



Influence of salinity and temperature on the germination of *Kochia scoparia*

M. Ajmal Khan¹, Bilquees Gul¹ & Darrell J. Weber*

Department of Botany and Range Science, Brigham Young University, Provo, Utah 84602, U.S.A.; ¹Current address: Department of Botany, University of Karachi, Karachi-75270. Pakistan; *Author for correspondence: Department of Botany and Range Science, Brigham Young University, Provo, Utah 84602, U.S.A.; Tel: 1-801-378-2237; Fax: 1-801-378-7499; E-mail: Darrell_Weber@byu.edu

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Abstract

Kochia scoparia is one of the most common annual halophytes found in the Great Basin. Seeds were collected from a population growing in a salt playa at Faust, Utah and were germinated at 5 temperature regimes (12 h night/12 h day, 5–15 °C, 10–20 °C, 15–25 °C, 20–30 °C and 25–35 °C) and 6 salinities (0, 200, 400, 600, 800 and 1000 mM NaCl) to determine optimal conditions for germination and recovery of germination from saline conditions after being transferred to distilled water. Maximum germination occurred in distilled water, and an increase in NaCl concentration progressively inhibited seed germination. Few seeds germinated at 1000 mM NaCl. A temperature regime of 25 °C night and 35 °C day yielded maximum germination. Cooler temperature 5–15 °C significantly inhibited seed germination. Rate of germination decreased with increase in salinity. Germination rate was highest at 25–35 °C and lowest at 5–15 °C. Seeds were transferred from salt solutions to distilled water after 20 days and those from high salinities recovered quickly at warmer temperature regimes. Final recovery germination percentages in high salt treatments were high, indicating that exposure to high concentration of NaCl did not inhibit germination permanently.

Introduction

Kochia scoparia (L.) Schrader (Chenopodiaceae) also known as Summer-cypress is an annual herb, distributed along the roadsides, canal banks, field margins and other waste places in salt marsh, sedge-rush, mountain brush, and Pinyon-juniper communities at 850 to 1985 m in probably all Utah counties. It was introduced to the United States as an ornamental plant in the early 1900's and has become naturalized in the central and western United States (Welsh et al., 1987). This is a highly palatable, nutritious, and productive forage species (Vavra et al., 1977).

Halophytes from the Great Basin usually are very highly salt tolerant during the germination period (Khan and Ungar, 1999). Maximum germination of these halophytes is reported in non-saline control (Khan and Weber, 1986; Khan et al., 1987) and their germination decreased with increases in salin-

ity. Great Basin species reported to be highly salt tolerant at the germination stage include *Salicornia bigelovii* (856 mM NaCl, Rivers and Weber, 1971); *Salicornia pacifica* var. *utahensis* (856 mM NaCl, Khan and Weber, 1986); *Kochia americana* (1712 mM NaCl, Clarke and West, 1969); *Triglochin maritima* (400 mM NaCl, Khan and Ungar, 1999); *Suaeda moquinii*, *Salicornia rubra*, and *Halogeton glomeratus* (1000 mM NaCl, Khan, Gul and Weber, unpublished data). The rate of germination also decreased with the increase in salinity and was usually much lower at highest salinities (Khan and Ungar, 1999).

Several factors (water, temperature, light and salinity) interact in the soil interface, which regulate seed germination. They may even co-act with the seasonal variation in temperature to determine the temporal pattern of germination. Osmotic and matric potential narrow the range of temperature that is effective

for the germination of temperate halophytes such as *Hordeum jubatum* (Badger and Ungar, 1989), *Suaeda depressa* (Ungar and Capilupo, 1969), *Salicornia bigelovii* (Rivers and Weber, 1971), *Atriplex triangularis* (Khan and Ungar, 1984), *Polygonum aviculare* (Khan and Ungar, 1998a); *Triglochin maritima* (Khan and Ungar, 1999) and *Allenrolfea occidentalis* (Gul and Weber, 1999).

The ability of the seeds to remain viable after a long-term exposure to soil salinity have been reported (Woodell, 1985; Keiffer and Ungar, 1995; Khan and Ungar, 1996, 1997b, 1998ab, 1999) but little data is available for *Kochia scoparia*. Halophytes show a range of responses from partial to complete recovery when salinity stress is alleviated (Woodell, 1985; Ungar, 1991) and this variation could be due to change in thermoperiod (Khan and Ungar, 1999).

