EVALUATION OF THE SALINITY TOLERANCE OF RUSSIAN THISTLE TO DETERMINE ITS POTENTIAL FOR FORAGE PRODUCTION USING SALINE IRRIGATION WATER

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ABSTRACT

Utilization of New Mexico's saline groundwater supplies for irrigated agriculture could reduce the demand on good quality water and conserve it for other purposes. The successful use of saline water will depend upon the identification of crops and potential crop species specifically adapted to saline environments. Russian-thistle (Salsola species) is a plant species with economic potential as a forage crop. This species is known to be drought and heat tolerant, water use efficient, capable of high productivity on margin lands and suspected of being salt tolerant. Greenhouse and laboratory studies were conducted to determine the salinity tolerance of Russian-thistle and evaluate the effect of salinity on some nutritional qualities.

The salinity tolerance of Russian-thistle was studied in three plant developmental stages: (1) germination, (2) juvenility and (3) reproduction. A variable response to salinity was observed among these stages of plant development. Russian-thistle is considerably less salt tolerant during germination than at later stages of growth. When initially exposed to a saline environment in the seedling stage in a sand solution culture, Russian-thistle plants developed a relatively high level of tolerance to salinity. This tolerance appeared to increase with time of exposure. An enhancement of biomass yield due to salinity was observed which resulted in a 56 and 24 percent increase in biomass yield over that of the control at 64 days after planting at electrical conductivities of treatment solutions of 10.5 and 18.2 dS m^{-1}, respectively. Russian-thistle plants were considerably less tolerant to salinity when initially exposed to salinity during the transition from the vegetative to the reproductive stage.

Salinity generally increased crude protein content of Russian-thistle plants but reduced the levels of acid detergent fiber and acid detergent lignin. Levels of potentially toxic components of Russian-thistle plants, nitrate and water soluble oxalates, were reduced by salinity. Ash content, however, increased with increased salinity.

A literature search revealed a number of chemical compounds of potential economic value that have been isolated from *Salsola* species. No attempt was made to isolate these chemicals from Russian-thistle. However, if these chemicals can be economically extracted from this species, it could increase the potential of Russian-thistle as an arid lands crop.

Key words: salinity, salt tolerance, greenhouse studies, water management, xerophilic plants, water utilization, forage crop.

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INTRODUCTION

The most recent water resources assessment for New Mexico concludes that existing freshwater supplies will not be adequate to support projected economic growth in the state (U.S.D.I. Bureau of Reclamation 1976). Under the most optimistic set of assumptions the demands on freshwater could outstrip supplies before the year 2000. Available surface water supplies of approximately one million acre feet per year are, for all practical purposes, fully appropriated. Groundwater supplies of freshwater, especially in the eastern portions of the state, are being depleted at an alarming rate. On the other hand, groundwater supplies of slightly saline water [1000-3000 mg/L total dissolved solids (TDS)] to brackish (3000-10,000 mg/L TDS) ground and surface water in New Mexico are considerable, having been estimated to be 15 billion acre feet. It is noteworthy that large quantities of these waters can be found in areas with soils that are classified as highly suitable for irrigation but are not being irrigated due to limited amounts of freshwater supplies. All of these areas have not been identified for the simple reason that using brackish water for irrigation has not been considered until quite recently. On the basis of available information, however, these areas are believed to be extensive. Thus, the water management option of irrigating crops with brackish water as a means of conserving freshwater supplies and expanding our economic base is apparently not limited by existing soil and brackish water resources. The limiting factor for saline irrigation is the identification of crops of sufficient economic value and salinity tolerance.

The potential for developing new crops specifically adapted to arid environments is relatively unexploited as the traditional approach has been to use conventional cultivars and adapt the environment, the soil and water, to meet the needs of the crop or to make genetic selections from these established cultivars for improved performance under arid conditions. The former approach is extremely costly in terms of dollars, good water, and energy. An alternative is to search for plant species with economic potential as crops that are already adapted to the conditions of arid lands agriculture, especially those of salinity and limited water. Russian-thistle (Salsola spp.) is thought to be such a species.

Russian-thistle has been sporadically studied as a potential forage crop, especially during periods of drought in the United States (Bailey and Gustafson 1902; Briggs and Shantz 1914; Cave et al. 1936; Donaldson and Goering 1940). Cave et al. (1936) found Russian-thistle hay (apparently uncultivated) to be a good source of protein, Ca, carotene, P and metabolizable energy (1.8 kcal/kg) for dairy cattle. Range cattle have been observed to consume Russian-thistle during eight months of the year (Nelson et al. 1970).

Russian-thistle's drought tolerance and water use efficiency are well documented. Briggs and Shantz (1914) found it to require one-half to one-third as much water per unit dry weight produced as alfalfa. Dillman (1931), in a study of water requirements of certain crops and weeds of the Northern Great Plains, found the lowest water requirement among the species tested was for Russian-thistle. More recent studies have confirmed the reported drought tolerance and water-use efficiency of Russian-thistle (Dwyer and Wolde-Yohannis 1972; Fowler and Hageman 1978).

Results of recent studies of Russian-thistle grown both in the greenhouse and in the field under controlled nitrogen and water application conditions suggest a strong potential for Russian-thistle as a drought tolerant and very water use efficient forage crop (Farmer et al. 1976; Hageman et al. 1978; Fowler and Hageman 1978; Fowler and Hageman 1979). Preliminary results from *in vitro* digestibility studies carried out at Ralston Purina Company in St. Louis (W. Sadler, personal communication) on some plant samples from the above studies support the reported chemical analyses. Both types of results suggest that Russian-thistle has high value as an animal forage.

Russian-thistle species are thought to be salt tolerant, as suggested by anecdotal reports, a few reports from trained observers, and by the name "saltworts," which is commonly used for these species in Europe. However, little rigorous scientific work appears to have been done in this respect. Therefore, the primary objective of this study was to evaluate the salinity tolerance of Russian-thistle from germination through plant maturity with a view to establishing this plant as a livestock feed source for arid-lands agriculture using saline irrigation water. Specifically, the effects of salinity on the rate and percentage of seed germination, seedling growth, biomass yield and selected nutritional qualities were determined. A secondary objective was to make an extensive literature search to determine if specific chemicals or other biological substances of economic value have been discovered in *Salsola* species whose extraction from *Salsola* plants may improve their potential as a new crop.

MATERIALS AND METHODS

Two species of Russian-thistle, *S. iberica* Sessen & Pau and *S. paulsenii* Litv., were initially selected for this series of experiments. These two species differ phenotypically in several respects [see Beatley (1973) for species descriptions], and there is evidence of physiological differences that may be important in the development of Russian-thistle as an arid lands forage crop (Evans and Young 1982; Beatley 1973). Both are alien annuals reportedly found throughout much of the western and southwestern United States. *Salsola paulsenii*, however, is not as widely distributed throughout the western and southwestern United States as *S. iberica* and is not known in southern New Mexico. Seeds of *S. paulsenii* were obtained from the Renewable Resource Center, University of Nevada, Reno. Seeds of *S. iberica* were collected locally from a single plant selection which was more or less typical of *S. iberica* as described by Beatley (1973).

Salinity Tolerance Experiments

Salinity tolerance of *Salsola* plants were evaluated during three stages of plant development: (1) germination, (2) juvenile stage, and (3) the reproductive stage. Germination studies were conducted in low temperature incubators and the other developmental stages were evaluated under greenhouse conditions.

Experiment No. 1: Reproductive Stage. Salinity tolerance during the reproductive stage of plant development was evaluated in the first experiment because the plant material from this experiment was to be used in the chemical analyses for nutritional properties. A water distribution system was designed and constructed to allow for automated distribution of the treatment solutions to individual pots in a greenhouse. The distribution system consisted of five 750 L polyethylene tanks with pumps, filters, distribution lines, headers, drip lines and emitters. Because of the poor germination and vigor of *S.*

paulsenii seed, all seed were germinated in an incubator at 20°C in covered 9 cm petri dishes containing 50 seed on three circles of Whatman #1 filter paper and moistened with 5 ml of distilled H_2O beginning on 10 Dec. 1984. Germinants were transferred to Jiffy-7 peat pellets when they were 1-2 cm in length. After the radicles of the seedlings were firmly established in the peat pellets under artificial light in the laboratory, seedlings were transferred to the greenhouse and transplanted at eight days after planting (DAP) into 20 L plastic pots, 26.25 cm in diameter X 31.5 cm high, filled with washed (tap water) plaster sand. Approximately 4 cm of 1-2 cm sized gravel was placed in the bottom of the plastic pots to keep the plaster sand from flowing out the four drain holes in the sides of the cans near the base. Seedlings were irrigated with a one-quarter strength Hoagland's solution (Hoagland and Arnon 1950) as required to maintain an adequate moisture level in the pots until the roots of the seedlings were well established in the sand and seedlings were growing vigorously. Salinity treatment solutions consisting of a control and four salt solutions (100, 200, 300 and 400 mmol L^{-1}) were made up of equal mole quantities of NaCl and ½ $CaCl_2$ using guaranteed reagent NaCl and $CaCl_2 \cdot 2H_2O$. Treatment solutions were prepared by weighing the appropriate molar quantities of each chemical in the laboratory and preparing a 4 mol L^{-1} stock solution of NaCl and ½ $CaCl_2$ in an 80 L graduated tank. The treatment solutions were prepared by adding the appropriate number of liters of stock solution to each treatment solution tank and bringing the tank up to the required level with tap water. Nutrients were added to the control tank and each treatment solution tank to approximate a one-quarter strength Hoagland's solution. Electrical conductivity of each solution was checked for correspondence with target levels of electrical conductivity which were determined from laboratory prepared solutions (table 1). Adjustments were made as

Table 1. Electrical conductivities of the saline irrigation solutions used in Experiment No. 1 as sampled from the drip lines and as leachate from randomly selected pots.

