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Forage Kochia Germination Response to Temperature, Water Stress, and Specific Ions[1]

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ABSTRACT

Forage kochia [*Kochia prostrata* (L.) Schrad.] may be useful for revegetating salt affected soils. This study was designed to quantify the effects of temperature, water stress, and specific ions on the germination of 'Immigrant' forage kochia. Fruits and seeds were germinated at 10, 20 and 30°C in solutions of polyethylene glycol (PEG) with osmotic potentials ranging from −0.52 to −2.32 MPa. Seeds were also germinated at 20°C in PEG solutions containing 0 to 53 640 μmol L^{-1} potassium chloride (KCl–PEG) and 0 to 68 480 μmol L^{-1} sodium chloride (NaCl–PEG) with osmotic potentials ranging from −0.3 to −2.2 MPa. Germination was reduced by declining osmotic potentials. Total germination was highest at 20°C and lower at 10 and 30°C. Germination in NaCl-PEG and KCl-PEG solutions was primarily reduced by low osmotic potentials; percent germination was not affected by increasing NaCl concentrations but was reduced by increasing KCl concentrations. Number of days to 50% final germination was similar in both salts, increasing as osmotic potential declined and salt concentration increased. Forage kochia appears moderately tolerant of NaCl and KCl during germination and growth and may be well suited for revegetating salt affected soils in the Intermountain Region. Fruits are recommended for planting because abnormal germination was less than with seeds. Forage kochia should be sown prior to periods when soil temperatures are in the 10 to 20°C range, and cultural practices that extend the period of high soil osmotic potentials should be used to maximize seed germination.

***Additional index words:* *Kochia prostrata* (L.) Schrad., Range seeding, Fruits, Seeds, Potassium chloride, Sodium chloride, Polyethylene glycol.**

FORAGE kochia or prostrate kochia [*Kochia prostrata* (L.) Schrad], a half-shrub of the Chenopodiaceae family, appears useful for revegetating greasewood (*Sarcobatus vermiculatus* (Hook.) Torr.] communities in the Intermountain Region (McArthur et al., 1974; 1978). The species is salt tolerant (Francois, 1976; McArthur et al., 1978), drought resistant (Blauer et al., 1976), and produces high quality forage (Davis, 1979; Welch and Davis, 1984). When forage kochia is used for revegetating extensive tracts of rangelands, direct seeding will probably be necessary due to the higher cost of propagating and planting bare root stock or container grown transplants. Forage kochia establishes well from container grown transplants (Van Epps and McKell, 1983), but reports on establishment from direct seeding show inconsistent success (Keller and Bleak, 1974; Blauer et al., 1976; Stevens and Van Epps, 1984). To maximize establishment of forage kochia from direct seeding into salt affected soils of greasewood communities (Rollins et al., 1968), germination requirements must be understood.

Soils of greasewood communities usually have high concentrations of sodium, and potassium concentrations may also be high (Shantz and Piemeisel, 1940; Gates et al., 1956; Rickard, 1965; Wallace et al., 1973; Roundy, 1984). Salinity can decrease germination and growth by reducing osmotic potential of the soil solution, modifying concentrations of toxic ions, or producing imbalances of soil nutrients (Hayward and Bernstein, 1958; Ungar, 1982). The effect of ions on germination varies with species or cultivars, environmental conditions, and osmotic potential (Dewey, 1960; Ayers, 1962; Redmann, 1974; Ungar, 1978). Depending on the specific ions, germination may be stimulated, depressed, or unaffected (Choudhuri, 1968; Hyder and Yasmin, 1972; Ungar, 1978; Roundy et al., 1985).

The purpose of this research was to quantify the effects of temperature, water stress, sodium chloride, and potassium chloride on the germination of 'Immigrant' forage kochia.

MATERIALS AND METHODS

Fruits (utricles) of Immigrant forage kochia were harvested during 1981 and 1982 from plants grown near Ephraim, UT. Harvested fruits were sent to the Eastern Oregon Agricultural Research Center near Burns, OR, and stored in a laboratory for approximately 180 days before germination was tested. All studies were conducted with fruits sorted by air to reduce variation in size; the heavier one-half of each seed lot was studied.