Kochia scoparia is one of the highly palatable forage species from the Great Salt Lake region of Utah. Initial establishment of the species in salt marsh habitats is related to germination response of seeds to salinity and temperature regimes and this usually determines if a population will survive to reproductive maturity. Each species has very specific germination requirements and response to stress. This leads us to study the effect of salinity and temperature on total germination, rate of germination, and ability of seeds to recover from high salt stress under different thermoperiod regimes.

Methods

Seeds of *Kochia scoparia* were collected during the fall 1996 from a salt marsh located 30 miles south of the Great Salt Lake, at Faust, Utah. Seeds were separated from inflorescence, air-dried and stored at 4 °C. Germination studies were started during August 1997. Seeds were surface sterilized using the fungicide Phygon. Germination was carried out in 50 × 9-mm (Gelman No. 7232) tight-fitting plastic petri dishes with 5 ml of test solution. Each dish was placed in a 10-cm-diameter plastic petri dish as an added precaution against loss of water by evaporation. Four replicates of 25 seeds each were used for each treatment. Seeds were considered to be germinated with the emergence of the radicle.

To determine the effect of temperature on germination, 12h alternating temperature regimes 5–15 °C, 10–20 °C, 15–25 °C, 20–30 °C and 25–35 °C, were used. Seeds were germinated in distilled water, and

200, 400, 600, 800 and 1000 mM NaCl at the above mentioned temperature regimes. The percentage germination was recorded every alternate day for 20-days. Ungerminated seeds from the 20-day NaCl treatments were transferred to distilled water to study the recovery of germination, which was also recorded at 2-day intervals for 20 days. The recovery percentages was determined by the following formula: $(a-b)/(c-b)*100$, where a is the total number of seeds germinated after being transferred to distilled water, b is the total number of seed germinated in saline solution and c is the total number of seeds. The rate of germination was estimated by using a modified Timson index of germination velocity = $\Sigma G/t$, where G is the percentage of seed germination at 2-days intervals and t is the total germination period (Khan and Ungar, 1984). The maximum value possible using this index with our data was 50 (i.e., 1000/20). The higher the value, the more rapid the rate of germination.

Germination data (20 day and rate of germination) were transformed (arcsine) before statistical analysis. These data were analyzed using SPSS, V. 9 (SPSS Inc., 1999). A two way ANOVA was also used to demonstrate the significance of main factors (salinity × thermoperiod) and their interaction in affecting the rate and percentage germination.

Results

Temperature, salinity and their interaction significantly ($p < 0.0001$) affected the final percent germination of *Kochia scoparia* (Table 1). Seed germination was highest in distilled water and germination percentages decreased with increase in salinity (Fig 1). Low salinity (200 mM NaCl) did not have any effect on germination and there was little change in germination percentage after 10 days of treatment (Figure 1). High salinity inhibited seed germination, however, 24% of the seeds germinated at 1000 mM NaCl under optimal thermoperiod (Figure 1). Change in thermoperiod had little effect at 0 and 200 mM NaCl (Figures 1 & 2). However, higher concentrations of salinity interacted with temperature. Germination percentages improved with an increase in temperature under higher salinity treatments (Figures 1 & 2). The rate of germination (Timson's Index) decreased with an increase in salinity (Table 2). Germination rate was highest at the warmer thermoperiod (25–35 °C) and lowest at 5–15 °C. Different thermoperiods and salinity concentration individually, and their interaction

Table 1. Results of Two-way ANOVA of characteristics by salinity, thermoperiods and their interaction.

Independent variable	Salinity	Thermoperiod	Salinity × thermoperiod
Percent germination	235.6***	8.1***	3.6***
Rate of germination	359.2***	29.0***	3.4***
Percent germination after transfer to distilled water	21.2***	11.8***	3.0***
Percent recovery	87.8***	15.0***	3.9***
Rate of recovery	50.3***	9.4***	2.2**

Note: Number represents F-values. ** $p < 0.01$; *** $p < 0.001$.