Concentration†	Electrical conductivities			
	Target level‡	Drip lines	Leachate	Mean of drip lines + leachate
$mmol\ L^{-1}$	$dS\ m^{-1}$§			
0	1.5	1.3	1.6	1.5
100	11.2	10.6	17.2	13.9
200	19.5	19.5	28.9	24.2
300	27.0	26.8	36.4	31.6
400	33.7	33.9	42.3	38.1

†Approximate total concentration of equal mole quantities of NaCl and ½ $CaCl_2$ used to prepare the treatment solutions.
‡Determined from laboratory preparation of small quantities of treatment solutions.
§One $dS\ m^{-1}$ equals one $mmhos\ cm^{-2}$.

needed. Salinity treatments were begun at 42 DAP and increased in stepwise increments over a seven-day period reaching target salinity levels at 49 DAP. Pots were irrigated one time per day in the late afternoon with sufficient solution to provide for leaching of pots. The electrical conductivity of the treatment solutions at the drip line emitters and of the leachate from the pots was monitored periodically (table 1). The length of the daily irrigation period was adjusted to maintain the electrical conductivity of the leachate at an approximately constant level.

Initially, the experiment described above was laid out in the greenhouse as a split plot design with species as main plots and salinity treatments as subplots. However, because of the tremendous difference in the growth and development of the two species under the existing photoperiod, the two species were analyzed as separate experiments in randomized complete block designs with four replications. Each replication consisted of 20 pots in two rows of 10 pots each on one greenhouse bench. The end pots of each row served to eliminate end row effects and the plants in these pots were excluded from the experimental data. A replication of each treatment consisted of three pots with six plants per pot.

The _S. paulsenii_ plants began to flower at about 24 DAP and a few flowers were observed among the _S. iberica_ plants by 49 DAP. Two plant harvests of three plants per pot were made in the _S. iberica_ at 67 and 91 DAP and 25 and 49 days, respectively, after initiation of treatments. The _S. iberica_ plants were still in the early stages of flowering at first harvest and at the full bloom stage at the second harvest. Only one harvest of six plants per pot at 67 DAP was made in the _S. paulsenii_ because the plants flowered, set seed and matured in the 19.5, 26.8 and 33.9 dS m^{-1} treatments by the first harvest date. Harvesting was accomplished by cutting each plant 1-2 cm above the sand surface in the pots. The nine plants from each replication were weighed collectively for fresh weight determination, sacked in a paper bag, dried in a forced draft oven at 60-65°C for 72 h and reweighed. Greenhouse conditions of temperature and humidity are given in table 2. Salsola paulsenii was dropped from the remainder of the experiments after observations during the initial experiment indicated that the growth habit, biomass production and general plant characteristics were not suitable for a forage crop.

Experiment No. 2: Juvenility. A second greenhouse experiment was initiated to determine the salinity tolerance of S. iberica in the juvenile state. A sufficient number of plants was planted to carry the experiment through four successive harvests taking the plant development well into the flowering stage. The experimental design was similar to that of the first experiment with a randomized complete block design with four replications. The potting medium, treatment solutions, number of pots per replication and arrangement of pots on the benches were similar to that of the first experiment. The seed, however, for establishing the experiment were planted directly into the pots by using a template to make 12 evenly spaced holes in a circle 20 cm in diameter centered on the surface of the sand in each pot. Three to four seeds were placed in each hole at a depth of 5 mm and pots were irrigated with tap water on April 18, 1985. After seedlings were well established, pots were thinned to two plants per location (24 plants per pot). Treatments were initiated on April 24, (7 DAP) and increased in stepwise

Table 2. Greenhouse conditions of temperature and humidity during Experiments No. 1 and 2.

Experimental period	Temperature		Relative humidity	
	Maximum	Minimum	Maximum	Minimum
DAP†	----------°C----------		----------%----------	
		Experiment No. 1		
8 to 42	37.4	19.0	55.9	14.9
43 to 67	36.2	19.3	63.0	25.3
68 to 91	36.4	18.9	56.2	21.9
		Experiment No. 2		
0 to 7	37.9	19.0	51.4	17.0
8 to 22	38.4	19.5	57.9	21.1
23 to 36	37.3	19.6	57.2	21.9
37 to 50	37.6	22.6	55.9	23.4
51 to 64	38.0	21.0	77.2	29.5

†DAP - Days after planting.

increments over a seven-day period reaching target levels on May 1, at 14 DAP. Electrical conductivities of the treatment solutions are given in table 3.

Four harvests to determine biomass were made at two-week intervals on May 10, May 24, June 7, and June 21 (22, 36, 50 and 64 DAP, respectively). Plants were harvested by cutting the main axis 1-2 cm above the sand surface as in experiment 1. The number of plants per harvest sample varied with harvest date with 10 plants per pot X 3 pots on May 10, 6 plants per pot X 3 pots on May 24 and 3 plants per pot X 3 pots on June 7 and 21. In effect, plants were thinned to 12 plants per pot at first harvest, 6 plants per pot at second harvest, 3 plants per pot at the third harvest and the remaining 3 plants in each pot were harvested at the final harvest. Fresh weight, partial dry weight and percent moisture determinations were made on these plant samples as in experiment 1. Greenhouse conditions of temperature and humidity for the experimental period are listed in table 2.

Experiment No. 3: Germination. Evaluation of *S. iberica* plants for salinity tolerance during germination was accomplished by placing 50 seed in 90 X 15 mm glass petri dishes containing three circles of Whatman #1 filter paper to which 5 ml of distilled water or an aqueous solution of equal mole quantities of NaCl and ½ $CaCl_2$ were added. Germination responses to concentrations of 0, 100, 200, 300 and 400 mmol L^{-1} were determined. Measured values of electrical conductivity and osmotic potential along with target levels of mmol L^{-1} concentrations and total dissolved solids (TDS) of the treatment solutions are given in table 4. The covered petri dishes were arranged in the germinator in a randomized complete block experimental design with one block per shelf over five

Table 3. Electrical conductivities of the saline irrigation solutions used in Experiment No. 2 as sampled from the drip lines and as leachate from randomly selected pots.

Concentration†	Electrical conductivities			
	Target level‡	Drip lines	Leachate	Mean of drip lines + leachate
$mmol\ L^{-1}$	$dS\ m^{-1}$			
0	1.5	1.3	1.5	1.4
100	11.2	10.5	20.6	15.6
200	19.5	18.2	28.7	23.4
300	27.0	26.7	37.1	31.9
400	33.7	33.2	45.2	39.2

†Approximate total concentration of equal mole quantities of NaCl and ½$CaCl_2$ used to prepare the treatment solutions.
‡Determined from laboratory preparation of small quantities of treatment solutions.

Table 4. Characteristics of saline treatment solutions used in the *Salsola* seed germination studies.

Concentration†	Total dissolved solids	Electrical conductivity	Osmotic potential
$mmol\ L^{-1}$	mg/l	$dS\ m^{-1}$	-MPa
0	0	0.1	0.0
100	5,697	10.1	0.35
200	11,393	18.8	0.72
300	17,090	26.7	1.13
400	22,786	33.8	1.54

†Approximate total concentration of equal mole quantities of NaCl and ½ $CaCl_2$ used to prepare treatment solutions.

shelves. Germination response to salinity over a range of six temperatures--5, 10, 15, 20, 25 and 30°C--were evaluated. Temperatures were maintained within ±1°C of target levels and germination counts were made at 2, 4, 6 and 8 days of incubation. One blank (petri dish, 3 circles of filter paper and 5 ml of distilled water) per shelf was randomized with the treatment dishes. A quantity of distilled water determined from the mean loss of water from the blanks was added to each petri dish on days 2, 4 and 6 to maintain salt concentrations near target levels throughout the germination period.