Experiment 1 was conducted to determine the influence of seed appendages on germination of the 1981 seed lot at three temperatures and six osmotic potentials. Two classes of seeds were used: fruits with seeds fully enclosed by bracts, and naked seeds whose bracts had been removed by gentle hand rubbing.

Osmotic solutions were prepared by adding polyethylene glycol (PEG) (MW 6000) to distilled water as described by Michel and Kaufmann (1973). Osmotic potentials were determined the sixth and twelfth day of the study for filter paper discs placed in each Petri dish with a Wescor[3] HR-33T microvoltmeter and a Wescor[3] C-52 sample chamber psychrometer (Wescor, Inc., Logan, UT) after calibration with standard NaCl solutions. Osmotic potentials were similar between dates of determination. Thus, they were averaged for analyses. Osmotic potentials ranged from −0.56 to −2.32 MPa at 10°C, −0.52 to −2.10 MPa at 20°C, and −0.56 to −2.10 MPa at 30°C.

Twenty-five fruits or seeds were incubated on a #4 Whatman[3] filter paper disk (Whatman, Inc., Clifton, NJ) underlain by germination blotter and moistened with 25 mL of osmotica in each Petri dish. Dishes were covered and sealed in plastic bags to prevent desiccation and arranged in incubators in a randomized complete block design with four replications per seed class and osmotic potential. Seeds were incubated at 10, 20 and 30°C without light for 14 days. Germination was recorded daily for the first 10 days and at 2-day intervals through 14 days. Seeds were considered germinated when the embryo was completely uncoiled and the hypocotyl arch was raised (Young et al., 1981). Germination was recorded as abnormal for seeds in which the embryo uncoiled but the hypocotyl arch was not raised. The number

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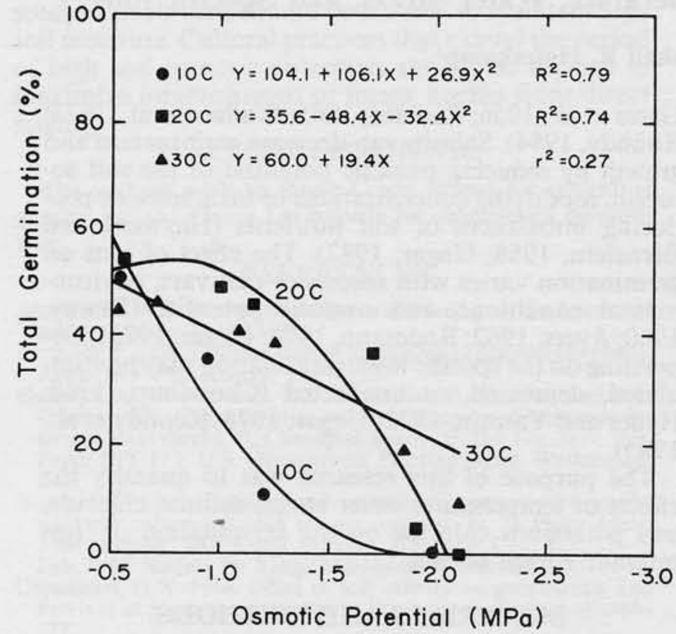

Fig. 1. Total percent germination of forage kochia fruits and seeds as affected by water potential at constant temperatures of 10, 20, and 30°C. Each symbol represents the means of eight replications.

