A Selective Breeding Program to Improve the Water-Use Efficiency and Nutritive Acceptability of Kochia as a Forage Grazing Crop

by

H. D. Fuehring
R. E. Finkner
Prinicipal Investigators
New Mexico State University
Agricultural Science Center at Clovis

and

Carroll French
Weston Pierce
William Stallings
Research Technicians
New Mexico State University
Agricultural Science Center at Clovis

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ABSTRACT

Through selection, slow progress is being made for lower oxalate and alkaloid levels in *Kochia scoparia*. Oxalate and alkaloid contents varied considerably under different environments. Kochia can thrive at salt levels of irrigation water up to one-third that of salt water, making it a high potential crop where the underground water is brackish. Several phenotypic plant characteristics were observed but none were stabilized in a true breeding line.

Key words: Dragendorff's reagent, forage toxicity, alkaloid, salt tolerance, drought tolerance, phenotypic differences, oxalate

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JUSTIFICATION OF WORK PERFORMED

The High Plains of New Mexico has highly productive soils, level terrain, and a climate favorable to agricultural enterprises. In addition to these resources, the area has significant but exhaustible quantities of groundwater. In the early 1950s, only 3,000 acres were irrigated in Curry County (Lansford and Sorensen 1971). Thirty years later, in the early 1980s, more than 222,000 acres in Curry County were irrigated (Lansford et al. 1980). This irrigation was largely supplied by water from the Ogallala aquifer. As irrigated acreage expanded, water use increased and the Ogallala aquifer supply decreased. The problem of depletion of the Ogallala aquifer water supply to support irrigation crop farming in the High Plains was addressed by the U.S. Congress in Section 193 (P.L. 94-587 90 Stat. 2943.193). The congressional intent was clear and concise in directing the Secretary of Commerce, "to examine the feasibility of various alternatives to provide adequate water supplies," for the High Plains region and, "to assure the continued economic growth and vitality of the region." One result of this directive was the formation of the High Plains Study Council, representing six states, which included New Mexico. A summary of the council's findings and recommendations was published in December 1982 (High Plains Study Council 1982).

Energy costs also was a major factor in the development of irrigation on the High Plains. However, in 1973, the Arab oil embargo forcefully brought to the attention of all Americans, especially irrigation farmers, the importance of energy. Prices for natural gas, electric power, LP gas, and all forms of petroleum products increased several fold while farm prices stagnated at a low economic level. Therefore, with a declining aquifer, skyrocketing energy prices, and depressed farm income, the High Plains Study Council made several recommendations they thought would help continue and/or maintain the economic growth and vitality of the region.

The High Plains Study Council listed seven categories of recommendations. The first was, "Water Conservation Technology, Research and Demonstration." One of the recommendations (A-3) stated, "Increase public and private funding for research, demonstration and market development for more water-efficient crops adapted to High Plains growing conditions."

The council made the following suggestion for the implementation of recommendation A-3:

> A significant research emphasis for both private and public investments in agricultural research in the 1980s and beyond should be assigned to the development of more water-use efficient varieties of the principal High Plains crops and the intensive investigation of new alternate crops for adaptation to both irrigated and dryland production conditions throughout the region. Although a large number of alternative crops adapted to arid or semiarid growing conditions are currently undergoing field tests in other locations--e.g., Crambe sp, sunflower, milkweed and others--few have been examined for High Plains conditions. As locally adapted plants with commercial potential are identified in the research phase, a market development phase should be organized to ensure local marketing capabilities. Concurrently, an intensive local information, extension and demonstration phase will be necessary to gain farmer acceptance and trials of new crops.

Kochia (Kochia scoparia) is a vigorous growing annual of the Chenopodiaceae family that has become established on the Great Plains since the early 1940s. Erickson and Moxon (1947) made extensive feeding trials in South Dakota and established that the feeding value approached that of alfalfa. Sherrod (1971) at Pantex, Texas, obtained protein levels ranging from 25% in May to 13% in July. Similar protein levels have been determined at this research center (Fuehring 1983 through 1985). Thus, kochia has the potential of producing high quality forage if properly managed. Erickson and Moxon (1947) reported hay yields of 3.6 T/A and seed yields up to 1,500 lb/A. Sherrod (1971) reported kochia yields of over 5 T/A dry matter by July 15 without irrigation and about 12 inches of rainfall. Baker (1974) in Montana reported kochia yields of 5.5 T/A dry matter from 14 inches of water used. In the same study, Russian thistle was slightly more water efficient. Bell et al. (1952) recorded kochia yields three times that of alfalfa. Similar yields and estimated water-use efficiency were found in spot checks of dryland fields in Curry County, New Mexico, in 1977 and also in a preliminary greenhouse study in 1978. These production figures per inch of water used are much greater than those reported for alfalfa (Hanson 1967). Thus, kochia is a potentially high producing forage or grazing crop for the High Plains of New Mexico under dryland (40 to 45 cm annual rainfall) or limited irrigation. Durham and Durham (1979) wrote of kochia growing during a drought which dried up pastures of native grasses.

The above yield levels have been confirmed at this research center by Fuehring (1980) and cultural practices are being studied. No particular disease or insect problems with the crop have been noted. In view of its very high water efficiency, it appears that kochia has great potential as a dryland or limited irrigation crop for semiarid regions such as the Great Plains. Although an annual, it reseeds profusely, thus, reestablishing itself each year. Establishment of kochia as a forage crop can result in considerably greater livestock production per unit of water used. As the water available for irrigation from the Ogallala Formation becomes depleted, a very drought tolerant crop such as kochia can make up a considerable portion of the difference. While it takes 15-20 acres of native pasture to carry a cow, well managed dryland kochia in eastern New Mexico has the potential to carry a cow on 2-3 acres or less.

Kochia has been reported to grow very well in saline seep areas in Montana. This vitality would indicate tolerance to salt and a possibly very good forage crop where saline or brackish water is available for irrigation. New

Mexico is estimated to have 3 billion acre-feet of recoverable fresh water (Governors Council of Economic Advisors 1977). However, an additional 15 billion acre-feet of underground water is considered to range from slightly saline to brackish. Thus, salt tolerant crops such as kochia have a large potential for utilizing this vast underground water resource.

Kochia has an extremely wide range in adaptation. However, it is found mainly in the Great Plains states, which are generally considered arid or simi-arid lands. Kochia probably has undergone several cycles of natural selection for drought resistance, which makes it such a water efficient plant.

Many methods and procedures have been used, with various degrees of success, in trying to find and breed drought tolerant crops. Little success in screening plants for drought tolerance has been obtained by selection for morphological features such as extensive root systems or fewer stomata. Field testing for drought resistance is often complicated by genotypic environmental interactions, irrigation, rainout shelters, etc. Recent methods have included more sophisticated equipment such as psychrometers, pressure chambers, porometers, neutron probes, etc. Solutions with various osmotic pressures to control moisture availability have been used by several investigators (Ayres 1952; Helmerick and Pfeifer 1954; Powell and Pfeifer 1956; Shull 1951; Thimann 1954; Uhvits 1946; and Williams et al. 1967). Sodium choride, D-mannitol, sucrose, inositol and others have been used to produce solutions of variable osmotic pressures. Germinating seeds in these osmotic pressure solutions and selecting genotypes showing the highest percent germination and growth appears to be one of the simplest and most useful methods in screening plants for drought tolerance.

In replicated greenhouse tests at this research center, little reduction in total plant dry weight was observed after 76 growing days when watering with variable amounts of salt solution (0 to 21 g/l), (Fuehring 1981 and 1982).

Under certain conditions, kochia accumulated high mineral levels, especially oxalates, which may be poisonous to livestock (Davis 1973; and Sperry et al. 1965). Results from this research center indicate that plants contain 5% oxalate on average and occasional reports of possible oxalate poisoning have been made from the area. It is assumed that oxalate is the chemical compound that is detrimental to animals consuming this plant if the oxalate content is present in excessive amounts (not definitely known). In preliminary tests, variability in oxalate percentage has been found between lines and among plants within lines. Much of this variability was speculated to be under genetic control.