Chemical Analyses

The plant material harvested in the two harvests of experiment 1 were analyzed for crude protein, acid detergent fiber (ADF), acid detergent lignin (ADL), nitrate and oxalate levels. Mineral ash determinations were also made and mineral analyses for K, P, Ca, Mg, Na, Zn, B, Fe, Mn and Cu were performed.

Preparation of plant material for chemical analyses. All chemical analyses were performed on dried ground plant material. After harvesting, plants were immediately dried in a forced draft oven at 60-65°C to a constant weight (48 to 72 h). The samples were coarsely ground in a large Wiley mill using a 6 mm stainless steel screen. The coarsely ground sample was thoroughly mixed and a 50-100 g subsample was ground in a small Wiley mill to pass a 40-mesh screen. The samples were then redried for 24 hours at 60-65°C and stored in screw-capped glass jars. The residual water of the partially dried samples averaged less than 4 percent by weight. A portion of each ground sample was dried overnight at 110°C to determine percent dry matter of the sample to be analyzed. All values for chemical analyses were calculated on a 100 percent dry matter basis.

Crude protein. A slightly modified version of the Association of Official Analytical Chemists (AOAC) method (AOAC 1980, p. 858) was used for crude protein determinations. The 0.2000 g samples were digested using circa 0.5 g Kel-pac Powder No. 2 (Curtain Matheson Scientific) and 4 ml of concentrated H_2SO_4. Twenty milliliters of deionized H_2O was added after digestion to dissolve solids. For distillation, a few grains of Zn dust and 20 ml of 50 percent NaOH were added. Circa 30 ml of distillate was collected in a 2.9 percent boric acid solution containing methyl purple indicator and titrated to the end point with 0.1 N HCl. All assays were done in duplicate or triplicate.

Acid detergent fiber and acid detergent lignin. The AOAC method (AOAC 1980, p. 134-135) was used with Hyflo Super-Cel (Fisher Scientific) used instead of asbestos for the crucible mats. All assays were done in duplicate or triplicate using 1 g samples.

Nitrate. The procedure of Cataldo et al. (1975) was followed without modification. All samples were analyzed in duplicate and the results expressed as percent NO_3^-.

Oxalates. The AOAC method (AOAC 1980, p. 541-542) was modified slightly using procedures outlined by Baker (1952) to accommodate a dried plant sample rather than a canned vegetable product and to allow for the determination of water-soluble as well as total (soluble and insoluble) oxalates. The insoluble oxalates are not toxic to animals as they are not absorbed but excreted without effect (Kingsbury 1964). The results are expressed as percent oxalate as oxalic acid. Oxalates were determined by titration with 0.01 N $KMnO_4$.

Mineral ash analyses. The AOAC method (AOAC 1980, p. 125) was slightly modified for the ashing of samples and the mineral analyses. Duplicate 1 g samples were ashed in aluminum weigh pans for 4.5 to 5 h at a temperature of 500 to 600°C in a muffle furnace to achieve complete ashing of sample. A few samples were ashed in fritted glass crucibles rather than aluminum weigh pans for comparison purposes. The ash from the plant samples was transferred (using a brush) to a beaker and 15 ml of 3 N HCl and a few drops of concentrated HNO_3 were added. After covering the beaker with a watch glass, the sample was boiled for 10 min. in a hood, then gravity filtered into 100 ml volumetric flasks and diluted to volume. Mineral composition (K, P, Ca, Mg, Na, Zn, B, Fe, Mn, and Cu) was determined by scanning inductively coupled argon plasma emissions spectroscopy (Baker and Suhr 1982).

Literature Search for Natural Products of Commercial Value Found in *Salsola* Species

A very extensive computer-assisted search of the chemical, biological and agronomic literature was carried out to determine what types of compounds have been isolated from the genus, *Salsola*, and reported in the literature. Resources were not available to attempt to isolate from *S. iberica* or *S. paulsenii* any of the compounds uncovered in the literature review.

RESULTS AND DISCUSSION

Most crop species seem to tolerate salinity equally well during seed germination and later growth stages (Bernstein 1974; Bernstein and Hayward 1958). However, as a plant changes during its ontogeny, its salinity tolerance may also change (Nieman and Shannon 1976). Sugar beet, for example, is highly tolerant to salinity during most of its life cycle but sensitive during seed germination (Ayers and Hayward 1948). Sorghum, on the other hand, is considerably more salt tolerant at germination than at later stages of growth (Francois et al. 1984). Because of the differential sensitivity of some species to salinity during different stages of growth and development, the salinity tolerance of Salsola plants were evaluated at three developmental stages: (1) germination, (2) juvenility and (3) the reproductive stage. Germination, as defined for this study, included the physiological processes that were initiated with the imbibition of water or salt solution by the seed up to the point when the radicle of the seedling protruded through the seed coat. The second developmental stage, juvenility, is usually defined as the period following germination in which most plants enter a state of vigorous vegetative growth during which they cannot be readily induced to a reproductive type of growth (Leopold and Kriedemann 1975). The reproductive stage as defined for this study, encompassed the later part of juvenility, in which the plants began the transition from the vegetative to the reproductive stage, up to full flower.

Salinity Tolerance - Effects on Biomass Yield and Germination

Experiment No. 1: Reproductive Stage. The effect of salinity on biomass yield was first determined for *S. iberica* plants initially exposed to salinity during the late vegetative or juvenile stage just before the transition into the flowering or reproductive stage. The salinity treatments for both *S. iberica* and *S. paulsenii* plants were initiated at the same time in this experiment but the two species were not at the same stage of development at 42 DAP when the treatments were initiated.

Both *S. iberica* and *S. paulsenii* are indeterminately fruiting plant types beginning to flower while in the exponential vegetative growth stage and continuing to flower until the plant nears maturity. Plants of *S. paulsenii*, as we observed them, were more determinate in growth and fruiting than *S. iberica* and are apparently more easily induced by photoperiod and/or environmental stress into flowering and early maturity. For example, in experiment 1, *S. iberica* plants began flowering in a few instances at 49 DAP and were in full flower at the final harvest (91 DAP) but continued to flower and grow vegetatively throughout this 42-day period. The *S. paulsenii* plants, on the other hand, began to flower at 24 DAP and were completely mature in the three highest salinity treatments and approaching maturity in the control and lowest salinity treatment at 67 DAP. Growth or maximum size obtained before maturity of *S. paulsenii* under these short-day conditions was much less in the control plants than had been observed in another greenhouse experiment conducted under long day conditions.

Fresh weight, dry weight and percent moisture of *S. iberica* at 67 and 91 DAP are given in table 5. At both harvests all three of these

Table 5. Biomass yield and moisture content of _Salsola iberica_ plants grown at five salinity levels initiated at 42 days after planting and harvested at two plant developmental stages, early flower and full flower.

Salinity of irrigation solution	Early flower			Full flower		
	Fresh weight	Dry weight	Percent moisture	Fresh weight	Dry weight	Percent moisture
$dS\ m^{-1}$	g	g	%	g	g	%
1.3	474.3	76.8	83.8	1443.0	300.4	79.2
10.6	436.9	71.4	83.7	1228.2	231.5	81.1
19.5	326.4	53.5	83.6	952.9	177.6	81.4
26.8	266.5	47.0	82.4	704.1	133.6	81.0
33.9	200.7	39.1	80.6	255.7	115.9	54.6

Analysis of variance

Source	df	Mean squares: Early flower			Mean squares: Full flower		
		Fresh weight	Dry weight	Percent moisture	Fresh weight	Dry weight	Percent moisture
Salinity	4	52,502.23**	1,032.02**	7.53**	857,509.86**	22,710.87**	547.27**
Linear	1	205,765.30**	4,012.52**	22.60**	3,297,952.79**	88,999.52**	858.38**
Quadratic	1	1,300.02	1.29	6.86**	115,844.89**	1,651.35*	965.57**
Cubic	1	2,014.02	66.01	0.53	11,500.96	106.62	298.52**
Error	12	1,522.12	61.00	0.48	4,517.74	205.29	2.99
C.V. (%)†		11.44	13.57	0.84	7.33	7.47	2.29

*,**Significant at the 5 and 1% level of probability.
†C.V. - coefficient of variation.

determinations were significantly affected by salinity. Both fresh weight and dry weight decreased in a linear manner as salinity increased, with a 50 percent reduction in dry weight biomass yield occurring at approximately the midpoint between the 19.5 and 26.8 dS m^{-1} treatment levels in the final harvest (full flower). The extremely low moisture content of the plant material of the 33.9 dS m^{-1} treatment level at final harvest was apparently the result of an overdose of salt to those plants due to improper mixing of a new batch of treatment solutions. This short exposure (2-3 days) to an excessively high salt concentration (up to 86.3 dS m^{-1}) resulted in an extremely high level of salinity stress from which the plants did not recover. The experiment was terminated at that point when it was realized that these plants would not recover. This stress apparently affected ash content and the accumulation of certain mineral elements and may have affected dry weight biomass because of the increase in ash content. There was no apparent effect of salinity on flower induction or rate of flowering of S. iberica in experiment 1.

