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Kochia scoparia emergence from saline soil under various water regimes

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Abstract

Kochia scoparia **(L.) Schrad. invades disturbed soils and serves as a pioneer species on saline rangelands and sodic mine spoils. The percent germination of kochia seeds declined with increasing salinity, averaging -3.3 %/dS/m between 12 and 30 dS/m. The emergence and early survival of kochia seeded into 2 media whose respective saturated-paste extracts averaged 1 and 18 dS/m in electrical conductivity (EC_e) were investigated in a greenhouse under simulated rainfall regimes. Water was applied according to 3 average rates: 0.6 mm/day (low); 1.2 mm/day (medium); 2.5 mm/day (high). These rates were administered in 2 phases. Phase I (14 days) involved low and medium on the nonsaline seedbeds, and medium and high on the saline seedbeds. Phase II (42 days) followed sequentially on only the saline soil in phase-I:II combinations of high-high, high-medium, medium-medium, and medium-high. Kochia seedlings did not emerge under the low rate. Seedlings did emerge from the nonsaline seedbeds when watered at the medium rate, but failed to emerge from the saline seedbeds treated only at this rate. Seedlings emerged from the saline soil under all regimes that included the high rainfall rate. About 30 plants successfully emerged from every 100 seeds sown in the seedbeds where EC_e decreased to 15.7 dS/m or less. Despite the severely saline seedbed, kochia emerged within 3 days at a rate of 8 plants/day under the Phase I high regime because the water apparently diluted saline seedbed-solutions sufficiently for germination to occur. Phase II of the medium-high regime stimulated a similar response but only after 13 days under the wetter rate. Kochia's germination and emergence favor its addition to seed mixtures designed to establish forages in saline soils.**

Key Words: revegetation, reseeding, kochia forage, salinity, seedbed ecology, forage establishment, precipitation dependency

Saline soils are often found within western rangelands. Plant establishment on these soils can be very difficult, despite the seeding of forage mixtures which include salt-tolerant perennials (Majerus 1992). Many of the saline sites remain unproductive for years because of establishment problems.

Kochia (*Kochia scoparia* (L.) Schrad.) is a fast-growing annual that naturally invades freshly disturbed sites, and is frequently observed growing in saline soils (Braidek et al. 1984). Kochia also dominates in plant count and coverage among all the pioneer species in sodic soils resulting from surface mining activity (Wali and Freeman 1973). Kochia offers the possibility for obtaining a rapidly established, but short-lived, protective vegetative-cover on saline soils, that can also be harvested for forage (McClung et al. 1976, Vavra et al. 1977). Perhaps it should be considered as an addition to seeding mixtures. Iverson and Wali (1981) state that kochia competes poorly with the emerging perennial vegetation after its initial year in a site. This trait should allay concerns that the pioneering kochia will eventually dominate the rangelands.

Forage yields from kochia approach that of alfalfa, *Medicago sativa,* (Bell et al. 1952). If water is not limiting, annual forage yields of 11 t/ha have been measured (Sherrod 1971, Derdall 1988); however, available water limits production to averages between 4 and 7 t/ha. Harvested early, kochia is a palatable, nutritious forage (Green et al. 1986), possessing crude protein ranging from 11.3% to 22.6% (Erickson and Moxon 1947).

Everitt et al. (1983) investigated the germination characteristics of kochia seed produced in Texas. They observed that germination equalled 88% or more when the seeds were treated with distilled water, under 8 hours of light, and held at fixed temperatures between 5 and 25° C. Percentages began to decrease significantly when the seeds were placed on substrates treated with individual solutions of NaCl, $CaCl_2$, $MgCl_2$, KCl, Na_2SO_4, or $MgSO_4$ in concentrations giving electrical conductances exceeding a threshold of 20 ds/m. Kochia, under ideal conditions, germinates rapidly, commonly penetrating its seed coat within 24 hours.