Under certain conditions, serious health problems develop for livestock grazing on kochia (Dickie and Berryman 1979; and Galitzer and Oehme 1978). The prebloom stages of growth give little trouble, but at blooming and later stages, photosensitivity and kidney and liver damage may develop. The toxic principle has not been determined but oxalates, alkaloids and saponins may be involved. The toxicity is especially severe during prolonged drought and immediately after a drought. Some groups of cattle seem to be much more sensitive than others. Usually, only 10 to 20% of the cattle in any one group are sensitive. While considerable work has been done at this research center on oxalates and salt tolerance of kochia, less has been done on the alkaloids and none has been done on saponins. The hay seems to be much less toxic than the grazed plants, indicating that alkaloids may be the main toxic property. Kiesling et al. (1984) conducted serum chemistry profiles on kochia fed steers and found evidence for the involvement of hepatotoxicants; they also concluded that oxalate does not appear to be the primary toxicant.

To our knowledge, there have been no serious plant improvement programs applied to kochia for domestication. For the past 30 years, it has been considered a troublesome weed. Kochia is still considered a problem for many crops, including sugar beets. However, for the past five to eight years, many farmers and ranchers have been grazing and feeding kochia with excellent results.

Kochia has a complete flower (male and female organs are together in each flower). Several plants have been bagged for pollen control and seed was obtained under the bags, indicating the species is partially self-fertile. The wild plants show considerable variability in leaf and stem color, leafiness, flowering and growth habits. It is assumed that some of this variability is genetically controlled. To date, no good marker genes are available.

Relatively little is known about the genetics and sexual behavior of the kochia species. However, from preliminary observations and tests, considerable variability exists. If much of this variability is under genetic control, then this species could be improved by a systematic plant breeding program.

Kochia has been reported as a very salt tolerant species and investigation conducted at the Roswell Test Facility by Fuehring et al. (1985) confirmed these observations. Greenhouse investigations were conducted from 1981 through 1985 to determine the salt tolerance of kochia and its reaction to different fertilizer treatments.

METHODOLOGY

The kochia breeding project had its beginning with the bagging of 11 plants in 1979 and the selecting of open-pollinated seed from eight other plants. The kochia plant has flowering branches and the inflorescence contains complete flowers (male and female organs in the same unit), which are small and numerous. Paper pollinating bags were placed over a single flowering branch before any florets had opened enough to shed pollen. Therefore, any seed obtained under the paper bags would be self-bred or inbred seed. Open-pollinated seed was collected by stripping the ripe seed off the flowering branches.

The 1980 kochia breeding nursery consisted of the 19 lines each planted in the center of a 40-inch wide bed with plots 12-feet long. The seeding rate was approximately two plants per foot. When the plants were 2 to 3 feet tall, a vegetative sample consisting of leaves, branches and stems was harvested from each plant. The collected material was dried, finely ground (0.61 mm), and oxalate content was determined by the Dye (1956) method. Several different chemical attributes can be determined on a single ground sample analyzed.

In 1980, plants that showed a low oxalate content were selected for future breeding investigations. The flowering branches of these plants were bagged before any florets were open. A few high oxalate content plants were also selected so divergent selection could be practiced, which would be helpful in determining the heritability of oxalate content in the kochia plant.

The resulting seeds from the selected plants were harvested, threshed and cleaned. A sample of seed from each line was germinated on blotter paper and the resulting seedings were transplanted to peat moss plugs. When the seedling reached the 4 to 6 leaf stage, the peat moss plugs were again transplanted to 8 inch greenhouse pots or planted directly into the greenhouse floor soil. In later plantings, the bare seeds were planted directly into the floor soil and the peat moss plugs were eliminated.

From 1981 through 1986, all field nurseries were seeded directly in the center of a 40 inch wide bed. The nursery was cross marked and seed were planted 2 feet apart. The beds were approximately 700 feet long, therefore, the nurseries were about 0.8 acre in size each year.

An infrared analyzer was obtained in 1980 and this analytical instrument was used throughout the remainder of this project to determine oxalate content, protein percentage, and TDN (total digestible nutrients) values. Protein was determined on individual plants by using a microkjeldahl procedure and correlated with values obtained with the infrared analyzer. Table 1 shows the correlations between wet lab analyses and infrared readings. In all cases, the correlations were statistically highly significant. Total digestible nutrients were run on several plants by the New Mexico State University animal science department. The same individual plant samples were used to calibrate the infrared analyzer.

Table 1. Correlation coefficients between wet lab chemical analyses and Technicon Infralyzer 400 readings

Constituent	R Value
Oxalate	.927
Protein	.924
Phosphorus	.986
Digestibility	.996

In 1983, 1984, 1985 and 1986, each plant in the nursery was tested for alkaloids, using a method developed by Burns (1964) which uses Dragendorff's reagent on filter paper. Dragendorff's reagent is a simple screening test for alkaloids in many plants. The reagent is dried on filter paper and produces a color reaction of orange, purple or black when exposed to plant juice containing alkaloids. Filter paper 11 cm in diameter was quartered. The resulting pie shaped section was folded over some kochia leaves and the paper and leaves were squeezed with pliers. Sufficient pressure was applied so plant juices were absorbed into the impregnated filter paper. If a color reaction occurred, the filter paper was rated on a scale from 1 to 6, based on the intensity of the developed color. Standards varying in color intensity were developed so comparison could be made. This method produced a semiquantitative rating for each plant in the nursery.

Plants showing the desired characteristics under study were selected each year. Selection pressures were based on the data obtained from the forage samples harvested and analyzed and on phenotypic appearance. Selected plants were bagged for inbreeding in order to maintain the plants' genetic purity. The bagged seed branches were hand threshed and the resulting seed were planted the following year. Ten to 25 progenies were grown from each selected plant. The progenies were sampled, analyzed for oxalate and alkaloid contents, and the mean value of each selected line was used for comparison.

Divergent selection for high and low oxalate and alkaloid content was employed and the progenies of each group were compared. They were also compared each year to a group of unselected wild plants. The wild population was used each year as a check to determine if the selection pressure was effective. Approximately 500 wild plants were analyzed for oxalate content each year, but only one mean per year was used in the analysis of variance computation. Approximately the same number of wilds were analyzed for alkaloid content each year, but the wild plants were grouped in blocks. The mean of each block was used in computing the analysis of variance. The number of selected plants differed each year, therefore, a nonorthogonal analyses of variance was used for mean separation. The analyses of variance and the means for both years and selections were computed.

Phenotypic characteristics were recorded for vigor, stem color and leafiness. Vigor was rated on a scale from 1 to 9; 1 having very poor vigor with 9 having extremely good vigor. Plant stems were rated on the degree of red and green color with five classes: 1 = green, 2 = green with a very light red stripe, 3 = green and red stripes about equal, 4 = mainly red with a slight green stripe, and 5 = nearly completely red. Plant leafiness was visually rated on a scale of 1 to 5: 1 = a very stemmy plant with few leaves, and 5 = a very leafy plant that would have a high leaf-to-stem ratio. Plant architecture was observed and a considerable amount of variation was noted; tall and straight, barrel shaped, dwarf and round. Differences in leaf type such as curled, broad and narrow were also observed.