The fresh weight, dry weight, and percent moisture determinations for S. paulsenii which was harvested at 67 DAP are given in table 6. Both fresh weight and percent moisture were significantly affected by salinity, decreasing in a linear manner as salinity increased but with quadratic and cubic components to these responses as well. The dry weight yield was not significantly influenced by salinity but there was a trend to decreasing accumulation of dry weight as salinity increased. Visual observations clearly indicated that the maturity and size of the S. paulsenii plants were affected by salinity, but the plants were so close to maturity at the time of the initiation of treatments that little response in terms of dry weight was measurable. Salsola paulsenii appeared to be sensitive to photoperiod because plants grown under long-day photoperiodic conditions in another greenhouse experiment,

Table 6. Biomass yield and moisture content of _Salsola paulsenii_ plants grown at five salinity levels initiated at 42 days after planting and harvested at physiological maturity.

Salinity of irrigation solution	Fresh weight	Dry weight	Percent moisture
$dS\ m^{-1}$	------------g-----------		%
1.3	53.17	25.12	70.6
10.6	24.30	16.52	45.2
19.5	15.65	14.65	19.9
26.8	12.95	12.85	5.5
33.9	13.82	13.52	4.6

Analysis of variance

		Mean squares		
Source	df	Fresh weight	Dry weight	Percent moisture
Salinity	4	1,146.6243**	99.9808	3,223.85**
Linear	1	3,483.0448**	308.5722*	12,186.62**
Quadratic	1	1,038.3428**	82.8991	587.10**
Cubic	1	61.7375*	4.4798	123.56*
Error	12	11.0266	54.9241	22.73
C.V.† (%)		13.85	44.82	16.35

*,**Significant at the 5 and 1% level of probability.
†C.V. - coefficient of variation.

responded much differently in terms of growth and maturity than the plants grown under the short day conditions of this experiment. The stiff, spiny nature of S. paulsenii from very early in its life cycle and the relatively low biomass yield potential even under long day conditions further discourages its potential usefulness as a forage crop. The S. iberica selection used in this study, on the other hand, has excellent biomass potential, did not appear to be sensitive to photoperiod and remains soft (spines not pungent) until nearing maturity. For these reasons, the remainder of the study was carried out with S. iberica only.

Experiment No. 2: Juvenility. The effect of salinity on S. iberica in the juvenile stage was determined by initiating salinity treatments at 7 DAP as soon as the required stand of plants was established. The first biomass harvest was made at 22 DAP or 15 days after initiation of treatments. Three additional harvests were made at 14 day intervals and fresh weight, dry weight and percent moisture determinations were obtained (table 7). Yield among harvests are not comparable except at 50 and 64 DAP because of differences in sample size and population density. In the first harvest, all determinations were linearly reduced by increasing salinity. By the second harvest, however, a different pattern was beginning to emerge as the fresh weight and dry weight determinations for the 10.5 dS m^{-1} treatment level were slightly higher, numerically, than that of the control. By 50 DAP (third harvest), this effect was much more pronounced with the 10.5 dS m^{-1} treatment showing a 46 percent increase in dry weight over that of the control. Fresh weight and dry weight yields of the 18.2, 26.7 and 33.7 dS m^{-1} treatments decreased with the increase in salinity at both the 36 and 50 DAP harvests. At 64 DAP, the fresh weight and dry weight yields of not only the 10.5 dS m^{-1} treatment but also that of

Table 7. Biomass yield and moisture content of *Salsola iberica* grown at five salinity levels initiated at six days after planting (DAP) and harvested at 22, 36, 50 and 64 DAP.

Salinity of irrigation solution	Harvested at 22 DAP			Harvested at 36 DAP		
	Fresh weight	Dry weight	Percent moisture	Fresh weight	Dry weight	Percent moisture
$dS\ m^{-1}$	--------g-------		%	---------g-------		%
1.3	70.6	6.7	90.5	316.4	45.3	85.8
10.5	64.8	6.1	90.6	355.0	48.8	86.2
18.2	34.1	3.7	89.1	240.4	27.6	88.5
26.7	19.7	2.5	87.7	147.5	16.2	89.1
33.2	12.4	1.9	84.9	68.3	9.1	86.7

Analysis of variance

Source	df	Mean squares: Harvested at 22 DAP			Harvested at 36 DAP		
		Fresh weight	Dry weight	Percent moisture	Fresh weight	Dry weight	Percent moisture
Salinity	4	2,735.45**	18.29**	22.56**	56,047.65**	1,221.65**	8.50**
Linear	1	10,429.73**	69.90**	77.21**	192,252.10**	4,346.23**	9.50*
Quadratic	1	7.27	0.00	12.24**	21,354.94**	126.44*	12.01*
Cubic	1	401.13*	2.22*	0.07	8,058.38**	307.32**	12.21*
Error	12	56.35	0.32	0.26	292.41	15.91	1.53
C.V.† (%)		18.38	13.63	0.57	7.58	13.57	1.42

*,**Significant at the 5 and 1% level of probability.
†C.V. - coefficient of variation.

Table 7 (continued). Biomass yield and moisture content of *Salsola iberica* grown at five salinity levels initiated at six days after planting (DAP) and harvested at 22, 36, 50 and 64 DAP.

Salinity of irrigation solution	Harvested at 50 DAP			Harvested at 64 DAP		
	Fresh weight	Dry weight	Percent moisture	Fresh weight	Dry weight	Percent moisture
$dS\ m^{-1}$	----------g--------		%	----------g----------		%
1.3	396.3	69.0	82.6	921.4	179.6	80.7
10.5	516.0	100.8	80.5	1217.0	279.8	77.1
18.2	330.6	59.3	82.1	972.8	222.4	77.2
26.7	256.2	43.8	82.9	625.6	131.4	79.0
33.2	131.2	21.2	83.9	386.6	75.0	80.7

Analysis of variance

		Mean squares					
		Harvested at 50 DAP			Harvested at 64 DAP		
Source	df	Fresh weight	Dry weight	Percent moisture	Fresh weight	Dry weight	Percent moisture
Salinity	4	83,904.28**	3,504.95**	6.52**	416,863.97**	25,117.05**	12.880**
Linear	1	237,401.38**	8,794.08**	9.25**	1,039,325.73**	47,136.23**	1.03
Quadratic	1	58,265.29**	2,801.22**	11.29**	515,690.43**	43,506.09**	47.74**
Cubic	1	19,707.16**	1,405.99**	3.95**	107,023.29**	9,526.70**	2.75*
Error	12	869.71	36.15	0.3240	2,449.51	248.35	0.44
C.V.† (%)		9.05	10.23	0.69	6.00	8.87	0.84

*,**Significant at the 5 and 1% level of probability.
†C.V. - coefficient of variation.

the 18.2 dS m^{-1} treatment exceeded that of the control. A 50 percent reduction in biomass yield occurred at some point between the 26.7 and 33.2 dS m^{-1} salinity levels at 64 DAP. This response is considerably different from that of the first experiment which indicated a linear response of decreasing yield with increasing salinity for harvests made at 67 and 91 DAP. It appears that the plants in experiment 2 in the 10.5 dS m^{-1} treatment level made an adjustment to the saline environment by 36 DAP that enabled those plants to grow at the same or greater rate than those of the control. By 50 DAP, it is evident that the 10.5 dS m^{-1} treatment plants were growing at a much faster rate than those of the control indicating that something in the treatment solutions actually enhanced biomass growth which resulted in a 56 percent increase in dry mass yield over that of the controls by 64 DAP. This effect was consistent across all replications and visibly apparent. It is of interest to note that the plants in the 18.2 dS m^{-1} treatment made a similar adjustment. However, the adjustment was not clearly evident until the final harvest. These responses raise the question of why S. iberica plants from a homogenous seed population and grown in similar saline environments would respond so differently in the two experiments. One possible reason, of course, is that the treatments were initiated very early (7 DAP) in the life cycle of the plants in experiment 2 and much later (42 DAP or just prior to the transition from the vegetative to the reproductive stage) in the life cycle of the plants in experiment 1. This finding suggests that adaptive mechanisms to salinity are present in S. iberica; however, after certain stages in the ontogeny of the plant or after some threshold in the life cycle, these mechanisms cannot be induced. Another possibility is that S. iberica is simply less tolerant to salinity in the reproductive stage. This intolerance seems unlikely, however, because the control plants and those in the 10.5 and 18.2 dS m^{-1} treatments in experiment

2 were in the early flower stage by 50 DAP and growth enhancement by salinity in the 18.2 dS m^{-1} treatment became apparent between 50 and 64 DAP. The radiation levels and day lengths to which the plants were exposed during the two experiments were also considerably different. The plants in experiment 2 were exposed to higher radiation intensities and longer day lengths; however, most observations (Nieman and Paulsen 1971) suggest that plant tolerance to salinity is inversely related to light intensity.