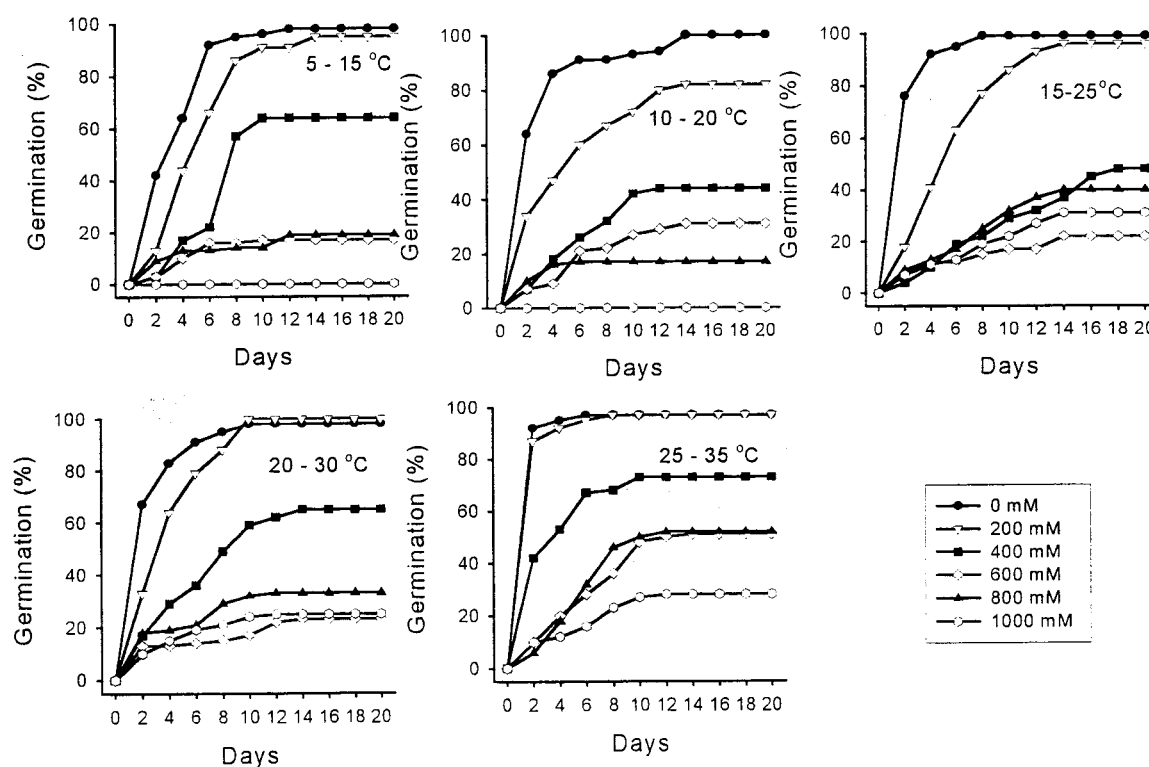


Figure 1. Rate of germination of *Kochia scoparia* seeds in 0, 200, 400, 600, 800 and 1000 mM NaCl at thermoperiods of 5–15 °C, 10–20 °C, 15–25 °C, 20–30°C, and 25–35 °C.

were significant ($p < 0.0001$) in affecting the rate of germination of *K. scoparia* seeds (Table 1).

After 20 d of salinity treatment, seeds were transferred to distilled water to study the recovery of germination after prolonged exposure to salinity. The results presented in Figure 2 showed that there was almost complete recovery at 5–15 °C, 10–20 °C, and 15–25 °C and partial recovery at 20–30°C and 25–35 °C. Percent recovery data indicated a higher re-

covery at lower temperature regimes (Figure 3). Rate of recovery does not differ significantly with change in temperature (Table 3). A two-way ANOVA of rate of recovery indicated significant ($p < 0.0001$) main effects of salinity and thermoperiod (Table 1).