In the winter of 1982-83, several greenhouse plants were analyzed for oxalate content. These plants were divided into a high and low oxalate group and were transplanted in the greenhouse isolation chambers for a seed increase. Three other seed increase isolations were developed by transplanting field grown plants in the greenhouses. The selections were as follows and were based upon oxalate content of individual plants:

20 plants selected for low oxalate from inbred population

20 plants selected for low oxalate from wild population

20 plants selected for high oxalate from wild population

Two types of seed were produced in greenhouse isolation, based on selection for salt tolerance. Since description of each seed line was cumbersome, an abbreviated descriptive name was given to each seed line in this test. Furthermore, each seed line falls into one of four categories. Listed below are these seed lines by category and abbreviated name:

1. Three seed lines that are the result of allowing isolated cross-pollination of plants that showed similar oxalate levels to each other but significantly different oxalate levels than the wild population grown in the field during 1982. These individuals were transplanted from the field into the appropriate greenhouse isolation bay in the summer of 1982. Seed is classified according to the parent population:
   a. PLONGT - Pedigreed individuals with low oxalate content
   b. WLONGT - Wild individuals with low oxalate content
   c. WHONGT - Wild individuals with high oxalate content
2. Two seed lines that resulted from the cross-pollination of individuals whose parents showed significantly higher or lower oxalate content than the wild population of 1981. Seed from individuals grown in 1981 was greenhouse planted in isolation chambers in 1982. Individuals were sampled and analyzed for oxalate content. Those individuals that did not exhibit the oxalate level expected were rogued before cross-pollination was allowed.
   a. PLOOGS - Low oxalate
   b. PHOOGS - High oxalate
3. Two types of seed with respect to variation in the salt selection scheme:
   a. STCW - Seed from parents that were germinated in 20 g/l NaCl and treated only with 24 g/l NaCl while in pots prior to

transplanting in soil

b. STLS - Seed which differed from that above only in that an initial irrigation with tap water preceded treatment with 24 g/l NaCl solution

4. Wild seed to be used as a check

A replicated test, using the above mentioned eight lines, was planted in April of 1983. The seed lines were tested under three moisture regimes (dryland, limited irrigation and full irrigation) and replicated five times. Plot size was a single 40-inch bed, 10 feet long, with two rows planted 10 inches apart in each bed. The complete plot was harvested twice for yield. Four hail storms were experienced during the growing season, causing considerable damage and a great amount of variability. The results were of questionable value.

Kochia childsi is an ornamental species sold by several seed companies. It has a barrel or bush shape architecture and a high leaf-to-stem ratio. Crosses between Kochia childsi and Kochia scoparia were made and field tested.

During the eight years of this investigation, over 23,700 field plants and 1,155 greenhouse plants were observed in the plant breeding program (table 2). As the program developed, several preliminary but germane experiments were conducted. These experiments were designed to determine the oxalate content in various plant parts: leaves, stems, branches, and the effect plant age had on oxalate content. Both oxalate percentages and alkaloid readings were observed under different environmental conditions: irrigated, dryland, greenhouse, plant development, etc.

Greenhouse tests were conducted to determine the salt tolerance and fertilizer requirement of kochia. A greenhouse pot experiment was started October 7, 1981, growing kochia in soil contained in 1.9 liter pots. Due to the sticky nature of the local silty clay loam soil, 1/4 sand and 1/4 peat moss were added

Table 2. Number of kochia plants planted in field and greenhouse nurseries for breeding improvement from 1979 through 1986

Year	Number of Plants: Field	Number of Plants: Greenhouse
1979	19	
1980	500	
1981	4,500	340
1982	4,550[1]	600
1983	3,600	215
1984	3,390	
1985	4,600	
1986	2,580	
Total	23,739	1,155

[1]2,600 planted in April; 1,950 planted in July

by volume. After establishing one plant per pot, plants were irrigated with tap water containing 0, 1.36, 2.71, 4.01, 5.43, 8.14 and 10.85 g/liter of added NaCl. Ten replications were used and water was added to the pots periodically to bring up to field capacity as determined by weighing the pots. The plants were harvested January 13, 1982.

A second pot experiment, over a wider range of salt levels, was started during the spring of 1982. The NaCl levels used were 0, 2.72, 5.44, 8.16, 10.88, 13.6, 16.32, 19.04 and 21.76 g/liter. Seven replications were used and plants were harvested after 144 days.

A third pot experiment during the fall of 1982 was run, using the same salt levels and procedures as in the preceding study except that more of the water was allowed to leach through the pots in order to prevent a salt buildup. Plants were harvested after 76 days.

A fourth pot experiment in the spring of 1983 had treatments extending up to 43.5 g/liter of NaCl in the irrigation water. Harvest was after 90 days of growth.

A fifth pot experiment in the fall of 1983 had salt applied directly to the soil at 0, 112, 224, 448, 897, 1794, 3588 and 5381 kg/ha and was watered with tap water.

A sixth pot experiment in the spring of 1984 involved varying levels of soil applied sodium, potassium, chloride and sulfate on kochia growth. The pots were reseeded in the fall of 1984 and a second crop of kochia obtained.

A seventh pot experiment in the spring of 1985 involved a base treatment of high sodium, potassium and chloride with low sulfate. Treatments included varying levels of sodium, potassium, chloride, sulfate, magnesium, calcium and phosphorus.

An eighth pot experiment was started in the fall of 1985 to study the effect of potassium, magnesium, calcium, sulfate and phosphate on kochia growth when watered with tap water (low salt) or high salt water (14 g/liter of NaCl).

RESULTS AND DISCUSSION

The original objectives of this project were to develop kochia cultivars that had low oxalate content, high protein percentage, high total digestible nutrient (TDN) content, and that were vigorous and very leafy. An additional objective, developing a low alkaloid cultivar, was started in 1983. Table 3 gives correlation coefficient values for the various physical and chemical attributes under study. Many of the correlation values were significant at the 5 and 1% levels of probability. The number of plants observed for the various attributes varied from 453 to 676. Two of the highest correlation values were in a positive direction for plant breeding selections; vigor and height (0.444), and vigor and leafiness (0.697). However, other correlations had a negative effect on plant breeding selection pressure; percent oxalate and protein (0.539), oxalate and leafiness (0.214), oxalate and alkaloid (-0.138), and oxalate and TDN (-0.246). Plant vigor was positively associated with alkaloid content (0.165), leafiness (0.697), percent protein (0.238), and percent oxalate (0.103). Height was associated positively with stem color, vigor, leafiness and percent protein. Stem color was significantly correlated with plant vigor, leafiness and height, indicating the green stem types on the average had higher vigor and leafiness ratings but were slightly shorter.

Although many of the correlations were significant, their values were not high enough to be useful for predictive purposes. The correlation values also indicate that considerable amount of variation exists and these associations should not be a major constraint in plant breeding procedures if the various traits have reasonably high heritability values.

Individual plants were harvested on August 25 and again on September 14 and the plants were divided into three different plant parts: leaves, branches

Table 3. _Kochia scoparia_ field test - correlation coefficients for various attributes, using plants from all nurseries, 1984

	ALK	HT	SC	VIG	LF	%P	%O
HT	0.075						
SC	0.014	0.096*					
VIG	0.165**	0.444**	-0.221**				
LF	0.034	0.261**	-0.206**	0.697**			
%P	-0.070	0.142**	0.003	0.238**	0.240**		
%O	-0.138**	-0.030	0.023	0.103*	0.214**	0.539**	
TDN	0.037	0.092*	0.081	-0.020	-0.004	-0.092*	-0.246*

*Significant at the 5% level of probability
**Significant at the 1% level of probability

Note: ALK = alkaloid quick test; HT = height; SC = stem color; VIG = vigor; LF = Leafiness; %P = % protein; %O = % oxalate; TDN = total digestible nutrients and main stem. The oxalate and protein results are shown in table 4. Leaves had 2.5 to 4.0 times more oxalate content than the main stems. Leaf protein was 1.5 to 2.5 times higher than that found in the branches or stems. Both the oxalate and protein content drops as the plants mature.