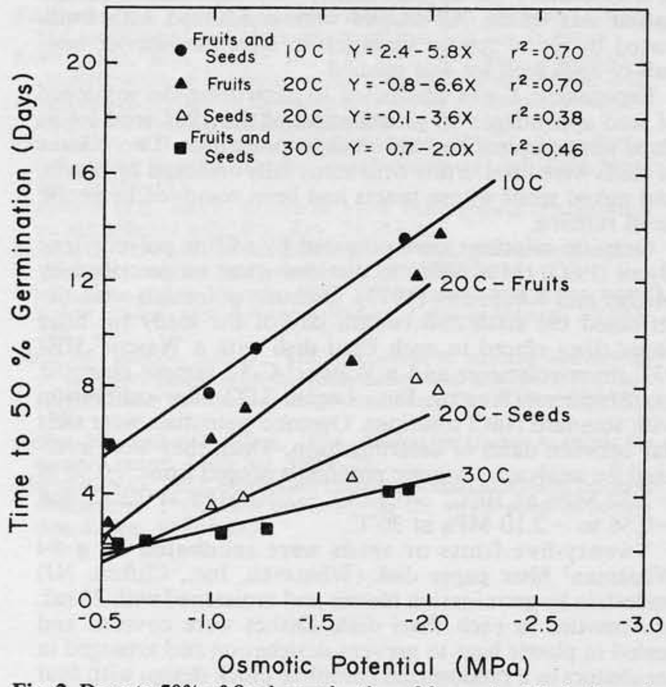

Fig. 2. Days to 50% of final germination of forage kochia fruits and seeds as affected by water potential at constant temperatures of 10, 20, and 30°C. Each symbol represents the mean of eight replications at 10 and 30°C. At 20°C, each symbol represents the mean of four replications.

of days to 50% of final germination was used to quantify germination rate.

In Experiment 2, the effects on germination of five levels of water stress combined with five concentrations of sodium chloride (NaCl) or potassium chloride (KCl) were examined with naked seeds from the 1982 seedlot. Osmotic solutions were prepared by adding PEG (MW 20000) to distilled water, and solutions were buffered to pH 8.0 with Tris [tris-(hydroxylmethyl)amino-methane] buffer. Each solution was divided into 9 aliquots, and, as needed, NaCl or KCl 2 mol L^{-1} solutions were added to bring solutions to 0, 8 560, 17 120, 34 240, and 68 480 μmol L^{-1} for NaCl and 0, 6 705, 13 410, 26 820, and 53 640 μmol L^{-1} for KCl. The addition of NaCl and KCl should have reduced the osmotic potential of PEG solutions, but differences in osmotic potentials between salt concentrations were not detected using psychrometric procedures. Osmotic potentials averaged −0.3, −0.7, −1.2, −1.6, and −2.2 MPa for the respective concentrations of NaCl and KCl.

Petri dishes were prepared as described above, and 50 seeds were placed in each dish. Seeds were incubated in dark incubators at 20°C, and germination was recorded at 2-day intervals up to 14 days. In Experiment 2, treatments were applied factorially in a randomized complete block design with two replications in each of three blocks. Time was used as a blocking factor with experiments repeated at approximately 2-week intervals.

Within experiments, osmotic potentials were not significantly different from final potentials; osmotic potentials recorded on each date of determination were averaged for statistical analyses. Data from experiments were initially analyzed with a factorial analysis of variance (Snedecor and Cochran, 1980). Polynomial response curves were developed for the seed appendage study, and multiple linear regression was used to develop response surfaces for the water potential and specific ion experiment. Counts were transformed with arcsin $\sqrt{\hat{p}}$ (Snedecor and Cochran, 1980) for analysis of variance; untransformed data were used in regression analyses. All statistical tests were conducted using $P = 0.05$.

RESULTS

Effects of Osmotic Potential, Temperature, and Seed Appendages on Germination

Total percent germination was similar for fruits and seeds (data not shown), but the osmotic potential × temperature interaction was significant ($P=0.05$). Thus, data were analyzed with regression analyses within temperatures. Total percent germination was lowest at 10°C and higher at 20 and 30°C (Fig. 1). As temperature increased, the coefficient of determination between osmotic potential and germination percentage decreased (Fig. 1).

Seeds and fruits incubated at 10°C germinated at osmotic potentials greater than −2.0 MPa (Fig. 1). At 20°C, germination occurred at osmotic potentials above −2.1 MPa (Fig. 1); germination was observed at all osmotic potentials tested at 30°C (Fig. 1). Variation in observed germination was high at 30°C, and percent germination was linearly related to osmotic potentials; higher order models were not significant ($P=0.05$).

At all temperatures, osmotic potential and the number of days to 50% of final germination were linearly related (Fig. 2). Germination was fastest at 30°C and slowest at 10°C. At 20°C, seeds germinated faster than fruits, but at 10 and 30°C, fruits and seeds germinated at similar rates.

Although germination percentage was similar for fruits and seeds, abnormal germination was greater in seeds (Table 1). Significantly ($P=0.05$) more seeds than fruits germinated abnormally at 10 and 20°C but not at 30°C.

Table 1. Mean percent abnormal germination of forage kochia averaged over water potentials within temperatures. Values in parentheses are 95% confidence limits.

