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Short communication. Suitable growth stage to start irrigation with saline water to increase salt tolerance and decrease ion accumulation of *Kochia scoparia* (L. Schrad)

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Abstract

Kochia scoparia L. Schard (common name: kochia) is a mesohalophyte, C_4 plant. It has the potential of being an important fodder crop in arid and semi arid environments. In order to evaluate the effect of saline irrigation water on the seedling growth stage and to select the best growth stage to start using saline water, an experiment was conducted with seven different saline water treatments (1.5, 7, 14, 21, 28, 35 and 42 dS m^{-1}) at four growth stages [after emergence (T1), 5 cm (T2), 10 cm (T3), and 15 cm (T4) of plant height]. Results showed that shoot dry biomass increased slightly up to 7 dS m^{-1} and after that decreased with increasing salinity. Salt tolerance of kochia increased at the T3 and T4 growth stages. Sodium content of the plant was increased by using high saline water. The adverse effect of salinity on the Na content of the plant was lower at the 10-15 cm growth stage than at earlier growth stages. Potassium content was not greatly affected by salinity. As conclusion, kochia is sensitive to saline irrigation at the earliest stages of growth, and the best plant height to start saline irrigation is between 10 and 15 cm.

Additional key words: early growth stage; forages; halophyte; salinity; sodium content.

Resumen

Comunicación corta. Etapa de crecimiento adecuada para iniciar el riego con agua salina a fin de aumentar la tolerancia a la salinidad y disminuir la acumulación de iones de *Kochia scoparia* (L. Schrad)

Kochia scoparia L. Schard (nombre común: coquia o falso ciprés) es una planta C_4 mesohalofita que tiene el potencial de ser un cultivo forrajero importante en ambientes áridos y semiáridos. Con el fin de evaluar el efecto del riego con agua salina en la fase de crecimiento de las plántulas y de seleccionar la fase de mayor crecimiento para empezar a utilizar el agua salina, se realizaron siete tratamientos salinos diferentes (1,5, 7, 14, 21, 28, 35 y 42 dS m^{-1}) en cuatro etapas de crecimiento [después de la emergencia (T1), y 5 cm (T2), 10 cm (T3) y 15 cm (T4) de altura de la planta]. Los resultados mostraron que la biomasa seca de la parte aérea se incrementó ligeramente hasta 7 dS m^{-1}, y después disminuyó con el aumento de la salinidad. La tolerancia a la sal de la coquia aumentó en las fases de crecimiento T3 y T4. El contenido de Na de la planta se incrementó con el uso de agua con alta salinidad. El efecto adverso de la salinidad sobre el contenido de Na de la planta fue menor en la etapa de crecimiento de 10 a 15 cm que en etapas de crecimiento anteriores. El contenido de potasio no se vio muy afectado por la salinidad. Como conclusión, la coquia es sensible al riego salino en las primeras etapas de crecimiento, y la mejor altura de las plantas para iniciar el riego salino es entre 10 y 15 cm.

Palabras clave adicionales: contenido de sodio; fase de crecimiento temprano; forrajeras; halófitas, salinidad.

Conventional water resources and crops do not meet all the requirements of human societies living in dry and saline areas. 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 species have recently attracted the attention of researchers worldwide. 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

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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 and Salmon (1972) reported that kochia seed might be a useful source of protein (29%), oil (10%) and energy for a variety of domestic animals. Al-Ahmadi and 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 and Poss, 1989). A better knowledge on how salt tolerance changes during some stages of growth may improve new strategies for the utilisation of saline drainage water.

The objectives of this study were to determine the sensitivity of kochia seedlings to salinity at different early growth stages and the best time to start using saline irrigation water when seeds emerge after rainfall or are irrigated by fresh water in spring cropping.

In a pot experiment carried out in 2009, kochia seeds were exposed to saline water by using a completely randomized block design with seven treatments with three replications. The seed origin was Sabzevar city in Khorasan province, Iran. Plants were grown in approximately 5 kg pots which filled with silty clay loam soil. Saline drainage water (325 dS m^{-1}) and non-saline (0.9 dS m^{-1}) water sources were blended to obtain water with 1.5, 7, 14, 21, 28, 35 and 42 dS m^{-1} salinity. The chemical compositions of non saline and drainage water are given in Table 1. Salinity treatments were imposed at four initiation times: soon after emergence (T1), 5 cm (T2), 10 cm (T3), and 15 cm (T4) of plant height. Plants were harvested after 30 days of treatment and then oven dried at 72°C for 48 h. Flame photometer (Jenway model PFP7, Staffordshire, UK) was used for measuring Na and K content of shoot and root.