Table 4. Average oxalate and protein percentages for individuals sampled for leaf-branch-stem analysis

Harvest Date	Number of Plants	Plant Parts	Oxalate Percent	Protein Percent
8/25	11	Main stem	2.83	14.75
		Branches	3.72	15.66
		Leaves	6.62	26.95
9/14	10	Main stem	1.53	9.49
		Branches	1.68	8.86
		Leaves	6.06	22.55

Thirty individual plants (preblooming stage) were randomly harvested on June 10, 1982 (46 days after seeding), and weekly thereafter for six consecutive weeks. These were sent to Dr. Woldeghebriel at the NMSU animal science department for part of his Ph.D. thesis study (1983). In the seven-week period, the leaf-stem ratio decreased from 1.9 to 0.6. Oxalate content of the leaves remained fairly constant while the oxalate content of the stems decreased 50%. Crude protein percent remained fairly constant in the leaves (25.3 to 24.0) but showed a significant decrease in the stems (16.3 to 11.5). However, the oxalate content for an individual plant basis does not change greatly during the first 10 to 12 weeks of maturity.

Progenies from individual plants were grown in both the greenhouse during the winter of 1981 and 1982 and in the field in 1982. Table 5 gives the average oxalate and protein content of 14 lines grown under these two environments.

Table 5. Average oxalate and protein percentages for lines grown both in the 1981-82 greenhouse and 1982 field

		Mean Oxalate (% by weight)		Mean Oxalate (% by weight)	
1980 Line No.	1981 Line No.	1982 field	1981-82 greenhouse	1982 field	1981-82 greenhouse
8-02	167	5.36	6.37	21.10	24.96
9-4	443	5.50	6.10	20.69	23.55
10-2A	669	5.84	6.35	21.74	24.34
"	689	5.13	6.58	20.14	25.76
10-12	949	5.72	6.37	21.21	24.79
10-16	1050	5.02	6.36	20.40	24.79
11-2	1332	5.37	6.63	20.74	25.96
16-14	1800	5.39	5.78	20.20	22.56
"	1812	5.06	6.40	19.20	24.34
"	1816	4.90	6.22	23.91	23.84
17-6	1907	4.99	6.51	19.11	25.07
-	W439	5.20	6.40	19.31	26.18
-	W614	5.59	6.12	21.93	23.62
-	W2089	5.59	7.28	19.80	27.69
Average		5.33	6.39	20.68	24.82

The greenhouse environment produced a greater quantity of both oxalate and protein than occurred in the field. The correlation for the 14 lines under the two environments was nonsignificant: 0.043 for oxalate and -0.394 for protein. During the same winter, a replicated strain test was planted in the greenhouse. Plants in replication 1 had the southernmost location while plants in replication 5 were the furthest north. The distance between these two different replications was less than 50 feet. Significant differences in replications were detected among the five replications as shown in table 6. The southernmost

Table 6. Average oxalate and protein contents by replication of 48 selected kochia lines grown in the greenhouse during the 1981-82 winter

Replication Number[1]	% Oxalate	% Protein
2	6.96 a[2]	26.54 a
1	6.77 ab	26.78 a
3	6.50 b	24.94 b
4	6.08 c	23.47 c
5	5.87 c	22.89 c

[1]Replication 1 represents plants grown in the southernmost exposure while replication 5 is the northern part of the greenhouse

[2]Duncan's multiple range test - means followed by the same letter are not significantly different at the 5% probability level

location produced plants with the greatest content of oxalate and protein and the northernmost location produced plants with the least. The results are probably related to leaf-to-stem ratios. The plants with the southern exposure produced more leaves and finer stems than the northern group. These two examples demonstrate the sensitivity of these plants to minor environmental influences in the production of oxalate.

Selection Results for Oxalate

The results of the selection pressures applied to obtain high and low oxlate breeding lines are given in table 7. Significant differences were obtained in some years between the divergent selected families; however, in 1986, no differences were detected between the high and low selected families even though some families had been under selection for six generations (figure 1). The analysis of variance given in table 7 shows significant differences between years, selections, and the interaction between the two. When averaged over all six years, a significant difference, although very small, was detected between the high and low selected families. However, the wild population was significantly higher than the families selected for high oxalate content. Greater success was achieved during the first three years of selection (figure 1) when the average oxalate percentages were the highest. This selection study suggests that oxalate content is not simply inherited but that its expression is strongly influenced by environments. The data indicates that this character has a low heritability that is poorly transmitted from parent to its progenies. Therefore, environment has a very strong influence in determining the expression of this character.

Selection Results for Alkaloids

Table 8 gives the analysis of variance, year means, and selection means for the alkaloid ratings. Significant differences were detected among year

Table 7. Analysis of variance and means for years and selections for percent oxalate in kochia plants, 1981 to 1986

	Degrees of Freedom	Sum of Squares	Mean Square	F Value (within)	Probability Percent
Total	123	54			
Between	17	36	2.11	12.22	.000
Within	106	18	0.17		
Oxalate level uncorrected	2	7	3.43		
Year uncorrected	5	19	3.76		
Oxalate level corrected	2	7	3.70	21.41	.000
Year corrected	5	19	3.87	22.38	.000
Interaction	10	10	0.97	5.61	.000

Means for Percent Oxalate for Each Year

Year	No. of Families	Corrected Mean
1981	13	4.194
1982	20	4.927
1983	20	4.597
1984	17	3.689
1985	15	4.479
1986	39	4.033

Means for Percent Oxalate for Each Selection

Oxalate Level	No. of Families	Corrected Mean
1 = High selection	58	4.48
2 = Low selection	60	4.05
3 = Wild-unselected[1]	6	4.86

[1]Approximately 500 wilds were tested each year and treated as a single family

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Table 8. Analysis of variance and means for years and selections for alkaloid ratings in kochia plants, 1984 to 1986

	Degrees of Freedom	Sum of Squares	Mean Square	F Value (within)	Probability Percent
Total	213	155			
Between	8	65	8.08	18.42	.000
Within	205	90	0.44		
Alkaloid level uncorrected	2	27	16.25		
Year uncorrected	2	33	13.48		
Alkaloid level corrected	2	27	16.11	36.73	.000
Year corrected	2	32	13.34	30.41	.000
Interaction	4	5	1.36	3.10	.016

Means for Alkaloid Rating for Each Year

Year	No. of Families	Corrected Mean
1984	73	5.074
1985	73	4.870
1986	68	4.234

Means for Alkaloid Rating for Each Selection

Alkaloid Level	No. of Families	Corrected Mean
1 = High selection	62	5.189
2 = Low selection	88	4.288
3 = Wild-unselected	64	4.917

means, selection means, and the interaction between years and selections. The highest alkaloid ratings were obtained in 1984 while the lowest ratings were recorded in 1986. Difference in selection pressure was observed each year and when averaged over all three years, the low selection was significantly different from the high selection and the wilds. However, the high selection was not significantly different from the wilds at the 5% level of probability (figure 2.

Environment also influences this characteristic as shown in table 9. The data indicates that as plants become stressed, the alkaloid content increases.

Table 9. Alkaloid rating under different moisture regimes from the same replicated test

Moisture Regimes	Alkaloid Rating
Irrigated	4.07
Dryland	4.81

Table 10 shows that as the plant matures, the alkaloid content also increases. Flowering and seed setting may also be physiologically stress periods.