Visual observations on the stage of flowering at 50 and 64 DAP were also recorded. Increasing salinity had much the same effect on flowering in experiment 2 as it did on biomass production. By 50 DAP, plants in the control, 10.5 and 18.2 dS m^{-1} treatments had some flowers on most plants while the plants in the 26.7 and 33.2 dS m^{-1} treatments had none. By 64 DAP, most plants in all treatments had flowers and the degree of flowering among treatments closely corresponded to biomass production.

Experiment No. 3: Germination. *Salsola iberica* plant's tolerance to salinity during germination was determined at six temperatures--5, 10, 15, 20, 25 and 30°C (tables 8-13). Germination was monitored over an eight-day germination period. Although temperature X salinity interactions appeared to be significant (fig. 1), this could not be determined statistically from this study because the temperature treatments were not replicated. There appeared to be little difference in the response of *S. iberica* seeds to salinity at the medium temperatures of 10, 15 and 20°C. Both rate of germination and final germination percentage were affected by salinity. At temperatures of 10, 15 and 20°C, final germination percentages were reduced by slightly more than 50 percent at the 18.8 dS m^{-1} treatment level. However, the seed used in the germination tests were over a year old at the time of testing and *Salsola* seed generally do not remain viable under our laboratory storage conditions

Table 8. Cumulative germination percentages of *Salsola iberica* seed at five salinity levels and a temperature of 5°C.

Salinity of treatment solution	Days after initiation of germination			
	2	4	6	8
$dS\ m^{-1}$	-------------------- % --------------------			
0.1	0.0	4.8	31.6	54.4
10.1	0.0	0.8	4.8	12.4
18.8	0.0	0.0	1.6	4.8
26.7	0.0	0.0	0.8	1.6
33.8	0.0	0.0	0.0	0.0

Analysis of variance

Source	df	Mean squares: Days after initiation of germination			
		2	4	6	8
Salinity	4	–	21.76**	904.64**	2,583.84**
Linear	1	–	59.39**	2,471.96**	7,738.86**
Quadratic	1	–	24.78**	959.65**	2,253.58**
Cubic	1	–	2.79	176.58	318.77
Error	16	–	1.26	48.64	86.44
C.V.† (%)		–	100.22	89.87	63.51

*,**Significant at the 5 and 1% level of probability.

†C.V. – coefficient of variation.

Table 9. Cumulative germination percentages of *Salsola iberica* seed at five salinity levels and a temperature of 10°C.

Salinity of treatment solution	Days after initiation			
	2	4	6	8
$dS\ m^{-1}$	%			
<0.1	0.0	26.8	77.6	83.2
10.1	0.8	10.4	60.0	74.8
18.8	0.0	1.2	18.0	35.2
26.7	0.0	0.8	4.4	7.2
33.8	0.0	0.0	0.0	0.4

Analysis of variance

		Mean squares			
		Days after initiation of germination			
Source	df	2	4	6	8
Salinity	4	0.64	651.44**	6,054.40**	7,180.24**
Linear	1	0.27	2,136.07**	22,704.75**	27,163.17**
Quadratic	1	0.43	450.74**	371.12	48.30
Cubic	1	1.35	4.74	866.18**	1,473.74
Error	16	0.64	25.04	89.40	75.54
C.V.† (%)		500.00	63.83	29.55	21.64

*,**Significant at the 5 and 1% level of probability.
†C.V. - coefficient of variation.

Table 10. Cumulative germination percentages of *Salsola iberica* seed at five salinity levels and a temperature of 15°C.

Salinity of treatment solutions	Days after initiation of germination			
	2	4	6	8
$dS\ m^{-1}$	%			
<0.1	3.6	40.4	70.8	78.8
10.1	3.2	26.8	63.2	66.4
18.8	2.0	10.0	30.8	37.2
26.7	0.0	1.2	12.0	20.0
33.8	0.0	0.0	3.6	8.8

Analysis of variance

Source	df	Mean squares: Days after initiation of germination 2	4	6	8
Salinity	4	14.64*	1,528.16**	4,504.56**	4,448.24**
Linear	1	53.64**	5,823.09**	17,214.90**	17,407.25**
Quadratic	1	0.53	178.22*	24.04	6.10
Cubic	1	3.41	102.21	704.35**	318.45*
Error	16	3.24	26.86	60.06	66.54
C.V.† (%)		102.27	33.05	21.48	19.31

*,**Significant at the 5 and 1% level of probability.
† C.V. - coefficient of variation.

Table 11. Cumulative germination percentages of *Salsola iberica* seed at five salinity levels and a temperature of 20°C.

Salinity of treatment solutions	Days after initiation of germination			
	2	4	6	8
$dS\ m^{-1}$	%			
<0.1	18.4	65.6	81.2	83.2
10.1	8.8	36.8	60.4	64.8
18.8	0.8	10.8	30.0	38.4
26.7	0.0	2.8	12.8	17.2
33.8	0.0	0.4	1.6	4.0

Analysis of variance

Source	df	Mean squares			
		Days after initiation of germination			
		2	4	6	8
Salinity	4	384.80**	3,840.56**	5,486.00**	5,360.16**
Linear	1	1,103.63**	14,108.02**	21,635.07**	21,276.42**
Quadratic	1	181.17**	1,133.39**	61.05	4.29
Cubic	1	2.74	59.13	193.81*	152.87*
Error	16	5.50	14.66	34.50	23.56
C.V.†(%)		41.88	16.45	15.79	11.69

*,**Significant at the 5 and 1% level of probability.
†C.V. - coefficient of variation.

Table 12. Cumulative germination percentages of *Salsola iberica* seed at five salinity levels and a temperature of 25°C.

Salinity of treatment solutions	Days after initiation of germination			
	2	4	6	8
$dS\ m^{-1}$	--------	%	--------	
< 0.1	19.2	56.0	70.8	76.8
10.1	7.6	22.8	30.4	42.4
18.8	0.0	2.0	6.4	9.2
26.7	0.4	1.6	1.6	4.8
33.8	0.0	0.0	0.4	0.4

Analysis of variance

Source	df	Mean squares: Days after initiation of germination			
		2	4	6	8
Salinity	4	348.24**	2,880.56**	4,472.56**	5,292.56**
Linear	1	1,115.66**	9,479.49**	15,278.07**	19,000.29**
Quadratic	1	261.09**	1,945.54**	2,560.85**	1,876.36**
Cubic	1	0.67	7.44	2.53	50.41
Error	16	23.34	32.16	27.46	38.36
C.V.† (%)		88.81	34.41	23.91	23.18

*,**Significant at the 5 and 1% level of probability.

†C.V. - coefficient of variation.

Table 13. Cumulative germination percentages of *Salsola iberica* seed at five salinity levels and a temperature of 30°C.

Salinity of treatment solutions	Days after initiation of germination			
	2	4	6	8
$dS\ m^{-1}$	--------------------------	%	--------------------------	
<0.1	21.6	58.4	73.2	76.8
10.1	1.6	6.0	8.8	13.6
18.8	0.0	1.2	2.4	3.6
26.7	0.0	1.6	2.0	2.0
33.8	0.0	0.0	0.8	1.2

Analysis of variance

		Mean squares			
		Days after initiation of germination			
Source	df	2	4	6	8
Salinity	4	451.84**	3,184.24**	4,906.64**	5,265.04**
Linear	1	1,113.87**	8,110.17**	12,674.46**	14,514.24**
Quadratic	1	577.88**	3,794.85**	5,788.82**	5,694.51**
Cubic	1	108.73**	800.65**	1,106.10**	811.75**
Error	16	6.54	17.34	28.74	31.04
C.V.† (%)		55.12	30.98	30.74	28.66

*,**Significant at the 5 and 1% level of probability.

†C.V. - coefficient of variation.