Incubation temperature (°C)	Seeds	Fruits
	Abnormal germination (%)	
10	16.8 (7.9)	3.0 (1.6)
20	17.2 (7.5)	6.7 (2.8)
30	8.3 (3.9)	4.0 (2.0)

Effects of Osmotic Potential, Sodium Chloride, and Potassium Chloride

Total germination and abnormal germination in NaCl–PEG solutions were related only to osmotic potential (Table 2); as osmotic potential declined, total germination decreased and abnormal germination increased (Table 2). Number of days to 50% of final germination was related to osmotic potential and the interaction of osmotic potential and NaCl concentration (Table 2). As osmotic potential decreased and salt concentration increased, days to 50% of final germination increased.

In KCl–PEG solutions, total germination and days to 50% of final germination were related to osmotic potential and KCl concentration (Table 2). As osmotic potential declined and KCl concentration increased, total germination decreased, and it took longer to reach 50% of final germination. Osmotic potential was the only significant factor ($P=0.05$) affecting abnormal germination (Table 2); abnormal germination increased as osmotic potential decreased.

DISCUSSION

Fruits of forage kochia should probably be planted instead of seeds. Total germination of fruits and seeds was not significantly different, but more seeds than fruits germinated abnormally at all temperatures and osmotic potentials tested. Sowing seeds during periods of high soil moisture may give rapid establishment, but attrition of the seed and seedling populations may be high under transient moisture conditions.

Higher abnormal germination for seeds than for fruits reflects a change in the structural or functional integrity of seeds associated with bract removal. Although it is possible seeds were damaged by bract removal, no physical damage was observed. Fruit bracts may be important in mineral nutrition during early phases of germination of halophytes. In another halophyte, *Sarcobatus vermiculatus*, seed appendages are a source of sodium for seedlings (Eddleman and Romo, 1987). Endogenous calcium and magnesium in fruit bracts of *Eurotia lanata* are important for germinating seeds and for hypocotyl growth of seedlings (Booth, 1985). The presence of calcium is paramount for maintaining membrane structure, enzyme activity (Bangerth 1979), ion transport, and ion balance (Rains, 1972). Calcium deficiencies can cause abnormal root and shoot growth (Marinos, 1962; Helms, 1971; Idris and Aslam, 1975) similar to that observed for forage kochia in this study. The role of fruit bracts in mineral nutrition of germinating seeds of forage kochia should be evaluated.

Forage kochia seeds and fruits germinated over a broad range of temperatures and osmotic potentials. Germination was closely related to osmotic potential at 10 and 20°C; at 30°C, the relationship between osmotic potential and germination was weak. This weak relationship at 30°C implies that temperature-imposed limitations on germination were greater than osmotic effects at 30°C. These data agree with the findings of Young et al. (1981) that seed vigor of prostrate kochia is low when incubated at 30°C and higher. Since effects of osmotic potential on germination were more predictable at 10 and 20°C, seeding should be done earlier in the season prior to occurrence of temperatures in this range. Seedbed temperatures of 10 to 20°C, in combination with high soil osmotic potential, should yield good germination. In the Intermountain Region, this combination of conditions usually exists in fall or spring.

Francois (1976) concluded that mature prostrate kochia plants were salt tolerant. Results of this study confirm that forage kochia was also moderately tolerant of high NaCl and KCl concentrations during germination. Tolerance of a wide range of salt concentrations has been reported for *Kochia americana* (Clarke and West, 1969), *Kochia scoparia* (Everitt et al., 1983), and several other halophytes (Ungar, 1962; Workman and West, 1967; Clarke and West, 1969; Romo and Eddleman, 1985). Of the ions common in saline soils, sodium is the usually the least toxic to germination of halophytes (Ungar, 1978); germination of halophytes is generally reduced more by osmotic potential than specific ions (Ungar, 1982). Similarly, germination of forage kochia was primarily reduced by declining osmotic potentials, but germination in a small proportion of the population was reduced by increasing KCl concentrations. The neutral effect of NaCl on total germination and abnormal germination is particularly important because Na^+ is often abundant in soils on western rangelands (Shantz and Piemeisel, 1940; Gates et al., 1956; Hayward and Bernstein, 1958; Roundy, 1984). Since osmotic potential reduced germination more than did NaCl or KCl,

Table 2. Regression equations and coefficients of determination for total germination, days to 50% of final germination, and abnormal germination for forage kochia seeds incubated 14 days in NaCl–PEG and KCl–PEG solutions in Experiment 2.