The establishment of kochia from seeds placed in a saline seedbed requires that the seeds germinate and that the seedlings grow by either avoiding the salts or tolerating them (Bower and Tamimi 1979). Conceptionally, seeds imbibe water when potential

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energy gradients favor the movement of water from the soil into the seed (Hillel 1971). Adverse gradients in saline seedbeds may stop or slow this movement, preventing or retarding germination. Even if germination occurs, the infant seedling may not be able to grow or survive in the saline environment (Mohammad et al. 1989). Rainfalls in quantities sufficient to leach salts out of the seedbed may give germinating seeds only a temporary advantage as the soil surface dries and salts accumulate again (Roundy et al. 1984).

Hanson (1988) canvased 59 livestock producers about their experience in cultivating and using kochia as a feed. They reported that kochia often would not establish on their most saline soils and that it seemed to require some threshold quantity of precipitation in order to emerge; rainfall volumes near 12.5 mm were cited most frequently (personal communications). Lesser amounts were thought to establish kochia on slightly- or non-saline soils, but not where salinity was moderate to severe. The objectives of this study were to identify the attributes of kochia favoring its establishment on saline soils, and to determine if controls on the emergence and early survival of kochia in saline seedbeds reflect its germination capacity in saline solutions and the possible existence of threshold precipitation volumes.

Materials and Methods

A mature population of kochia plants growing under moderate to severe salinity 15 km north of Swift Current, Saskatchewan, provided seed for this study. Firm, healthy-looking seeds were selected, and their calyx and pericarp removed. Seeds were stored in cloth bags at 10° C under dry conditions until required for testing. All tests used seed that had been harvested within 17 months.

Germination Test

An experiment to determine the germination response of kochia while subjected to increasing levels of salinity was conducted in a controlled-environment cabinet. The 1.75-m^3 growth chamber contained a single shelf large enough (1.42 m^2) to suspend all the germination containers at 1 level (9 cm above the floor). This maximized uniformity in the exposure of the seeds to a daily 12-hour period of combined fluorescent and incandescent light. The chamber temperature varied within 1.5 degrees above or below the 15° C set-point, while the relative humidity was maintained above 85%.

The seeds were germinated in glass petri dishes (90-mm diameter by 16-mm deep) with lids. Each dish contained 60 g of washed and dried silica sand (0.1–0.3-mm diameter, 99% pure) covered with a single sheet of ashless No. 41 filter paper upon which 35 kochia seeds were placed.

Saline solutions were formed by adding equal masses of NaCl and $CaCl_2$ (analytical reagent grade) with distilled water to give concentrations having electrical conductances of 0, 4, 8, 12, 18, 24, and 30 dS/m. Each petri dish received 16 ml of solution taken from 1 of the 7 concentrations; care was taken to ensure good solution-to-seed contact. The petri dish was placed within a second glass container (120-mm diameter by 60-mm deep) and covered. The inner dish rested on solid glass rods (4-mm diameter) positioned in a layer of distilled water 2-mm deep. The system helped reduce water-vapor pressure gradients and evaporation from the substrate solutions.

Treatments were replicated 3 times and the experiment conducted with a completely randomized design. Seeds were considered to be germinated when radicles visibly protruded through the seed coat. Germination was counted daily and the number accumulated until all counts reached a constant. The germination percentage was calculated for each dish and the means computed for each treatment. Data were analyzed by analysis of variance and the means compared with Duncan's new multiple range test (Statistical Analysis System Institute 1990). Interpretations were made at the 0.05 probability level.

Emergence Test

The seedbed media for testing kochia emergence and survival were bulk-mixed, air-dried, and derived from:

a. Swinton, Orthic Brown Chernozem, loam topsoil [Aridic Haploboroll] (Canada Soil Survey Subcommittee on Classification 1978);

b. Swinton, Saline Brown Chernozem, loam topsoil [Salic Haploboroll] (Canada) Soil Survey Subcommittee on Classification 1978);

c. Commercial silica sand, 99.8% pure quartz.