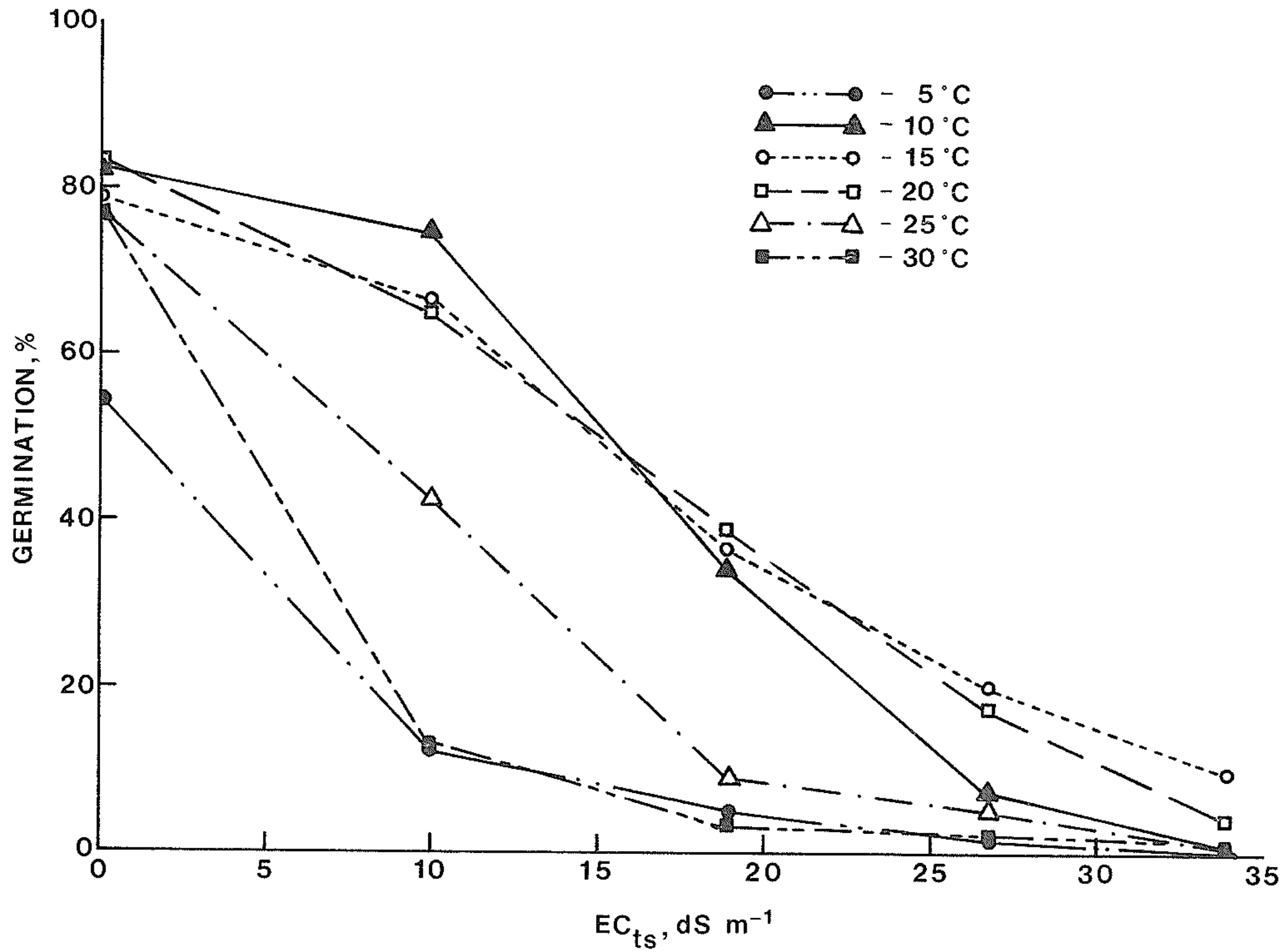


Fig. 1. Germination response of Salsola iberica to salinity at six temperatures.

approximately 24°C) for periods much longer than one year (Wayne Whitworth, personal communication). Germination percentages of the controls at all temperatures except those at 5°C exceeded 75 percent and had remained relatively constant at a 20°C germination temperature over the year since the seed were first tested. Seedling vigor, however, was not measured but may have been reflected in the germination response of these seed to salinity. A germination test at 5°C over the same range of salinities using eight-month-old seed harvested from plants grown from the original seed responded much more favorably to salinity than the original seed. There was insufficient time to repeat the experiment using the new seed for inclusion with the results of this report.

Chemical Analyses

Crude protein, acid detergent fiber (ADF), acid detergent lignin (ADL), nitrate, water soluble oxalates, total oxalates, ash content and mineral composition of the ash of the *S. iberica* plant material harvested in experiment 1 at early flower and full flower were determined. The effect of salinity on the crude protein, ADF and ADL content of *S. iberica* at both harvests is shown in table 14. Crude protein of the plant material harvested at early flower increased linearly with increasing salinity. Both ADF and ADL decreased linearly as salinity increased at early flower. Crude protein at full flower tended to increase with increasing salinity up through the 26.8 dS m^{-1} treatment level but dropped back to the level of the control at the 33.9 dS m^{-1} treatment level. The ADF and ADL contents at full flower tended to decrease as salinity increased in a manner similar to that at early flower.

Nitrate and oxalate levels are given in table 15. Nitrate levels of the plant material harvested at early flower was not affected by salinity but decreased linearly with increased salinity at full flower.

Table 14. Crude protein, acid detergent fiber and acid detergent lignin levels of *Salsola iberica* grown at five salinity levels and harvested at two plant developmental stages, early flower and full flower.

Salinity of irrigation solution	Early flower: Crude protein	Early flower: Acid detergent fiber	Early flower: Acid detergent lignin	Full flower: Crude protein	Full flower: Acid detergent fiber	Full flower: Acid detergent lignin
$dS\ m^{-1}$	--------------------------	---------% dry wt	---------	------------	------------	------------
1.3	17.18	23.71	3.78	14.31	29.48	5.05
10.6	18.58	21.18	3.28	16.22	26.11	4.30
19.5	18.65	20.90	3.11	16.70	25.54	4.32
26.8	19.48	18.18	3.20	16.87	23.50	4.18
33.9	19.69	15.64	3.02	14.09	16.78	3.16

Analysis of variance

Source	df	Mean squares — Early flower: Crude protein	Early flower: Acid detergent fiber	Early flower: Acid detergent lignin	Full flower: Crude protein	Full flower: Acid detergent fiber	Full flower: Acid detergent lignin
Salinity	4	3.9016**	38.1843**	0.3583*	7.2976**	88.8166**	1.8293**
Linear	1	14.2561**	143.3134**	1.1004**	0.2370	303.1740**	5.9704**
Quadratic	1	0.4609	3.7063	0.2087	25.8271**	25.0313**	0.1853
Cubic	1	0.2326	2.8834	0.1050	1.8776	26.9738**	1.1563**
Error	12	0.4626	2.7037	0.0934	0.4672	1.8538	0.0479
C.V.† (%)		3.63	8.25	9.32	4.37	5.61	5.21

*,**Significant at the 5 and 1% level of probability.
†C.V. - coefficient of variation.

Table 15. Nitrate, water soluble oxalate and total oxalate levels of *Salsola iberica* plants grown at five salinity levels initiated at 42 days after planting and harvested at two plant developmental stages, early flower and full flower.

Salinity of irrigation solution	Early flower			Full flower		
	Nitrate	Water soluble oxalate	Total oxalate	Nitrate	Water soluble oxalate	Total oxalate
$dS\ m^{-1}$	----------	----------	---------- % dry wt	----------	----------	----------
1.3	0.45	3.39	8.36	0.33	1.91	8.18
10.6	0.44	1.99	8.45	0.29	0.70	8.40
19.5	0.55	1.92	8.46	0.33	0.86	7.96
26.8	0.66	1.99	8.68	0.22	0.77	7.78
33.9	0.58	1.88	8.61	0.23	0.02	6.90

Analysis of variance

Source	df	Mean squares					
		Early flower			Full flower		
		Nitrate	Water soluble oxalate	Total oxalate	Nitrate	Water soluble oxalate	Total oxalate
Salinity	4	0.0351	1.6874**	0.0657	0.0117*	1.8499**	1.3179**
Linear	1	0.0946	3.9905**	0.2080	0.0318**	5.6141**	3.7311**
Quadratic	1	0.0015	2.0331**	0.0000	0.0013	0.1017**	1.3487*
Cubic	1	0.0418	0.7161*	0.0112	0.0000	1.6623**	0.0048
Error	12	0.0301	0.0862	0.1604	0.0031	0.0089	0.2384
C.V.†(%)		32.48	13.15	4.71	19.92	11.06	6.22

*,**Significant at the 5 and 1% level of probability.
†C.V. - coefficient of variation.

Water soluble oxalate decreased markedly at the lowest level of applied salt solution but did not respond further to increases in salinity. This decrease in oxalate content could be very useful in a practical sense as soluble oxalates are to be avoided in forages. Total oxalate levels remained constant with increasing salinity in the first harvest (early flower) but decreased with increasing salinity in the final harvest (full flower).

The percentage ash and the mineral compostion of S. iberica harvested at early flower are listed in table 16. Ash, K, Ca, Na and Zn increased with increased salinity. Phosphorus, B, Mn and Cu were not affected. Magnesium and Fe levels, on the other hand, were higher in the control plants than those subjected to salinity stress. The ash content was only partially accounted for by the mineral composition measured. If it is assumed that each of the cations in table 16 has Cl^- as a counterion, an ash content of up to 31 percent can be estimated. The sulfate ion ($SO_4^=$) may also serve as a counterion for some of these cations. It will be necessary to confirm this by measuring both chloride and sulfate content. In plants, some of the cations are tied up with organic anions; therefore, the ash content will show a greater content of cations than anions (Stan Smith, personal communication).