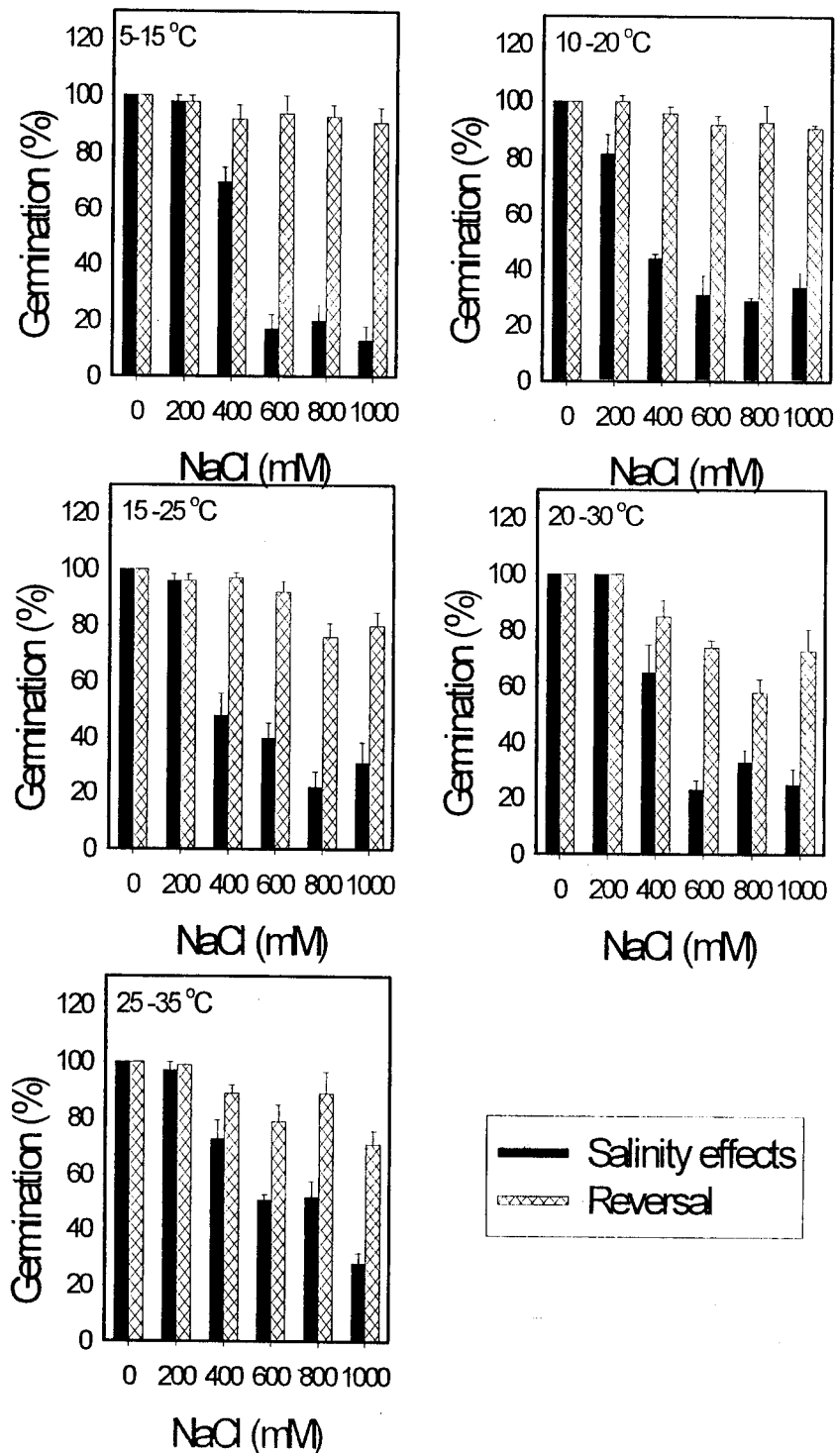


Figure 2. Mean (\pm SE) final germination percentages in salinity and recovery from salinity of *Kochia scoparia* seeds when transferred to distilled water from 0, 200, 400, 600, 800 and 1000 mM NaCl at thermoperiods of 5–15 °C, 10–20 °C, 15–25 °C, 20–30 °C, and 25–35 °C.

Table 2. Rate (Mean \pm SE) of germination of *Kochia scoparia* at 0, 200, 400, 600, 800 and 1000 mM NaCl at thermoperiods of 5–15 °C, 10–20 °C, 15–25 °C, 20–30 °C and 25–35 °C.

NaCl (mM)	5–15 °C	10–20 °C	15–25 °C	20–30 °C	25–35 °C
0	44 \pm 0.21	46 \pm 1.5	45 \pm 0.9	46 \pm 1.6	48 \pm 1.2
200	39 \pm 1.7	34 \pm 3.0	38 \pm 0.9	43 \pm 1.2	48 \pm 2.1
400	24 \pm 2.6	17 \pm 0.3	14 \pm 1.1	26 \pm 4.3	33 \pm 2.8
600	7 \pm 2.1	12 \pm 3.0	9 \pm 1.4	9 \pm 0.8	20 \pm 1.5
800	8 \pm 2.0	8 \pm 1.3	15 \pm 2.7	14 \pm 1.6	21 \pm 2.1
1000	0 \pm 0.0	0 \pm 0.0	11 \pm 2.7	11 \pm 2.4	11 \pm 1.3