Figure 2. Average alkaloid rating in kochia plants for selections within each year and over all three years

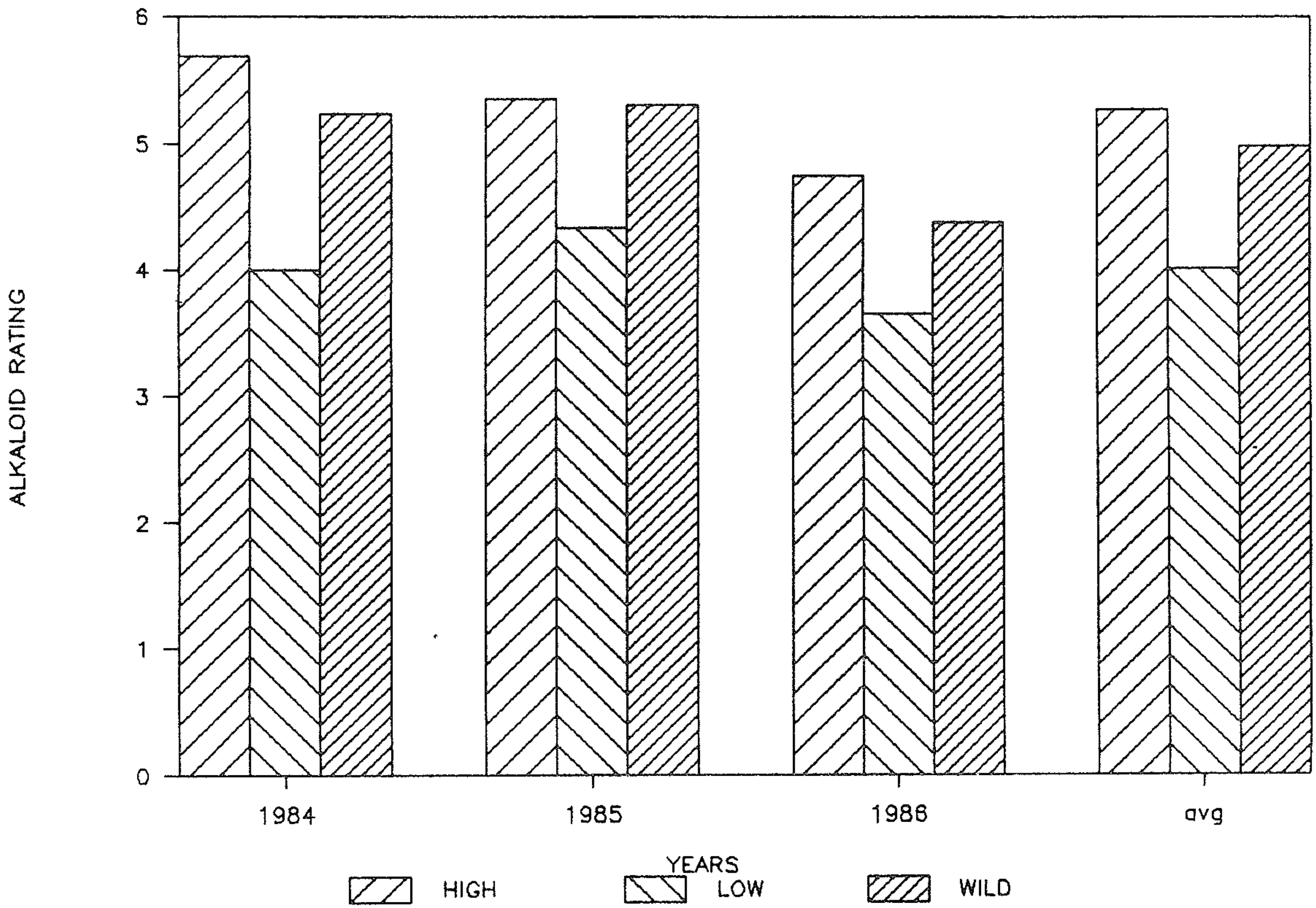

Table 10. Alkaloid rating of plants at different physiological growth stages

Growth Stage	Alkaloid Rating
Preflower	3.35
Bud	4.58
Seed set	4.66

Selections for Phenotypic Characteristics

Several hundred selected plants and progenies were classified for stem color. Plants classified as green-stemmed produced segregating populations, which included some red-stemmed plants. Red-stemmed plants also produced segregating progenies. Many ratios were obtained and studied, but no satisfactory factorial genetic analysis was obtained. The genetic control of stem color must be complex and, to some extent, influenced by environment. Stable, true breeding lines of completely red or green stems were not obtained, even with four to five years of inbreeding.

Other phenotypic characteristics studied were leafiness, leaf size, plant architecture, and maturity. Selecting plants for leafiness was somewhat counterproductive when selecting for low oxalate as the leaves contained higher amounts of oxalate than the stems or branches (table 4). Several different types of plant architecture were rated but, again, these characters could not be stabilized into a true breeding cultivar.

Species Crosses

Crosses were made between K. scoparia and K. childsi. K. childsi is an ornamental and crosses readily with K. scoparia. The main attribute of interest for K. childsi was its leafiness, and it had a high leaf-to-stem ratio. It also had a red anther, which possibly could be used as a marker gene. Progenies from these crosses did not produce any outstanding lines for the various attributes under study in the investigations.

Because of the problems in stabilizing and developing true breeding lines, the chromosome number was checked on several plants. All samples indicated the Kochia scoparia used in these studies was diploid with 2n = 18 in 9 bivalents with normal meiosis.

Replicated Yield Trials

The results of the replicated yield test of the eight selected cultivars are shown in table 11. The results are of questionable value as the test was hailed on four times and population per plot was greatly reduced. The stand was extremely poor for cultivars PLOOGS and PHOOGS under dryland conditions, which greatly reduced the yield.

In addition to the 180 mm of precipitation received during the growing season, the fully irrigated portion received five irrigations and the limited portion received three irrigations.

From the averages listed in table 11, it appears that most seed lines performed at least as well for the limited irrigation treatment as they did under full irrigation. The seed line STLS appears to have performed less favorably under limited irrigation than it did under full irrigation or dryland conditions.

One of the seed lines that appears to have performed better under limited irrigation is STCW. This seed line resulted from the cross-pollination of

Table 11. Forage yield of dry matter (3 harvests) and stand rating (population) in eight kochia cultivars under three moisture regimes, 1983

Cultivar	Irrigated 1	Irrigated 2	Irrigated 3	Irrigated Total	Limited Irrigation 1	Limited Irrigation 2	Limited Irrigation 3	Limited Irrigation Total	Dryland 1	Dryland 2	Dryland 3	Dryland Total	Average	Stand Rating[1]
	kg/ha													
PLOOTS	40	263	290	593	71	469	393	933	71	254	112	437	647	1.0
PHOOGS	129	312	156	597	156	464	201	821	27	89	0	116	513	2.0
WLONGT	254	603	596	1353	254	594	460	1308	71	429	509	1009	1223	2.4
WHONGT	192	567	549	1308	174	745	531	1450	22	397	518	937	1232	1.8
PLONGT	375	531	567	1473	482	830	560	1812	170	620	634	1424	1571	3.6
WILD	451	665	696	1812	205	737	402	1344	31	473	487	991	1388	2.8
STLS	451	665	705	1821	281	656	451	1388	121	696	750	1567	1594	4.0
STCW	446	705	594	1745	496	1116	594	2206	152	625	772	1549	1835	3.4
Average	290	536	504	1330	263	701	437	1401	80	446	469	995	1250	2.6

[1]Scale: 1 = very poor stand
5 = good stand

1st harvest: July 5 and 6
2nd harvest: August 9, 10 and 11
3rd harvest: October 13 and 14

plants which were germinated in 20 g/l NaCl and grown in 24 g/l NaCl solutions. Germination in salt water was done in hopes of obtaining more drought and salt tolerant lines. STLS differed from STCW in that the parents were initially irrigated with tap water. Many more seeds germinated after the tap water irrigation, and it was not possible to distinguish which plants had germinated in the salt solutions.

Two replicates for each of four seed lines were quick tested for alkaloid content under all three irrigation treatments during September to observe whether or not differences between lines and moisture stressed conditions were present

Poisoning of cattle grazed on kochia has been reported by several veterinarians to occur after rains preceded by long periods of drought.