	Regression equations†			
	NaCl–PEG		KCl–PEG	
Dependent variable	Equation	R^2	Equation	R^2
Total germination (%)	$Y = 90.60 - 5.75X_1 - 21.48X_1^2$	0.95	$Y = 95.03 + 6.08X_1 - 15.11X_1^2 + 0.0001X_1X_2$	0.94
Days to 50% of final germination	$Y = 1.91 - 1.57X_1 + 0.75X_1^2 - 0.00001X_1X_2$	0.76	$Y = 1.75 - 2.32X_1 + 0.51X_1^2 - 0.00001X_1X_2$	0.90
Abnormal germination	$Y = 1.06 - 7.41X_1 + 7.73X_1^2$	0.85	$Y = 0.66 - 7.69X_1 + 7.78X_1^2$	0.84

† X_1 = Osmotic potential (−MPa). X_2 = salt concentration (μmol L^{-1}).

seedbed treatments should be selected to maintain high soil moisture. Cultural practices that extend the period of high soil osmotic potentials should be applied to maximize establishment of forage kochia from direct seeding.

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REFERENCES

Ayers, A.D. 1952. Seed germination as affected by soil moisture and salinity. Agron. J. 44:82–84.

Bangerth, F. 1979. Calcium-related physiological disorders of plants. Annu. Rev. Phytopathol. 17:97–122.

Blauer, C.A., P. Plummer, E.D. McArthur, R. Stevens, and B.C. Giunta. 1976. Characteristics and hybridization of important intermountain shrubs. II. Chenopod family. USDA For. Serv. Res. Paper INT-117. U.S. Government Printing Office, Washington, DC.

Booth, D.T. 1985. Calcium and magnesium content of winterfat seedlings cultured at cold temperatures. p. 32. *In* Paper Abstr. 38th Meeting, Soc. Range Manage. Salt Lake City, UT. 11–15 Feb. 1985. Society for Range Management, Denver, CO.

Choudhuri, G.N. 1968. Effect of soil salinity on germination and survival of some steppe plants in Washington. Ecology 49:465–471.

Clarke, L.D., and N.E. West. 1969. Germination of *Kochia americana* in relation to salinity. J. Range Manage. 22:286–287.

Davis, A.M. 1979. Forage quality of prostrate kochia compared with three browse species. Agron. J. 71:822–824.

Dewey, D.R. 1960. Salt tolerance of twenty-five strains of *Agropyron*. Agron. J. 52:631–635.

Eddleman, L.E., and J.T. Romo. 1987. Sodium relations in seeds and seedlings of *Sarcobatus vermiculatus*. Soil Sci. In press.

Everitt, J.H., M.A. Alaniz, and J.B. Lee. 1983. Seed germination characteristics of *Kochia scoparia*. J. Range Manage. 36:646–648.

Francois, L.E. 1976. Salt tolerance of prostrate summer cypress (*Kochia prostrata*). Agron. J. 68:455–456.

Gates, D.A., L.A. Stoddart, and C.W. Cook. 1956. Soil as a factor influencing plant distribution on salt-deserts of Utah. Ecol. Monogr. 26:155–175.

Hayward, H.E., and L. Bernstein. 1958. Plant-growth relationships on salt-affected soils. Bot. Rev. 24:584–635.

Helms, K. 1971. Calcium deficiency of dark-grown seedlings of *Phaseolus vulgaris* L. Plant Physiol. 47:799–804.

Hyder, S.Z., and S. Yasmin. 1972. Salt tolerance and cation interaction in alkali sacaton at germination. J. Range Manage. 25:390–392.

Idris, M., and M. Aslam. 1975. The effect of soaking and drying seeds before planting on the germination and growth of *Triticum vulgare* under normal and saline conditions. Can. J. Bot. 53:1328–1332.

Keller, W., and A.T. Bleak. 1974. *Kochia prostrata*: A shrub for western ranges. Utah Sci. 35:24–25.

Marinos, N.G. 1962. Studies on submicroscopic aspects of mineral deficiencies. I. Calcium deficiency in the shoot apex of barley. Am. J. Bot. 49:834–841.