The influence of salinity on the ash content and mineral composition of the plant material harvested at full flower is given in table 17. Ash content was generally lower in the final harvest than in the first harvest. This is consistent with the observations of Nelson et al. (1970) who reported decreasing ash content of Russian-thistle forage with increasing maturity. The exceptionally high ash content of the plant material harvested from the highest salinity treatment was probably the result of the excessive salinity exposure that this treatment accidentally received a few days before harvest. The excessive accumulation of Ca and Na in this treatment undoubtedly resulted

Table 16. Percent ash and mineral composition of *Salsola iberica* plants grown at five salinity levels initiated at 42 days after planting and harvested at the early flower stage of plant development.

Salinity of irrigation solution	Ash	P	K	Ca	Mg	Na	Zn	B	Fe	Mn	Cu
$dS\ m^{-1}$	% dry wt.						ppm				
1.3	19.62	0.57	7.02	2.21	1.06	0.04	56	38	106	168	5
10.6	23.68	0.41	9.57	2.92	0.61	0.20	78	36	84	170	6
19.5	23.64	0.42	7.94	2.96	0.59	0.24	81	38	79	171	7
26.8	25.46	0.48	9.50	2.96	0.60	0.36	98	42	78	184	5
33.9	25.44	0.52	8.85	3.03	0.66	0.46	128	44	79	188	7

Analysis of variance

Source	df	Mean squares										
		Ash	P	K	Ca	Mg	Na	Zn	B	Fe	Mn	Cu
Salinity	4	22.9999**	0.0177	4.7458*	0.4698**	0.1590**	0.1047**	2,856.43**	39.80	630.13*	1,361.93	2.88
Linear	1	83.1276**	0.0012	5.4686*	1.2306**	0.2940**	0.4067**	10,388.85**	115.42	1,750.59**	4,862.72	5.84
Quadratic	1	5.9912**	0.0589**	2.9198	0.4695*	0.2955**	0.0003	467.22	30.85	706.75*	271.00	0.14
Cubic	1	0.2089	0.0108	2.2142	0.1739	0.0405**	0.0060	536.93	11.18	59.05	146.24	1.68
Error	12	0.5605	0.0058	1.1111	0.0630	0.0028	0.0057	182.26	30.37	128.63	1,677.83	2.28
C.V.† (%)		3.20	15.75	12.29	8.90	7.55	29.05	15.31	13.97	13.26	23.96	26.23

*,**Significant at the 5 and 1% level of probability.
†C.V. - coefficient of variation.

Table 17. Percent ash and mineral composition of <u>Salsola iberica</u> plants grown at five salinity levels initiated at 42 days after planting and harvested at the full flower stage of plant development.

Salinity of irrigation solution	Ash	P	K	Ca	Mg	Na	Zn	B	Fe	Mn	Cu
$dS\ m^{-1}$	% dry wt.						ppm				
1.3	17.46	0.58	4.35	2.77	1.04	0.02	44	41	84	194	4
10.6	20.38	0.46	5.19	3.31	0.61	0.16	76	37	79	221	5
19.5	21.33	0.43	5.65	3.12	0.57	0.20	71	42	76	226	6
26.8	22.41	0.38	5.90	3.26	0.50	0.48	79	45	80	193	6
33.9	37.42	0.38	3.72	4.83	0.43	2.91	86	41	84	179	6

Analysis of variance

Source	df	Mean squares										
		Ash	P	K	Ca	Mg	Na	Zn	B	Fe	Mn	Cu
Salinity	4	245.3777**	0.0261**	3.3273**	2.5259**	0.2272**	5.9389**	1,032.55**	37.13*	43.95	1,579.93**	3.13**
Linear	1	661.3801**	0.0929**	0.0196	6.1968**	0.7421**	13.7648**	3,085.12**	40.37	0.04	1,058.52*	10.48**
Quadratic	1	187.0593**	0.0091*	10.4518**	1.7037**	0.1088**	7.1270**	344.65*	0.29	167.78	4,523.14**	1.46
Cubic	1	117.9340**	0.0010	2.2799*	2.1752**	0.0521**	2.5776**	505.56**	107.82**	0.26	281.56	0.51
Error	12	0.9254	0.0016	0.2599	0.0262	0.0012	0.0123	41.65	9.23	59.35	140.39	0.39
C.V.† (%)		4.04	8.99	10.27	4.68	5.50	14.62	9.08	7.41	9.59	5.85	11.92

*,**Significant at the 5 and 1% level of probability.

†C.V. - Coefficient of variation.

from the salt overdose. Ash content increased slightly with increased salinity in the other treatments. Again, as in the plant material harvested at early flower, K, Ca, Na and Zn increased as salinity increased. The Cu content of the ash also increased slightly with increased salinity. Phosphorus, Mg and Mn decreased with increased salinity while Fe content did not change. Changes in the ash content can apparently be accounted for by the changes in the mineral composition determined, assuming the counterion is chloride or sulfate.

Crude protein, ADF, ADL, nitrate and water soluble oxalate levels were determined for the S. paulsenii plant material harvested in experiment 1. All of these components tended to decline as salinity increased (table 18). Ash and mineral composition data are given in table 19. Ash, Ca and Na increased with increasing salinity. Phosphorus, B and Fe decreased with increasing salinity while K, Mg, Zn, Mn and Cu levels were not changed by salinity.

Natural Products of Commercial Value Found in Salsola

Table 20 summarizes our literature search for compounds which have been isolated from Salsola species and may be of commercial value. For example, the isoquinoline alkaloids, salsoline and salsolidine, which first appeared in the Pharmacopeia of the USSR in 1968, are used as antihypertensive agents. An older report (Aizenman et al. 1963) showed that these compounds also have antitumor activity. In addition, citric acid, for which a large market exists, is quite high in some species of Salsola (Sabinin et al. 1942). At bulk prices for citric acid and assuming typical yields of Salsola (10,000 kg/ha) and 3.4 percent citric acid content at $12.50/kg, we have estimated that the value per hectare could be as high as $4,250. No costs for production or processing are estimated here. Finally, ferulic acid, a derivative of N-feruloylputresine (a component of S. subaphylla) has been patented in Japan

Table 18. Crude protein, acid detergent fiber, acid detergent lignin, nitrate and water soluble oxalate levels of <u>Salsola paulsenii</u> plants grown at five salinity levels initiated at 42 days after planting and harvested at physiological plant maturity.

Salinity of irrigation solution	Crude protein	Acid detergent fiber	Acid detergent lignin	Nitrate	Water soluble oxalate
dS m^{-1}			% dry wt		
1.3	18.05	26.64	4.54	4.00	2.72
10.6	16.22	24.25	3.75	2.38	0.79
19.5	15.14	24.48	3.44	1.78	0.39
26.8	14.59	22.34	3.48	1.62	0.07
33.9	15.06	21.04	3.41	1.68	0.03

Analysis of variance

		Mean squares				
Source	df	Crude protein	Acid detergent fiber	Acid detergent lignin	Nitrate	Water soluble oxalate
Salinity	4	7.7060**	18.0996**	0.9054**	3.9184**	4.9859**
Linear	1	24.8306**	70.1381**	2.7551**	12.4182**	15.8158**
Quadratic	1	5.8052**	1.2425	0.7768**	3.0784**	3.5879**
Cubic	1	0.1315	0.9512	0.0806	0.1342	0.4292
Error	12	0.4791	0.8986	0.0281	0.0561	0.1198
C.V.† (%)		4.38	4.04	4.50	10.25	43.33

*,**Significant at the 5 and 1% level of probability.
† C.V. - coefficient of variation.

Table 19. Percent ash and mineral composition of Salsola paulsenii grown at five salinity levels and harvested at physiological plant maturity.