The data presented in table 12 indicates that compounds responsible for

Table 12. Alkaloid test ratings averaged over four cultivars and two replications

Alkaloid Test Date	Fully Irrigated	Dryland
	---------- ratings	----------
September 7	4.05[1]	4.88[2]
13	4.62	5.04
16	3.58	4.66
20	3.95	4.55
27	4.00	4.86
Average	4.04	4.71

[1]Irrigated on September 7
[2]6.3 mm of rainfall between September 7 and 13

the alkaloid test reaction are present at higher levels following natural precipitation and irrigation with ground water. Plants were initially tested on September 7, prior to irrigation on the same date. Precipitation of 6.3 mm was also recorded between September 7-13. Alkaloid test averages for both the fully irrigated and dryland treatments were increased when checked September 13. A decrease in rating averages was noted on the 16th and subsequent rating averages showed a general tendency to increase, probably due to plants reaching maturity.

Overall alkaloid test averages were found to be 4.07, 4.14 and 4.81 for the full irrigation, limited irrigation, and dryland treatments.

Of the lines tested, STCW showed the greatest difference with respect to alkaloid test rating averages from the wild line. Listed below are the lines tested along with their average rating:

STCW - 4.10

STLS - 4.30

WLONGT - 4.45

WILD - 4.52

Because the rating resulting from the Dragensdorff test appears related to moisture stress, it follows that those individuals least affected by stress might possibly produce lower quantities of substances, which cause the reaction observed in the alkaloid test. The lines STCW and STLS also have performed well with respect to yield data collected thus far.

Greenhouse Studies

The yield of kochia dry matter (table 13) varied only slightly with increasing salt (up to 10.85 g/l) in the irrigation water. This finding indicated a high degree of salt tolerance by kochia and that rates needed to be greater in order to find the point of decreasing yields. Crude protein and phosphorus levels increased considerably with increasing salt levels.

Table 13. Yields and chemical composition for kochia plants grown in the greenhouse under various salt solutions, 1982

NaCl	Dry Weight	Oxalate	Protein	Ca	P
g/l	g/pot	%	%	%	%
Check	4.09 a'	4.96 a	20.41 c	0.328 b	0.092 d
1.36	2.99 b	5.00 a	20.37 c	0.367 a	0.099 cd
2.71	3.72 ab	4.72 a	20.66 c	0.367 a	0.102 bcd
4.01	3.10 b	5.03 a	21.67 bc	0.350 a	0.113 bc
5.43	4.10 a	4.67 a	21.54 bc	0.323 b	0.120 b
8.14	4.09 a	4.92 a	22.73 ab	0.310 b	0.132 a
10.85	4.56 a	4.56 a	24.04 a	0.328 b	0.139 a
Average	3.81	4.85	21.63	0.338	0.114
LSD .05	0.82	ns	1.31	0.023	0.017
LSD .01	ns	ns	ns	ns	ns
CV, %	21.31	3.90	6.01	6.600	24.900

'Duncan's multiple range test. Means followed by same letter are not significantly different at the 5% level of probability.

ns = nonsignificant

In the second greenhouse trial (table 14), dry matter yield levels started to drop off after the 5.44 g/l level in the irrigation water. This trial was carried longer than the first trial, and it is likely that salt was beginning to accumulate since very little leaching of the pots was allowed.

Table 14. Yield and composition of kochia forage as affected by salt concentration of the irrigation water, 1982

Irrigation Water NaCl, g/l	Yield of Dry Matter g/pot	Protein %	Oxalate %
Check 0	13.59	8.61	2.27
2.72	13.13	9.59	2.44
5.44	17.16	8.97	2.35
8.16	14.27	11.74	2.60
10.88	13.15	14.36	2.98
13.60	11.06	14.32	2.97
16.32	8.66	17.07	3.43
19.04	10.42	15.74	3.23
21.76	8.81	15.66	3.23
LSD .05	2.92	2.42	0.28
CV, %	22.30	17.60	9.10

Trial 3, using the same salt levels (table 15) but with more leaching, resulted in dry matter yields peaking out at about 13.6 g/l and only a small drop in yield at the 21.76 g/l level of salt. This finding indicates strong salt tolerance of kochia and a very good possibility for a crop capable of using the large amount of brackish underground water in New Mexico.

Table 15. Yield and composition of kochia forage as affected by salt concentration of the irrigation water, 1982

Irrigation Water NaCl, g/l	Yield of Dry Matter g/pot	Protein %	Oxalate %
Check 0	3.75	16.23	3.30
2.72	5.34	12.36	3.10
5.44	6.06	12.28	2.83
8.16	6.71	14.89	2.89
10.88	5.32	15.25	3.09
13.60	6.93	13.21	2.91
16.32	6.27	18.00	3.10
19.04	5.83	12.92	3.12
21.76	5.50	15.33	3.11
LSD .05	0.54	1.24	0.23
CV, %	10.60	9.50	8.30

The fourth trial extended the salt levels of the irrigation water to 43.52 g/l which is greater than that of sea water. The yields (table 16) for the first half of the salt levels are very similar to those obtained in the third

Table 16. Yield and composition of kochia forage as affected by salt concentration of the irrigation water, 1983

Irrigation Water NaCl, g/l	Yield of Dry Matter g/pot	Protein %	Oxalate %
Check 0	3.42	14.32	2.99
5.44	5.91	15.08	2.90
10.88	6.26	16.04	2.97
16.32	5.17	18.17	3.32
21.76	3.18	20.28	3.50
27.20	2.47	22.07	3.93
32.64	1.54	24.09	3.96
38.08	0.89	23.13	3.88
43.52	0.55	22.95	3.70
LSD .05	0.83	1.26	0.26
CV, %	26.80	7.30	8.60

trial. However, this is more of a cubic relationship as the salt levels go on out above sea water levels. While relatively small, the plants were still maintaining some growth even at the greatest salt levels.

In the fifth trial, with NaCl added directly to the soil at rates up to 5381 kg/ha, dry matter yields (table 17) increased up to the 448 kg/ha level. Above this level, yields varied with no definite trend. STLS, a salt tolerant selection, was higher in yield and TDN but lower in protein and oxalate than the wild kochia.

A sixth trial explored the effects of soil applied Na, K, Cl and sulfate at various levels on yields of kochia dry matter (tables 18, 19, 20 and 21).

Table 17. Main effects of a greenhouse experiment for height, yield and chemical composition for nine different salt treatments and two kochia cultivars, 1983

Treatment	Height	Green Weight	Dry Weight	Protein	Oxalate	TDN	Conductivity	Alkaloid
kg/ha (sodium chloride)	cm	g	g	percent	percent	percent	mmho/cm	rating
Check 0	39.35	12.01	2.22	15.03	3.90	60.57	1.40	2.85
112	49.79	18.80	3.23	15.83	4.00	58.09	1.34	2.86
224	49.21	24.57	3.61	16.78	4.26	57.78	1.48	3.08
448	54.30	26.94	4.90	18.51	4.50	56.29	1.49	3.20
897	47.71	22.56	3.47	17.44	4.46	57.98	1.58	3.17
1794	48.68	19.52	3.23	15.31	3.96	57.82	1.45	2.73
2691	50.35	22.12	3.67	16.86	4.23	59.72	1.55	3.00
3588	48.92	25.42	3.96	17.52	4.41	58.36	1.61	3.08
5381	51.12	29.23	4.79	18.41	4.50	57.73	1.82	3.38
LSD .05	ns	6.91	1.22	ns	ns	ns	0.22	ns
LSD .01	ns	9.16	ns	ns	ns	ns	0.29	ns
Cultivars								
STLS	51.38	23.36	4.00	15.73	3.97	61.15	1.46	3.08
WILD	46.19	21.11	3.31	17.83	4.49	55.67	1.58	3.00
LSD .05	4.36	ns	0.57	0.97	0.27	2.87	0.10	ns
LSD .01	ns	ns	ns	1.28	0.35	3.81	ns	ns
Average	48.69	22.20	3.64	16.82	4.24	58.31	1.52	3.04
CV, %	25.28	41.37	44.57	16.21	17.73	13.90	19.20	17.88

ns = nonsignificant

Table 18. Yield and composition of kochia forage as affected by soil applied sodium, potassium, chloride and sulfate, 1983