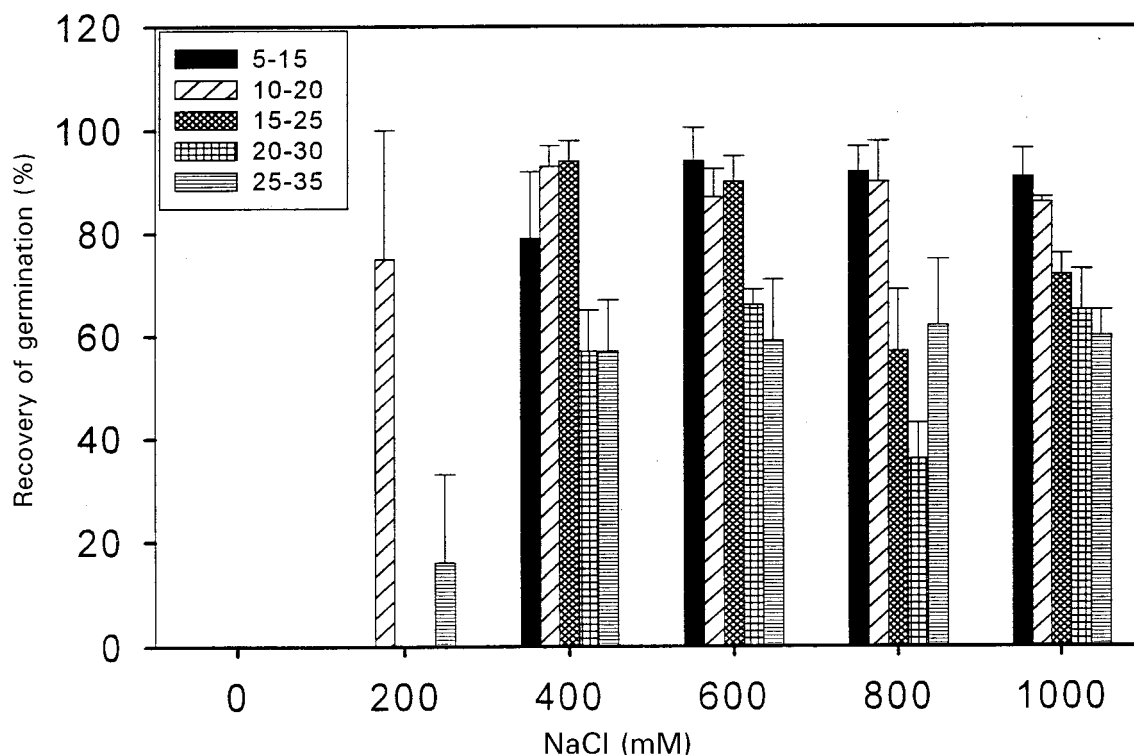


Figure 3. Percent recovery of germination of *Kochia scoparia* seeds after they are transferred from 0, 200, 400, 600, 800 and 1000 mM NaCl to distilled water at thermoperiods of 5–15 °C, 10–20 °C, 15–25 °C, 20–30 °C, and 25–35 °C.

Discussion

Deserts are regions of low and irregular rainfall in which potential evapotranspiration exceeds precipitation. In certain areas, the water table is high and a high rate of evaporation causes an accumulation of salts on the surface of the soil. These harsh conditions have led to differential life history strategies in desert plants in order to maximize their fitness (Kigel, 1995).

Seeds of *Kochia scoparia* germinated (28%) at 1000 mM NaCl treatment. Rivers and Weber (1971) reported that seeds of *Salicornia bigelovii* could germinate up to 1369 mM NaCl. Khan and Weber (1986) reported that the germination of Great Basin halophyte *Salicornia pacifica* var. *utahensis* was reduced from 55% in distilled water to 3% germination at 856 mM NaCl. No seeds of *Allenrolfea occidentalis* could germinate beyond 800 mM NaCl (Gul and Weber, 1999).

Table 3. Rate (Mean \pm SE) of germination recovery of *Kochia scoparia*. After they transferred from 0, 200, 400, 600, 800 and 1000 mM NaCl to distilled water at thermoperiods of 5–15 °C, 10–20 °C, 15–25 °C, 20–30 °C and 25–35 °C.