Salinity of irrigation solution	Ash	P	K	Ca	Mg	Na	Zn	B	Fe	Mn	Cu
$dS\ m^{-1}$	% dry wt.						ppm				
1.3	21.10	0.93	4.49	2.26	1.13	1.16	91	116	111	150	7
10.6	26.02	0.72	4.12	3.32	0.93	2.55	107	92	79	177	7
19.5	28.87	0.60	4.15	3.85	0.95	3.37	96	89	80	168	6
26.8	30.58	0.68	4.14	4.20	0.89	3.71	102	77	86	192	7
33.9	30.31	0.59	3.99	3.90	0.85	3.76	107	71	71	175	7

Analysis of variance

Source	df	Mean squares										
		Ash	P	K	Ca	Mg	Na	Zn	B	Fe	Mn	Cu
Salinity	4	62.3165**	0.0716**	0.1352	2.3561**	0.0461	4.7884**	204.63	1,197.08**	922.30**	907.25	0.33
Linear	1	221.4976**	0.2069**	0.3874	7.4583**	0.1443**	17.0473**	279.47	4,455.54**	2,246.36**	1,742.98	0.15
Quadratic	1	27.3131**	0.0463	0.0436	1.8808**	0.0150	2.1093**	7.70	125.34*	395.89	661.16	1.11
Cubic	1	0.1528	0.0164	0.1073	0.0279	0.0176	0.0021	354.10	94.23*	1033.84*	0.19	0.00
Error	12	1.4291	0.0102	0.1460	0.0717	0.0040	0.0846	108.96	17.54	153.43	391.08	0.39
C.V.†(%)		4.37	14.32	9.14	7.63	6.68	9.99	10.39	4.73	14.54	11.48	9.48

*,**Significant at the 5 and 1% level of probability.

†C.V. - coefficient of variation.

for use as a food preservative (Ryabinin and Il'ina 1951), but we do not know the extent of its current use.

Although we did not have the resources to analyze for any of the compounds listed in table 20 in the Salsola selections we have made, an analysis would be worthwhile. We have compiled a bibliography of procedures for the extraction and identification of the compounds listed, however.

Table 20. Natural products of potential commercial value which have been isolated from *Salsola* species.

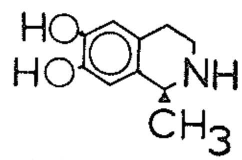
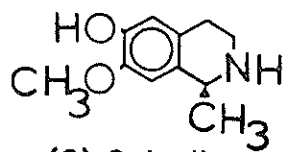
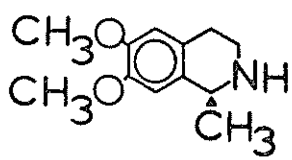
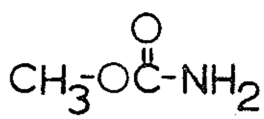
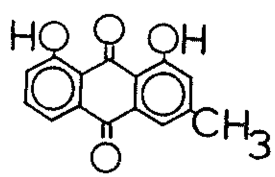
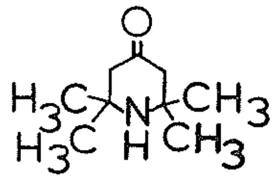
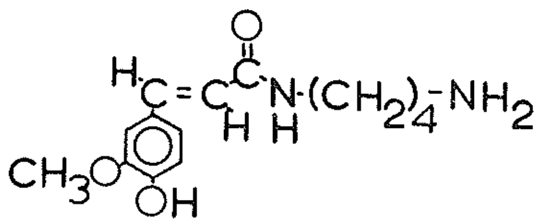
Salsola species	Compound	Amount	Potential use	References
S. richteri	 (S) Salsolinol	------	heart stimulant; binds to brain neuroreceptors; study of alcoholism	Chen and Liang 1982; Lucchi et al. 1981; Sjoquist et al. 1983
S. ruthenica *S. richteri* *S. kali*	 (S) Salsoline	0.2% (fruiting plants, *S. kali*)	antihypertensive drug; vasodilator	Wastl 1946; Karawya et al. 1971; Borkowski et al. 1959
S. ruthenica *S. richteri* *S. kali*	 (S) Salsolidine	0.2% (fruiting plants, *S. kali*)	vasodilator; antihypertensive drug	Borkowski et al. 1959; Krylov et al. 1962; Karawya et al. 1971
S. tetrandra *S. kali* *S. longifolia* *S. rigida*	 Methylcarbamate	0.05% of dry weight	-----	Karawya et al. 1972
S. macera *S. ericoides* *S. ruthenica*	 Chrysophanol	-----	-----	Melkumyan et al. 1969

Table 20. (continued) Natural products of potential commercial value which have been isolated from *Salsola* species.

Salsola species	Compound	Amount	Potential use	References
S. kali *S tetrandra*	 Triacetoneamine	------	------	Karawya et al. 1971
S. subaphylla	 N-Feruloylputrescine	------	weakly antihypertensive; ferulic acid is a food preservative	Ryabinin and Il'ina 1949
S. pestifer	Carotene	4.5 mg/100g	vitamin	Lantz 1944
S. pestifer	Ascorbic Acid	77 mg/100g (green plants)	vitamin	Lantz 1944
S. gemmascens	Citric Acid	3.4% of dry weight	food additive	Sabinin et al. 1942
S. iberica	Crude Protein	15-22% of dry weight	Animal or human food supplement	Hageman et al. 1978

SUMMARY AND CONCLUSIONS

Salsola species, S. iberica and S. paulsenii were evaluated for salinity tolerance as potential forage crop species for arid lands agriculture. Initial observations indicated that the growth characteristics and apparent photoperiodic response of S. paulsenii make it unsuitable as a forage and, therefore, S. paulsenii was not evaluated beyond the initial experiment. The salinity tolerance of S. iberica was studied in three developmental stages: (1) germination, (2) juvenility, and (3) reproduction. A variable response to salinity was observed among these stages of plant development.

Salsola iberica was less tolerant to salinity during germination than during the other developmental stages. A 50 percent reduction in germination occurred at all germination temperatures studied at an electrical conductivity of the treatment solutions (EC_{ts}) of less than 18.8 dS m^{-1}. Germination was generally best in the 10 to 20°C temperature range with significant reductions in germination at the lowest salinity level (10.1 dS m^{-1} EC_{ts}) at germination temperatures of 5, 25 and 30°C. There was little difference in the final germination percentages of the controls among the temperatures studied with the exception of that at 5°C which was reduced by 20-25 percent. The seeds utilized in this study were over a year old and vigor was noticeably reduced by age, although final germination percentages had not changed significantly over the period since harvest. A germination test over the same salinity levels at a temperature of 5°C utilizing a seed lot of similar genetic constitution but harvested a year later than the seed used in our tests showed a more favorable response of the younger seed to both salinity and the low temperature. This strongly suggests the importance of seed age in the germination response of S. iberica seed to salinity.

Biomass yield response of *S. iberica* plants to salinity was influenced by the timing of the initial exposure of the plants to salinity. When the salinity treatments were initiated during the seedling stage (7 DAP), tolerance to salinity increased with time of exposure as indicated by the increase in the EC_{ts} at which a 50 percent reduction in biomass yield occurred. For the four harvests at 22, 36, 50 and 64 DAP, the EC_{ts}'s at which a 50 percent reduction in biomass yield occurred were estimated to be 20.0, 22.2, 30.5 and 31.5 dS m^{-1}, respectively. Of significant interest was the enhancement effect of salinity on biomass yield which was clearly evident for the plants in the 10.5 dS m^{-1} treatment level at the 50 and 64 DAP harvests and in the 18.2 dS m^{-1} treatment level at 64 DAP. This enhancement effect on yield occurred in the salinity range of waters that would most likely be useful for irrigation purposes. When the initial exposure to salinity occurred during the transition from the vegetative to the reproductive stage, the *S. iberica* plants did not develop the same level of salinity tolerance as those plants initially exposed to salinity during the seedling stage. The later exposure to a saline environment resulted in a 50 percent biomass yield reduction at an EC_{ts} of about 24 dS m^{-1} at 91 DAP or 49 days after initial application of saline treatments. Neither was there an enhancement effect of salinity on biomass yield as had been observed when plants were exposed to salinity in the seedling stage.

Salinity generally increased crude protein content of *S. iberica* plants but reduced ADF and ADL levels. Nitrate, water soluble oxalate and total oxalate levels were reduced by salinity in the *S. iberica* plant material harvested at full flower. This reduction is significant as high levels of both nitrate and water soluble oxalates should be avoided in forages. Ash content generally increased with increased salinity.

The results of these greenhouse studies indicate that S. iberica plants have a relatively high level of salt tolerance if exposed to salinity early in their life cycle but are somewhat less tolerant to salinity during germination. The effects of salinity on nitrate and water soluble oxalate levels is encouraging as levels of both of these potentially toxic substances were reduced by salinity.

The literature search revealed a number of compounds that have been isolated from Salsola species that may be of commercial value. These included the isoquinoline alkaloids, salsoline and salsolidine, as well as more commonly known compounds such as citric acid and crude protein which may be present in commercially extractable quantities. No attempt was made to isolate any of these compounds from S. iberica.

Additional studies are needed on the salinity tolerance of S. iberica as a potential forage crop. The enhancement effect of salinity on biomass production should be further evaluated by carrying the experiment to plant maturity. The interaction of salinity, temperature and seed age on the germination response of S. iberica also should be studied. The point should be made that greenhouse and laboratory studies, although important in providing preliminary information on salinity tolerance, cannot duplicate field conditions; therefore, a logical next step is to evaluate the salinty tolerance of S. iberica under actual field conditions.

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