McArthur, E.D., B.C. Guinta, and A.P. Plummer. 1974. Shrubs for restoration of depleted ranges and disturbed areas. Utah Sci. 34:28–33.

———, A.P. Plummer, and J.N. Davis. 1978. Rehabilitation of game range in the salt desert. p. 23–50. *In* K.L. Johnson (ed.) Wyoming shrublands. Proc. 7th Wyoming Shrub Ecology Workshop, Laramie, WY. 31 May–1 June 1978. Range Management Division, University of Wyoming, Laramie, WY.

Michel, B.E., and M.R. Kaufmann. 1973. The osmotic potential of polyethylene glycol 6,000. Plant Physiol. 51:914–916.

Rains, D.W. 1972. Salt transport by plants in relation to salinity. Annu. Rev. Plant Physiol. 23:367–388.

Redmann, R.E. 1974. Osmotic and specific ion effects on the germination of alfalfa. Can. J. Bot. 52:803–808.

Richards, L.A. (ed.) 1954. Diagnosis and improvement of saline and alkali soils USDA Agric. Handb. 60. U.S. Government Printing Office, Washington, DC.

Rickard, W.H. 1965. The influence of greasewood on soil moisture penetraton and soil chemistry. Northwest Sci. 39:36–42.

Rollins, M.B., A.S. Dylla, R.E. Eckert, Jr. 1968. Soil problems in reseeding a greasewood-rabbitbrush range site. J. Soil Water Conserv. 23:138–140.

Romo, J.T., and L.E. Eddleman. 1985. Germination of greasewood (*Sarcobatus vermiculatus*) to temperature, water potential and specific ions. J. Range Manage. 38:117–120.

Roundy, B.A. 1984. Estimation of water potential components of saline soils of Great Basin rangelands. Soil Sci. Soc. Am. J. 48:645–650.

———, J.A. Young, and R.A. Evans. 1985. Germination of basin wildrye and tall wheatgrass in relation to osmotic and matric potential. Agron. J. 77:129–135.

Shantz, H.L., and R.L. Piemeisel. 1940. Types of vegetation in Escalante Valley, Utah, as indicators of soil conditions. USDA Tech. Bull. 173. U.S. Government Printing Office, Washington, DC.

Snedecor, G.W., and W.C. Cochran. 1980. Statistical methods. The Iowa State University Press, Ames, IA.

Stevens, R., and G.A. Van Epps. 1984. Seeding techniques to improve establishment of forage kochia [*Kochia prostrata* (L.) Schrad.] and fourwing saltbush [*Atriplex canescens* (Pursh) Nutt.]. p. 269–272. *In* A.R. Tiedemann et al. (compilers) Proc. Symp. of the Biol. of *Atriplex* and Related Chenopods, Provo, UT. 2–6 May 1983. USDA For. Serv. Gen. Tech. Rep. INT-172. U.S. Government Printing Office, Washington, DC.

Ungar, I.A. 1962. Influence of salinity on seed germination in succulent halophytes. Ecology 43:763–764.

———. 1978. Halophyte seed germination. Bot. Rev. 44:233–264.

———. 1982. Germination ecology of halophytes. p. 143–154. *In* D.N. Sen and K.S. Rajpurohit (ed.) Tasks for vegetation science. Vol. 2. Dr. W. Junk BV, Publishers, The Hague.

Van Epps, G.A., and C.M. McKell. 1983. Effect of weedy annuals on the survival and growth of transplants under arid conditions. J. Range Manage. 36:366–369.

Wallace, A., E.M. Rommey, and V.Q. Hale. 1973. Sodium relations in desert plants: 1. Cation contents of some plant species from the Mojave and Great Basin Deserts. Soil Sci. 115:284–287.

Welch, B.L., and J.N. Davis. 1984. *In vitro* digestibility of *Kochia prostrata* (L.) Schrad. Great Basin Nat. 44:296–298.

Workman, J.P., and N.E. West. 1967. Germination of *Eurotia lanata* in relation to temperature and salinity. Ecology 48:659–661.

Young, J.A., R.A. Evans, R. Stevens, and R.L. Everett. 1981. Germination of *Kochia prostrata* seed. Agron. J. 73:957–961.