NaCl (mM)	5–15 °C	10–20 °C	15–25 °C	20–30 °C	25–35 °C
0	50 \pm 0.0	50 \pm 0.0	50 \pm 0.0	50 \pm 0.0	50 \pm 0.0
200	49 \pm 1.0	49 \pm 0.3	48 \pm 1.2	50 \pm 0.0	50 \pm 0.0
400	44 \pm 2.6	45 \pm 1.6	45 \pm 1.1	41 \pm 3.0	48 \pm 1.0
600	42 \pm 2.8	42 \pm 1.1	41 \pm 1.0	34 \pm 1.5	43 \pm 1.8
800	42 \pm 2.0	41 \pm 2.6	36 \pm 1.9	28 \pm 2.3	34 \pm 1.3
1000	40 \pm 2.3	40 \pm 0.6	36 \pm 2.2	34 \pm 3.5	41 \pm 4.5

Great Basin halophytes that are known to tolerate high salinity at germination stage include *Suaeda linearis* and *Tamarix pentandra* (842 mM NaCl, Ungar, 1962, 1967); *Kochia americana* (1712 mM NaCl, Clarke and West, 1969); *Salicornia bigelovii* (1369 mM NaCl, Rivers and Weber, 1971); *Salicornia pacifica* var. *utahensis* (Khan and Weber, 1986); *Allenrolfea occidentalis* (800 mM NaCl, Gul and Weber, 1999); and *Salicornia rubra* and *Suaeda moquinii* (1000 mM NaCl, Khan, Gul and Ungar, unpublished data). It is interesting to note that so many different highly salt tolerant species are found in Great Basin desert compared to few species with similar tolerance reported from elsewhere (Khan, 1991; Onnis and Micelli, 1975; Khan and Gul, 1998).

Salt marshes and playas in the Great Basin are exposed to greater variation in temperature and salinity during the germination period ranging from early cooler temperatures and low soil salinity to hot temperatures and high salinities at the end of a germination period (Gul, 1998). Halophytes that germinate in these condition should have the ability to cope with this large variation in temperature and salinity (Khan and Weber, 1986) and this makes salinity and temperature the most important ecological factors determining the germination of Great Basin halophytes. Temperature and salinity have been reported to interact in affecting the seed germination of halophytes (Rivers and Weber, 1971; Khan and Weber, 1986; Khan and Ungar, 1996, 1997b, 1998ab, 1999; Khan and Gul, 1998; Gul and Weber, 1999). Our data showed that *K. scoparia* had poor germination under the low temperature regime (5–15 °C), the germination progressively improved with an increase in temperature and best germination was obtained at 25–35 °C. Similar results are reported for *Allenrolfea occidentalis*, *Suaeda moquinii*

and *Salicornia rubra* (Gul and Weber, 1999; Khan, Gul and Weber, unpublished data).

Seeds of *K. scoparia* from the Faust, Utah population, when transferred to distilled water after a 20-d treatment at various salinity concentrations responded differentially under different temperature regimes. Our data showed almost complete recovery at cooler temperature regime and only a partial recovery at warmer temperatures. Recovery was also inhibited in high salinity treatments at warmer temperatures. Gul and Weber (1999) reported that seeds of *Allenrolfea occidentalis* from high salinities recovered quickly (85 to 100%) at all temperature regimes. Khan and Ungar (1997a) reported that the percentage of ungerminated seeds that recovered when they were transferred to distilled water differed significantly with variation in species and thermoperiods. *Zygophyllum simplex* had little recovery from all NaCl concentrations in all thermoperiods. *Haloxylon recurvum*, *Suaeda fruticosa*, and *Triglochin maritima* showed substantial recovery. Khan and Gul (1998) reported that seeds of *Arthrocnemum indicum* recovered quickly and about 86% seeds after exposure to high salinity (1000 mM NaCl). Similar recovery germination responses were also reported for *Polygonum aviculare* (Khan and Ungar, 1998a) and *Suaeda fruticosa* (Khan and Ungar, 1998b). Non-dormant seeds of glycophytes may die when exposed to salinity (Partridge and Wilson, 1987), while those of halophytes do not (Keiffer and Ungar, 1995).

Kochia scoparia seeds are very highly salt tolerant at germination and its tolerance increased with an increase in temperature and germinated best at 25–35 °C. This is consistent with previous reports on the degree of salt tolerance of other Great Basin halophytes like *Salicornia utahensis*, *S. rubra*, *Suaeda torreyana* and *Allenrolfea occidentalis*. A significant

departure from the trend is noticed in the recovery pattern. Although there was substantial recovery of germination at all temperature regimes, recovery was higher under cooler thermoperiods. Seeds present in the soil are exposed to cooler conditions and low salinity during the late spring and this situation may enhance the germination and recruitment earlier in the season. However, seeds would still be able to germinate when conditions get warmer. It appears that better recovery response at cooler temperatures confers the advantage of preempting sites before other species could germinate and this would give *K. scoparia* an excellent opportunity to successfully colonize.

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