The 2 Swinton soils differ only in degree of salinity, caused by accumulations of Na, Ca, Mg, and K salts of SO_4, and to a lesser extent of Cl. Although high concentrations of Na relative to other cations may cause nutrient deficiencies in some crops (Janzen and Chang 1987), Curtin et al. (1992) determined that kochia is not affected by this imbalance. Other unknown specific interactions may result from saline Swinton soil, but adverse osmotic gradients are likely to impart the major biological consequences.

Two seedbed media were prepared based on the Swinton soils. The first consisted solely of the nonsaline soil, and the second a 1:2 mixture (by mass) of the nonsaline and saline variants. Equal volumes of sand were added to each seedbed medium resulting in mass proportions (nonsaline:saline:sand) of 3:0:1 for the nonsaline medium and 1:2:1 for the saline medium. The sand was necessary to prevent surface cracking of the soil during the experiment. The electrical conductivity of solutions extracted from saturated-pastes (EC_e) of samples obtained from the homogenized mixtures averaged 1 and 18 dS/m following the procedure described by Rhoades (1982). Thus, testing involved 2 seedbeds, 1 nonsaline and the other salinized.

Tests were conducted in a greenhouse (Lat 50.2° N) using wood "flats" each measuring 396 mm by 344 mm by 100-mm deep and filled with either test medium. The flats, 8 with the nonsaline Swinton soil and 20 with the saline Swinton, were grouped by their seedbed medium, placed on expanded-metal benches 0.66 m above the greenhouse floor, and arranged in rows. The 4 rows per medium formed replicated blocks within which treatments were randomized. One flat per row in the saline group was left unseeded for soil sampling during the test. Each remaining flat was sown with 100 kochia seeds (nominally 1 mm in diameter) on a smooth surface and covered with 2 mm of seedbed medium.

The experiment, conducted with ambient temperature maintained between 16 and 24° C and with relative humidity kept with 45 to 70%, lasted 56 days during April and May. Rainfall was simulated by irrigating with distilled water from a sprinkle can fitted with an attachment designed to deliver a measured volume uniformly across the surface of the test medium within the flat. Individual irrigations were never of such a volume to force water to drain from the bottom of the flat.

The treatments followed irrigation schedules that simulated rainfalls which were chosen to detect the possible existence of threshold precipitation volumes operating to control kochia emergence and early survival. Three irrigation rates were selected based on preliminary greenhouse experiences and modeled as closely as possible to actual precipitation volumes measured in a Canadian standard gauge on the Agriculture Research Station near Swift Current and averaged from observations taken during April, May, and June over 8 years, 1983 through 1990 (Fig. 1). The mean precipitation rate for these 3 months equalled 1.27 mm/day. The test rates averaged 0.6, 1.2, and 2.5 mm/day, and are described in relative terms as low, medium, and high. The seedbed media prior

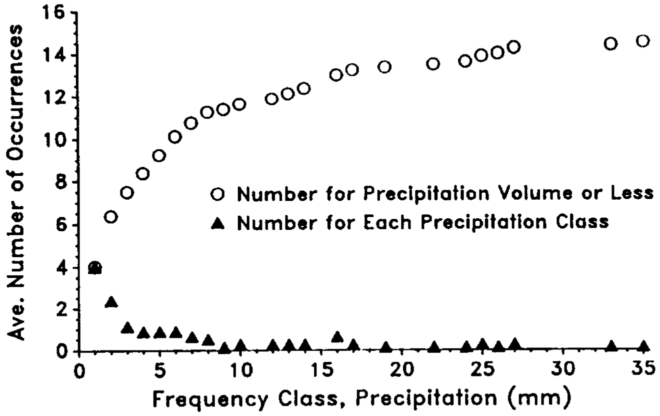

Fig. 1. The annual number of April, May, or June precipitation occurrences plotted for volume classes (0-1, 1-2, 2-3, . . 34-35 mm) and an accumulated precipitation of that class volume or less, recorded and averaged over 8 years (1983–90) from a Canadian standard precipitation gauge near Swift Current, Saskatchewan, (6 events which fell in classes >35 mm are not shown).

to the first irrigation were very dry (4.5% water by volume) to minimize any salt movement other than that resulting from the treatments. To overcome possible problems in the initial wetting of soil surface, irrigation volumes over the first 3 days were increased to 4.5, 9, and 12 mm for low, medium, and high, respectively.