Shoot dry biomass (yield) was expressed on a relative basis (Yr) in which Y is the absolute yield and Ym equal to the production where salinity had very little or no influence on the yield [eq. 1] (Maas, 1990):

$$Yr = Y / Ym \quad [1]$$

Equation [2] was used for describing Yr as a function of irrigation water salinity (EC_{iw}):

$$Yr = \frac{1}{1+(C/C_{50})^{\exp(sC_{50})}} \quad [2]$$

where C is the electrical conductivity of the water in dS m^{-1}, C_{50} defines C at $Yr = 0.5$ and s represents the response curve steepness. The salinity tolerance index (STI) was used for evaluating salt tolerance of crops [eq. 3] (Steppuhn *et al.*, 2005):

$$\mathrm{STI} = C_{50} + sC_{50} \quad [3]$$

For these functions, the respective C_{50} and s values were derived using the proc NLIN and REG procedures of the computer package SAS 9.1.

The effect of irrigation water salinity on shoot dry biomass was significant, and the highest shoot biomass yield was observed at 7 dS m^{-1} (Fig. 1). With increasing salinity above 7 dS m^{-1} shoot biomass yield decreased. Steppuhn *et al.* (2005) concluded that the yield of a crop under saline conditions relates more closely to a

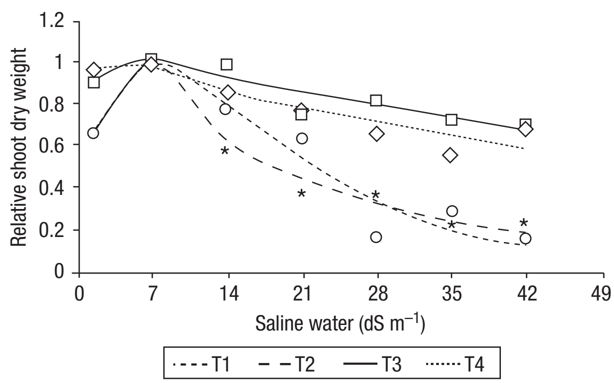

Figure 1. Effect of the salinity of irrigation water on relative kochia shoot dry biomass at different growth; after emergence (T1), 5 (T2), 10 (T3), and 15 (T4) cm height fitted to the discount equation [eq. 2] as a function of saline water (EC_{iw}). Symbols ○, ∗, □, and ◇ are observation data for T1, T2, T3, and T4, respectively.

Table 1. Chemical composition of irrigation water resources

Water resources	EC	pH	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+
Non saline water	0.9	7.3	0.0	5.5	0.4	3.1	3.0	2.8	3.2
Drainage water	325.0	8.0	0.0	5.6	940.0	3,014.4	4.0	206.0	3,750.0

modified discount function rather than to the threshold slope model. Equation [2] shows a yield reduction with increasing salinity, but halophyte production increases with salinity to some extent and then decreases with increasing salinity. This equation was used for data above 7 dS m^{-1}. For data at 1.5 and 7 dS m^{-1} a linear equation was used. Growth of the other tolerant dicot halophytes was stimulated by 180 mM NaCl relative to controls (Glenn and Brown, 1999). Salehi *et al*. (2009) reported that kochia produced maximum yield in summer cropping with 7 dS m^{-1} saline irrigation water.

Regression fits of the modified discount equation [eq. 2], with the relative shoot biomass plotted for each growth stage, resulted in R^2 value of 0.97 or higher and mean square error of 0.0113 or lower. Based on this equation, 50% reduction of shoot biomass (± standard error) production was observed by increasing salinity at 22.7 (± 1.9), 19.4 (± 1.9), 68.1 (± 20.6) and 56.7 (± 14.9) dS m^{-1} and the steepness of the equation was 0.49, 0.03, 0.007 and 0.004 at the T1, T2, T3 and T4 growth stages, respectively. Salinization with 42 dS m^{-1} water caused a 70% reduction of shoot dry biomass at the T1 and T2 growth stages (Fig. 1). The salinity tolerance indexes (STI) derived from Eq. [3] were 23.8, 20.1, 68.6 and 56.9 at T1, T2, T3 and T4 growth stages, respectively.

By increasing salinity from 1.5 up to 42 dS m^{-1} the shoot Na content increased by 41.1, 68.2, 16.0 and 10.7 mg g^{-1} DW, and the root Na content increased by 14.5, 6.3, 1.5 and 1.4 mg g^{-1} DW at the T1, T2, T3 and T4 growth stages, respectively (Table 2). Increased uptake of Na at higher salinities is a common phenomenon and most of the deleterious effects of salinity on plant growth are due to this increased uptake of Na (Levitt, 1972). The main site of Na toxicity for plants is the leaf blade, where Na accumulates after being transported by the transpiration stream (Munns and Tester, 2008). Halophytes have the ability to sequester NaCl in cell vacuoles, Na uptake into the vacuole appears to be mediated by Na/H antiporters in the tonoplast, although NaCl may inhibit growth also in halophytes (Glenn and Brown, 1999). In *Reaumuria hirtella* the accumulated salts contributed to the osmotic potential and improved the plant water status (Ramadan, 1998). Na concentration increased from 2% to 10% (dry matter) during the first stages (from T1 to T2) but decreased and remained at 2% during T3 and T4 stages.