Applied Nutrients' Na	K	Cl	S	Dry Weight g/pot	Protein %	TDN %	Oxalate %	Alkaloid rating	Conductivity mmho/cm
---Coded Levels---									
-1	-1	-1	-1	6.65	19.4	59.2	4.81	4.0	0.31
+1	-1	-1	-1	10.21	18.7	66.0	4.77	4.6	0.49
-1	+1	-1	-1	8.88	18.4	64.7	4.85	4.6	0.55
+1	+1	-1	-1	9.15	18.5	63.9	4.69	5.0	0.52
-1	-1	+1	-1	9.78	19.6	70.1	4.94	5.0	0.52
+1	-1	+1	-1	9.56	19.8	64.6	5.02	4.4	0.66
-1	+1	+1	-1	9.48	19.7	68.1	5.08	4.2	0.48
+1	+1	+1	-1	13.29	19.2	69.9	4.87	5.2	0.48
-1	-1	-1	+1	11.72	18.5	62.4	4.54	4.8	0.60
+1	-1	-1	+1	6.64	19.3	60.7	4.99	4.4	0.78
-1	+1	-1	+1	7.92	19.1	60.0	4.88	4.6	0.66
+1	+1	-1	+1	9.21	19.0	68.3	4.75	4.2	0.59
-1	-1	+1	+1	9.05	18.9	60.6	4.73	4.6	0.34
+1	-1	+1	+1	9.74	18.5	64.3	4.65	4.2	0.61
-1	+1	+1	+1	9.76	19.3	67.6	4.93	4.8	0.87
+1	+1	+1	+1	10.75	19.9	68.6	4.95	4.4	0.41
+2	0	0	0	10.19	18.1	67.8	4.58	4.6	0.64
-2	0	0	0	13.20	17.8	71.4	4.66	5.0	0.63
0	+2	0	0	7.78	18.6	65.2	4.68	4.4	0.53
0	-2	0	0	8.59	19.0	65.5	4.99	4.4	0.64
0	0	+2	0	9.42	18.8	63.9	4.90	4.2	0.51
0	0	-2	0	9.02	19.1	61.1	4.82	4.2	0.42
0	0	0	+2	10.58	18.0	67.7	4.58	4.6	0.54
0	0	0	-2	12.55	18.0	73.1	4.64	4.6	0.74
0	0	0	0	5.34	17.8	64.8	4.46	4.8	0.60

'Coded levels were: -2 = 0 kg/ha, -1 = 89 kg/ha, 0 = 179 kg/ha, +1 = 269 kg/ha, +2 = 358 kg/ha

Table 19. Regression equations for yield of kochia forage as affected by soil applied sodium, potassium, chloride and sulfate, 1984

Term	Nutrient	Yield of Dry Matter	Protein	TDN	Oxalate	Alkaloid	Conductivity
		g/pot	%	%	%	rating	mmho/cm
b 0		9.708	13.736	52.74	3.848	2.800	0.348
b 1	Na	-0.005	0.161	-0.55	-0.001	0.017	0.004
b 2	K	0.064	0.422	-1.44	0.058	-0.017	0.017*
b 3	Cl	0.281	0.131	-0.45	0.046	-0.033	0.003
b 4	S	0.952**	-0.400	0.36	-0.088	0.100	-0.009
b 11	Na^2	-0.399	0.198	0.86	0.026	0.163	0.014
b 22	K^2	-0.097	0.156	0.94	0.019	0.213	0.010
b 33	Cl^2	-0.117	0.165	-0.10	-0.003	-0.013	0.018
b 44	S^2	0.313	0.138	1.71	0.004	0.038	0.015
b 12	Na-K	0.467	-0.379	0.63	-0.095	0.025	0.006
b 13	Na-Cl	0.465	0.007	1.49	0.018	-0.175	-0.009
b 14	Na-S	0.412	-0.173	3.01*	-0.034	-0.025	0.009
b 23	K-Cl	0.668*	0.012	0.18	-0.014	-0.025	0.002
b 24	K-S	-0.552	-0.217	-0.72	-0.054	-0.125	0.003
b 34	Cl-S	-1.734**	0.476	-3.11*	0.093	0.025	0.001
b123	Na-K-Cl	-0.087	-0.295	1.28	-0.077	-0.075	-0.001
b124	Na-K-S	0.032	-0.332	1.38	-0.089	-0.025	-0.002
b134	Na-Cl-S	-0.432	0.444	-1.26	0.083	0.225**	0.012
b234	K-Cl-S	-0.873*	0.001	-1.14	-0.026	-0.125	0.007
CV, %		28.5	16.8	19.0	13.4	26.0	19.4

*Significant at 5% level of probability
**Significant at 1% level of probability

Table 20. Yield and composition of kochia forage as affected by soil applied sodium, potassium, chloride and sulfate, 1984

Applied Nutrients[1] Na	K	Cl	S	Dry Weight g/pot	Protein %	TDN %	Oxalate %	Alkaloid rating	Conductivity mmho/cm
---Coded Levels---									
-1	-1	-1	-1	1.03	23.01	75.5	7.01	2.6	1.98
+1	-1	-1	-1	0.39	23.11	81.2	7.54	2.8	1.66
-1	+1	-1	-1	0.40	24.21	73.3	7.26	3.0	1.50
+1	+1	-1	-1	0.56	22.15	73.8	7.01	3.2	1.83
-1	-1	+1	-1	1.39	21.96	72.4	6.76	3.2	1.34
+1	-1	+1	-1	1.59	21.95	73.8	6.63	3.0	1.00
-1	+1	+1	-1	1.66	21.86	67.7	6.59	3.4	0.79
+1	+1	+1	-1	1.93	22.53	75.4	6.57	3.0	0.88
-1	-1	-1	+1	1.84	21.69	70.8	6.46	3.2	1.13
+1	-1	-1	+1	1.07	21.80	70.6	6.85	2.8	1.43
-1	+1	-1	+1	1.43	21.98	67.4	6.45	3.2	1.20
+1	+1	-1	+1	1.07	21.86	74.8	6.52	2.6	1.30
-1	-1	+1	+1	1.30	21.72	71.0	6.45	3.0	1.18
+1	-1	+1	+1	1.43	21.10	66.9	6.26	3.6	0.95
-1	+1	+1	+1	1.80	22.14	66.8	6.36	3.0	1.27
+1	+1	+1	+1	2.31	22.20	78.3	6.43	3.2	1.01
+2	0	0	0	0.73	22.61	81.5	6.89	3.0	1.13
-2	0	0	0	2.11	22.41	81.8	6.51	3.2	0.84
0	+2	0	0	0.93	22.98	73.3	6.82	2.8	1.43
0	-2	0	0	0.66	22.00	67.5	6.82	2.8	0.89
0	0	+2	0	1.00	23.55	66.9	6.79	2.8	0.99
0	0	-2	0	1.34	21.46	69.2	6.31	3.0	1.03
0	0	0	+2	0.98	23.36	73.6	6.94	2.8	1.00
0	0	0	-2	1.77	22.25	67.8	6.28	2.4	0.86
0	0	0	0	1.75	22.69	70.4	6.48	3.0	0.94

[1]Coded levels were: -2 = 0 kg/ha, -1 = 89 kg/ha, 0 = 179 kg/ha, +1 = 269 kg/ha, +2 = 358 kg/ha

Table 21. Regression equations for yield of kochia forage as affected by soil applied sodium, potassium, chloride and sulfate, 1984