The flats representing nonsaline seedbeds were irrigated at the low and medium rates, while the saline seedbeds were treated in combinations of the medium and high irrigation rates. The treatments applied to the nonsaline seedbeds followed either the low or the medium water regime for 14 days. The medium and high irrigation rates applied to the saline seedbeds were scheduled in 2 sequential periods or phases, I and II, spanning 14 and 42 days, respectively. Four combinations (medium-medium, medium-high, high-high, and high-medium) formed the 4 treatment-water-regimes tested on the saline seedbeds. The Phase II medium and high irrigations were applied to seedbeds whose antecedent water contents were greater than at the start of Phase I. Consequently, the water application rates were adjusted downward to 0.9 and 1.8 mm/day for the medium and high rates.

Measurements during the test involved counting the number of live kochia plants, monitoring the water volumes sprinkled, and sampling the seedbed media to index salinity. The total number of seedlings which had emerged and survived were counted daily and scaled as a percentage of the number of seeds sown per flat. A plant was counted as having emerged if its stem extended above the surface of the test soil. All plants were counted if they persisted with live tissue to the day of the count, giving a time-dependent function for the number of vivified seeds which germinated, emerged, and survived. The seedbed media forming the 0–5 cm and 5-10-cm depth layers in each flat were sampled at the end of the experiment (except for 2 unseeded flats which were sampled in the 0-1 and 1-10-cm layers at the end of Phase I) and analyzed for EC_e by the Rhoades (1982) method. Data were evaluated statistically by analysis of variance and the means compared with Duncan's multiple range test (Statistical Analysis System Institute, Inc. 1990).

Results

Germination Test

Salinity generally reduced germination percentages and rates (Fig. 2). The maximum cumulative germination for seeds subjected to saline solutions appear to be inversely proportional to the salinity of the substrate (Table 1). The average time required to reach the germination plateau increased with salinity. However, a threshold value, where salinity began to adversely affect germination, is difficult to discern from these results.

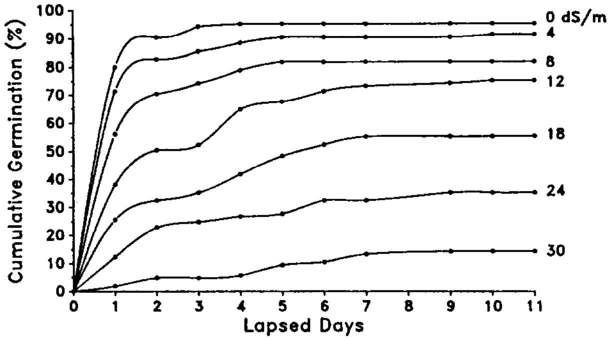

Fig. 2. Progressive cumulative germination percentages for kochia in petri dishes under increasing concentrations of NaCl and $CaCl_2$.

Table 1. Effect of substrate salinity on the maximum cumulative germination of kochia and the number of days before reaching this germination plateau.

	Substrate salinity						
	0	4	8	12	18		
	--------------	--------------	--------------	dS/m	--------------	--------------	--------------
Germination plateau (percent[1])	95.2[a]	90.5[ab]	81.9[ab]	73.3[bc]	55.2[c]	35.2[d]	14.3[e]
Number of days to reach plateau	4	5	5	7	7	9	9

[1]Superscripts of the same letter with the percentage values denote means which are not significantly different (p = 0.05) according to Duncan's new multiple range test.

Emergence Test

Significant differences in kochia emergence and early survival between treatments were observed on both seedbed media. Kochia emerged from the nonsaline seedbeds and reached a plateau averaging 68.75% within 10 days of seeding when stimulated by the medium water regime (Fig. 3). However, no seedlings emerged under the low-regime treatment. The initial water volume of 9 mm and the medium watering rate were sufficient to initiate germination and sustain emergence, while drier rainfall regime, equal to half that of the medium (i.e., the low rate), proved insufficient for any kochia emergence. These results were obtained under the evaporative conditions existing in the greenhouse during the experiment.

