hussian and M. Sadiq. 2000. Effect of Salinity on some growth parameters of cultivated sunflower under saline conditions. *International Journal of Agriculture & Biology*, 2: 210-213.

Knipfel, J.E., J.A. Kernan, E.C. Coxworth and R.D.H. Cohen. 1989. The effect of stage of maturity on the nutritive value of Kochia. *Can. J. Anim. Sci*., 69: 1111-1114.

Munns R. and M.Tester, 2008. Mechanism of salinity tolerance. *Annul. Rev. Plant Biol*. 59: 651-81.

Munns R., J. Guo, J.B. Passioura and G.R. Cramer. 2000. Leaf water status controls day-time but not daily rates of leaf expansion in salt-treated barley. *Aust. J. Plant Physiol*., 27: 949-57.

Poorter, H. 1989. Plant growth analysis: towards a synthesis of the classical and the functional approach. *Physiologia Plantarum*, 75: 237-244.

Qadir, M. and J.D. Oster. 2004. Crop and irrigation management strategies for saline-sodic soils and waters aimed at environmentally sustainable agriculture. *Science of the Total Environment*, 323: 1-19.

Radford, P.J. 1967. Growth analysis formulae—their use and abuse. *Crop Sci*., 7: 171-175.

Shannon, M.C. 1997. Adaptation of plants to salinity. *Adv. Agron*., 60: 76-81.

Steppuhn, H., M. Th. Van Genuchten and C.M. Grieve. 2005. Root–zone salinity: II. Indices for tolerance in agricultural crops. *Crop Sci*., 45: 221-232.

Steppuhn, H., D.G. Green, J.A. Kernan, E. Coxworth, and G. Winkleman, 1993. Comparing fall and spring seeding of *Kochia scoparia* on saline soil. *Can. J. Plant Sci*., 73: 1055-1065.

Yusuf, R.I., J.C. Siemons and D.G. Bullock. 1999. Growth analysis of soybean under no-tillage and conventional tillage systems. *Agron. J*., 91: 928-933.

(Received for publication 25 April 2009)