Potassium (K) is an essential nutrient for plant growth and development. Environmental stresses, such as metal toxicity, salinity, and drought are known to adversely affect K uptake and transport by plants (Szczerb *et al*., 2009). The results showed that the K

Table 2. Effect of saline water on the sodium and potassium content of shoot and root of kochia effects after emergence (T1), and at 5 (T2), 10 (T3) and 15 (T4) cm plant height

Saline water (dS m^{-1})	T1		T2		T3		T4	
	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
Na (mg g^{-1} DW)								
1.5	20.9^{c}	8.3^{c}	38.0^{c}	6.4^{b}	16.2^{c}	4.9^{bcd}	14.8^{b}	5.8^{a}
7	29.4^{bc}	8.0^{c}	52.7^{c}	9.0^{ab}	17.1^{c}	6.9^{b}	21.2^{ab}	6.5^{a}
14	42.1^{abc}	11.3^{c}	58.6^{c}	8.7^{ab}	17.1^{c}	9.8^{a}	17.2^{ab}	7.0^{a}
21	36.5^{abc}	15.4^{bc}	86.2^{b}	6.6^{b}	21.5^{bc}	3.3^{d}	14.2^{b}	4.7^{a}
28	62.6^{ab}	26.0^{a}	95.7^{ab}	6.4^{b}	27.1^{ab}	3.6^{cd}	20.3^{ab}	4.4^{a}
35	72.8^{a}	19.1^{ab}	111.3^{a}	7.8^{ab}	29.9^{a}	5.2^{bcd}	19.1^{ab}	5.6^{a}
42	62.0^{ab}	22.9^{ab}	106.2^{ab}	12.7^{a}	32.2^{a}	6.4^{bc}	25.5^{a}	7.2^{a}
K (mg g^{-1} DW)								
1.5	39.0^{a}	8.9^{ab}	62.9^{b}	6.2^{a}	31.9^{a}	5.1^{a}	35.5^{a}	3.1^{a}
7	35.7^{a}	9.6^{ab}	55.6^{b}	5.5^{ab}	29.0^{a}	5.3^{a}	40.9^{a}	4.8^{a}
14	49.2^{a}	17.1^{a}	51.8^{b}	5.2^{ab}	27.9^{a}	4.2^{ab}	43.5^{a}	8.9^{a}
21	51.6^{a}	14.4^{a}	69.2^{b}	4.9^{ab}	30.7^{a}	2.2^{ab}	34.4^{a}	1.8^{a}
28	54.5^{a}	0.2^{b}	85.0^{ab}	2.7^{b}	29.8^{a}	1.3^{b}	37.8^{a}	2.4^{a}
35	54.5^{a}	0.3^{b}	62.9^{a}	3.6^{ab}	38.1^{a}	2.7^{ab}	40.2^{a}	2.4^{a}
42	53.9a	0.3^{b}	57.1^{b}	5.9^{ab}	37.3^{a}	4.9^{a}	46.42	2.1^{a}

Values followed by the same letter for salinity levels within each growth stage are not statistically different according to the least significant differences (LSD) between all pairs at the α-probability of 0.05.

content of kochia did not change with a specific pattern when salinity increased (Table 2). Sastry and Prakash (1993) reported that the K content of wheat does not show any specific change along the salinity gradient. In kochia the K concentration increased from 5% to 8% (dry weight) during the first stages (from T1 to T2) but remained at 4% during T3 and T4 stages. Kernan *et al*. (1986) reported that K concentration was about 2.6 and 2.9 % of dry matter of kochia.

At the first growth stage, the K/Na ratio changed from 1.86 to 0.86 with increasing salinity, but at the third growth stage K/Na ratio was 1.96 and did not change greatly by increasing salinity. The ability of a plant to maintain a high cytosolic K/Na ratio appears to be critical to plant salt tolerance (Shabala and Cuin, 2008). The high percentage of K relative to other ions is advantageous in terms of forage use for ruminant animals.

At later growth stage plants had more biomass and more Na was translocated to the shoot through the transpiration stream. However, the Na content rarefied in different parts of the plants due to the increased biomass and reduced the negative effect of Na. The K content of plant did not change with salinity. This showed that increasing salinity did not have an adverse effect on K uptake and transportation in the plant. In summary, kochia is more sensitive at the early growth stage. If seeds are planted or spread on the farm in early spring, seeds have an opportunity to emerge and become established with spring rainfall. In summer cropping, one or two irrigations are needed for establishment of plants (Salehi *et al*., 2009). After establishment of plants the 10-15 cm plant height stage is the ideal time for starting irrigation with high saline water.

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