In contrast to kochia emergence from the nonsaline soil, medium-rate (medium-medium) irrigation on the saline seedbeds proved unsuccessful. However, seedlings, emerged from the high-high, high-medium, and the medium-high treatments (Fig. 4). Phase I of the experiment, which covered 14 days, showed the advantage of a high-rate rainfall simulation (Table 2). Emergence began on the third day after seeding and averaged 8 kochia seedlings per flat when sprinkled with 12 mm of water per unit area (high) compared to 0 plants/flat following 9 mm of water (medium). This difference between the high and medium rates widened until the watering rates changed. The first phase ended with over 25% of the potential plants from the sown seeds emerging and surviving (200 out of 800) from the high-rate flats, while only 4 plants out of 800 seeds emerged and survived from the medium-rate flats.

No response in cumulative emergence and survival of kochia during Phase II was observed immediately after changes in the irrigation rates. Five days lapsed before the medium-high treated

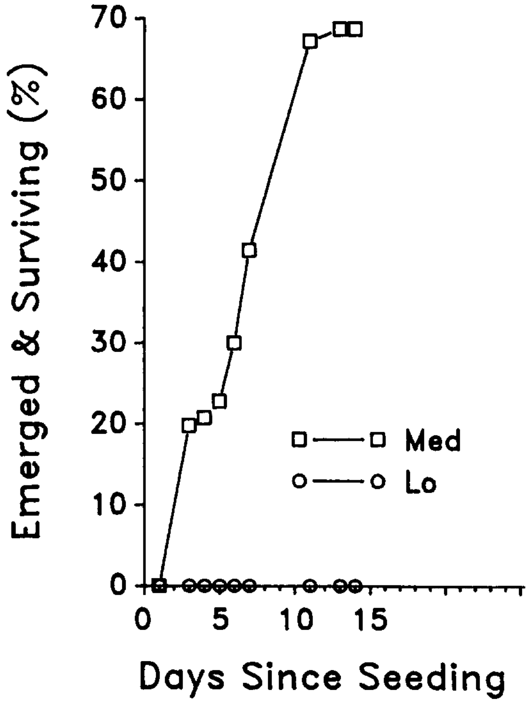

Fig. 3. Average number of kochia seedlings emerged and surviving from 100 seeds (%) sown in a nonsaline (EC_e = 1 dS/m) medium observed on successive days since seeding under relatively low (Lo) and medium (Med) rainfall regimes.

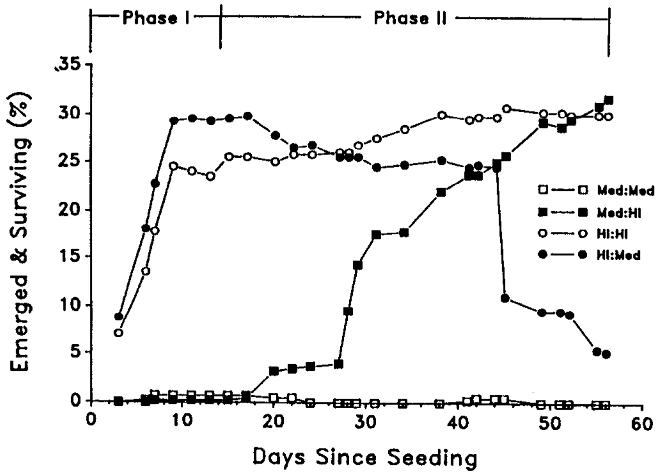

Fig. 4. Average number of kochia seedlings emerged and surviving from 100 seeds (%) sown in a saline (EC_e = 18 dS/m) medium subjected to 4 simulated precipitation regimes, following medium (Med) and high (Hi) watering rates, and observed on successive days since seeding.

seedbeds showed any increase in cumulative emergence-survival, and another 8 days passed before emergence was sustained at a rate comparable to the high-regimes during Phase I. The high-medium flats began to record decreasing totals on lapse-day 20, reflecting mortality. Kochia seedlings under this treatment continued to die with the average emergence-survival total ending at 5% on lapse-day 56.

Mean electrical conductivities, EC_e, of saline media extracts sampled at the end of Phases I and II are presented by treatments in Table 3. The mean EC_e-values in the 0-5-cm layers at the end of the medium-high, high-high, and high-medium water regimes were significantly lower than the comparable EC_e after the medium-medium treatment. The medium-medium value remained about equal to the pre-treatment EC_e-value of 18 dS/m. These differences did not extend to the EC_e values from the 5-10-cm layers. Here the conductivities did not decrease significantly from the original 18 dS/m. The EC_e results from the nonseeded flats followed the trends shown in the seeded flats, namely that only the upper layers under the wetter regimes resulted in EC_e-values lower than that of the pre-treatment medium.

Discussion and Management Implications

Results from the germination test supported previous observations that kochia germinates rapidly, expecially when not affected by salts. However, the results did not confirm the existence of a threshold at 20 dS/m before salinity caused a decrease in germination. A decline occurred, but it began gradually at lower conductivities and averaged -3.3 %/ds/m between 12 and 30 dS/m. Perhaps these characteristics reflect the specific nature of seed harvested from northern sources. Saline substrates were also effective in slowing the rate of kochia germination. This agrees with

Table 2. Average number of kochia seedlings emerging and surviving from 100 seeds (expressed in %) sown in a saline (EC_e = 18 dS/m) soil and watered in simulated rainfalls with volumes (mm) accumulated for selected lapsed days after seeding.

Lapsed days after seeding	Simulated rainfall regime (treatment)							
	medium-medium		medium-high		high-high		high-medium	
	%[1]	mm	%[1]	mm	%[1]	mm	%[1]	mm
Phase I								
3	0[a]	9	0[a]	9	7.0[b]	12	8.75[b]	12
6	0.25	12	0	12	13.5	18	18.0	18
9	0.75	18	0.25	18	24.5	26	29.25	26
12	0.75	20	0.25	20	24.0	35	29.5	35
14	0.75[a]	22	0.25[a]	22	25.5[b]	40	29.5[b]	40
Phase II								
18	0.75	26	0.5	37	25.5	51	29.75	44
24	0	31	3.75	44	25.75	59	26.75	48
27	0	32	4.0	48	26.0	63	25.5	50
30	0	34	14.25	51	26.75	66	25.5	51
36	0	41	17.75	63	28.5	78	24.75	59
42	0.5	48	23.75	76	29.75	91	24.75	66
45	0.5	51	25.75	82	30.75	97	11.0	69
51	0	54	28.75	91	30.25	106	9.5	72
56	0[a]	59	31.75[c]	98	30.0[c]	113	5.25[b]	76

[1]Averages within a row with the same superscript are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

Table 3. Electrical conductivities of saturated paste extracts, EC_e, from soil samples taken after completion of Phase I and II in each water regime (EC_e of the pre-treatment medium = 18 dS/m).

Simulated rainfall regime	No. of flats	Mean EC_e of the soil layer sampled				Seeded
		End of Phase I		End of Phase II		
		0–1 cm	1–10 cm	0–5 cm[1]	5–10 cm[1]	
		dS/m				
medium	1	23.7	17.2			no
high	1	13.1	16.2			no
medium-medium	1			17.3	17.9	no
high-high	1			11.3	17.1	no
medium-medium	4			17.3[b]	18.5[b]	yes
medium-high	4			15.0[a]	17.1[b]	yes
high-medium	4			15.5[a]	20.6[c]	yes
high-high	4			15.7[a]	16.5[b]	yes
Significance of effect				*	*	

[1]Averages with the same superscript are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

Shannon's (1984) emphasis that "salinity slows growth." Greater ambient salinity would tend to flatten osmotic gradients reducing flow rates of water into the seeds.

The emergence and early survival counts for kochia sown in both the saline and nonsaline test media were compatible with the results obtained from the germination test. Percentage emergence from the nonsaline seedbeds averaged less than percents recorded by the seeds nurtured with distilled water in the germination test, reflecting, perhaps, the added effects resulting from matrix water potentials compared to those exclusively osmotic. Inferences based on kochia emergence from the saline seedbeds requires estimates of the actual solution salinity (and total water potentials) surrounding the kochia seed. Although the conductivities of saturated extracts (EC_e) of a soil serve as workable indices of salinity, the actual salinity of the seedbed-solution depends primarily on soil water dilution and various chemical equilibria (U.S. Salinity Laboratory Staff 1954). Ayers and Westcot (1985) suggest using the general rule of 'EC(soil water) = 2 EC_e' in soils at field capacity. Evaporation from shallow seedbeds would tend to increase the value of the coefficient. Applying the rule to the index salinities of Table 3 results in solution-salinities considered as minima, and which relate comparatively to the germination results in Figure 2.

Kochia plants did not emerge from the saline seedbeds whose sampled soil contained salts averaging EC_e's of 17.3 ds/m or greater. Emergence did occur where EC_e measured 15.7 dS/m or less in the top 5 cm, defining a possible threshold EC_e-index between these 2 values, which for our test conditions and seed was lower than that of the pre-treated test medium. An EC_e of 15.7 dS/m indicates a "general" seedbed-solution salinity of 31 dS/m, a saline concentration which, according to Figure 2, would allow a 14% germination response. The EC_e-index for the top cm of soil under the high-rainfall rate measured 13 dS/m, which led to emergence-survival percentages under 30% compared to the 35% measured in the germination test at a solution-EC of 24 dS/m. Emergence and early survival tended to reflect kochia's germination response on saline substrates.

The appropriate seeding depth for kochia is about 1 cm or less (Everitt et al. 1983). Seeds germinating in this layer interact with soil solutions whose salinity varies widely, decreasing with influxes of water from precipitation and increasing with loss by evaporation. The Phase I medium-treatment resulted in kochia emergence from nonsaline media, but produced no emerged plants from the saline medium initially at an EC_e of 18 dS/m. Ancillary soil samples hint that the medium rate delivered just enough water for evaporation to enrich the salts (18 to 24 dS/m) in the top centimeter of the saline seedbed. Conversely, the high rate lowered EC_e in the same layer. One may reason that the medium rate was insufficient to leach enough salts from the upper seedbed for germination and emergence to proceed.

The medium-high treatment on the saline soil demonstrated that, although the Phase I medium rate provided insufficient water for kochia emergence, additional "rain" during the high phase could initiate emergence. The response was not immediate, requiring some 13 days before initiation of sustained emergence. This lag likely related to the time required to leach the excess salts out of the seedbed, or to a 'washing' requirement for possible autotoxins (Lodhbi 1979). It appears that a minimum rainfall rate is required to emerge and sustain kochia, and that this minimum seems to increase in a saline seedbed.

Kochia's ability to germinate, grow, and emerge rapidly generally favors its establishment within shallow, saline seedbeds. If, as indicated by this study, kochia's emergence in saline media is controlled primarily by its germination capacity while in contact with saline solutions, each rainfall that supplies sufficient water will provide a period of time for germination and growth of roots into the more tolerable soil before evaporation dries and resalinizes the seedbed. Any advantage for kochia establishment because of its rapid germination and root growth also hinges on there being just enough delay in germination for the infiltrating water to dilute a large enough volume of the soil solution for the seedling to survive.

The attributes which were investigated in this study support consideration for adding kochia to seed mixtures destined for saline soils. Kochia's salt tolerance, its rapid rate of germination, and its response to rainfall volumes typical of those received in semiarid climates (Fig. 1) further its establishment on saline soils, especially where a forage-cover is desired. Unfortunately, even after seeding kochia, the odds for forage establishment may remain mediocre. For example, the 8-year average frequency of an April--June rain or snow event at Swift Current totalling 12 mm or greater is only once every 3.8 weeks. Also, the actual precipitation thresholds for kochia emergence under actual field weather and soils, especially in very severely saline sites, may lower the probabilities for establishment even further.

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