Term	Nutrient	Yield of Dry Matter	Protein	TDN	Oxalate	Alkaloid	Conductivity
		g/pot	%	%	%	rating	mmho/cm
b 0		1.746	22.69	70.36	6.482	3.000	0.940
b 1	Na	-0.145*	-0.06	1.20	0.051	-0.033	0.018
b 2	K	0.060	0.19	0.31	-0.031	0.017	0.016
b 3	Cl	0.197*	-0.01	-0.84	-0.087	0.067	-0.145*
b 4	S	0.063	-0.17	-0.60	-0.094*	0.050	-0.043
b 11	Na^2	-0.057	-0.11	2.78*	0.058	0.058	0.056
b 22	K^2	-0.213*	-0.11	-0.03	0.089	-0.017	0.100
b 33	Cl^2	-0.119	-0.11	-0.61	0.021	0.008	0.062
b 44	S^2	-0.068	-0.03	0.04	0.037	-0.067	0.042
b 12	Na-K	0.117	-0.06	1.56	-0.045	-0.050	0.066
b 13	Na-Cl	0.183*	0.13	0.16	-0.063	0.050	-0.060
b 14	Na-S	-0.017	0.04	-0.02	0.012	0	0.022
b 23	K-Cl	0.192*	0.09	0.83	0.030	-0.050	0.003
b 24	K-S	0.062	0.07	1.27	0.014	-0.100	0.079
b 34	Cl-S	-0.159	0.25	0.89	0.094	0	0.156*
b123	Na-K-Cl	-0.061	0.23	1.25	0.091	-0.025	0.009
b124	Na-K-S	-0.019	0.12	1.34	0.038	-0.025	-0.069
b134	Na-Cl-S	0.038	-0.20	-0.15	-0.010	0.175*	-0.026
b234	K-Cl-S	0.034	0.06	-0.04	0.023	0.025	0.048
CV, %		47.7	6.2	11.6	7.0	20.7	36.7

*Significant at 5% level of probability

The optimum combination, as determined by regression analysis, called for high Na, K and Cl levels with sulfate kept low. This combination should have yielded about double that of the check, however, a second planting in the same pots resulted in considerably different results, indicating the necessity for further work.

A seventh pot study was set up with a base treatment of 359 kg/ha each of Na, K and Cl. Sulfate was set at 0, N at 448 kg/ha, P at 45 kg/ha, Ca at 29 kg/ha, and Mg at 0 kg/ha in the base treatment. Each of the nutrients except N was varied with all others as in the base treatment. Sodium and chloride (table 22) had a relatively neutral effect on yield. Potassium at 90 kg/ha yielded 40% above the check. The soil used in this test has not been found to respond to K applied to crops in general. The soil test was high for K. This finding indicates the response was due to the general high salt level. The responses to sulfate, P, Ca and Mg (table 22) were much greater than expected, also due to the high salt level. This increase indicates that the use of brackish irrigation water may result in considerably increased fertilizer requirements for high commercial yields of kochia forage.

An eighth pot study explored the response of kochia to soil applied K, Ca, Mg, sulfate and P at 14 g/l of NaCl in the irrigation water compared to irrigation water with no additional NaCl (tables 23 and 24).

The 1985 fall greenhouse experiment on response of kochia to soil applied fertilizers indicated no effect in the saline watered part. Phosphorus at 90 kg/ha was the only nutrient response in the nonsaline water part of the study. This low response rate was in contrast to the previous pot study on kochia where several nutrients gave considerable response under saline conditions. The saline check yielded 34% more than the nonsaline check, which was in line with earlier studies, indicating an increase in yield with increasing salt levels.

Table 22. Effect of sodium, chloride, potassium, magnesium, calcium, phosphorus and sulfur on yield and constitution of kochia grown in greenhouse pots with other nutrients as in base treatment', 1985

Nutrient Applied kg/ha	Yield g/pot	Protein %	Oxalate %	TDN %	Alkaloid[2] rating	Conductivity mmho/cm
Na						
0	10.21	18.7	4.77	66.0	4.6	0.49
90	8.88	18.4	4.85	64.7	4.6	0.55
179	9.15	18.5	4.69	63.9	5.0	0.52
269	9.78	19.6	4.94	70.1	5.0	0.52
359	6.65	19.4	4.81	59.2	4.0	0.31
448	9.56	19.8	5.02	64.6	4.4	0.66
Cl						
0	9.21	19.0	4.75	68.3	4.2	0.59
179	9.05	18.9	4.73	60.6	4.6	0.34
359	6.65	19.4	4.81	59.2	4.0	0.31
538	9.75	18.5	4.65	64.3	4.2	0.61
718	9.76	19.3	4.93	67.6	4.8	0.91
897	10.75	19.9	4.95	68.6	4.4	0.41
K						
0	9.48	19.7	5.08	68.1	4.2	0.48
90	13.29	19.2	4.87	69.9	5.2	0.48
179	11.72	18.5	4.54	62.4	4.8	0.60
269	6.64	19.3	4.99	60.7	4.4	0.78
359	6.65	19.4	4.81	59.2	4.0	0.31
448	7.92	19.1	4.88	60.0	4.6	0.66
Mg						
0	6.65	19.2	4.81	59.2	4.0	0.31
179	7.78	18.6	4.68	65.2	4.4	0.53
359	8.59	19.0	4.99	65.5	4.4	0.64
538	9.42	18.8	4.90	63.9	4.2	0.51

continued

Table 22. Continued

Nutrient Applied kg/ha	Yield g/pot	Protein %	Oxalate %	TDN %	Alkaloid[2] rating	Conductivity mmho/cm
Ca						
29	6.65	19.4	4.81	59.2	4.0	0.31
179	9.02	19.1	4.82	61.1	4.2	0.42
359	11.58	18.0	4.58	67.7	4.6	0.54
538	12.55	18.0	4.64	73.1	4.6	0.74
P						
0	5.34	19.4	4.81	59.2	4.0	0.31
45	6.65	17.8	4.46	64.8	4.8	0.60
90	10.33	19.7	4.90	68.6	4.4	0.63
S						
0	6.65	19.4	4.81	59.2	4.0	0.31
90	11.95	18.1	4.58	67.8	4.6	0.64
179	13.20	17.8	4.66	71.4	5.0	0.63
LSD .01	5.19	1.8	0.59	11.5	1.1	0.45
.05	3.92	1.4	0.44	8.7	0.8	0.34
.10	3.28	1.2	0.37	7.3	0.7	0.29
CV, %	32.50	5.8	7.40	10.6	13.9	4.80

[1]Nutrients applied to soil, kg/ha: 502 N, 50 P, 402 Na, 402 Cl, 0 S, 0 mg
[2]Scale: 2 = low, 6 = high - determined visually on plant juice

Table 23. Effect of soil applied plant nutrients on yield and composition of kochia (greenhouse pot study) when watered with low salt water, 1985

Treatment kg/ha		Dry Weight g/pot	Protein %	Oxalate %	TDN %	Alkaloid rating
Potassium	45	4.44	21.5	5.82	72.5	3.6
	90	4.19	20.5	5.31	62.9	3.4
	135	4.12	19.0	5.06	75.4	3.2
Sulfur	90	4.62	19.7	5.21	71.2	3.6
	180	4.16	21.5	5.77	69.3	4.2
	270	2.61	21.2	5.57	61.8	3.2
Magnesium	180	3.67	19.2	4.98	69.4	3.0
	360	4.93	20.6	5.40	70.4	3.2
	540	4.39	19.7	5.30	74.1	3.0
Calcium	180	3.64	20.5	5.42	70.4	3.0
	360	6.40	20.8	5.43	71.4	3.8
	540	5.23	20.1	5.28	79.7	4.2
Phosphorus	45	5.37	20.3	5.40	68.8	3.4
	90	11.46	21.4	5.57	72.3	3.8
	135	6.56	21.3	5.51	67.7	3.6
Check	0	4.41	20.9	5.54	70.3	3.4
LSD .05		2.81	2.4	0.75	9.0	0.6
CV, %		44.40	9.4	10.90	10.1	12.9

Chemical composition (tables 23 and 24) indicated very little effect on protein levels of kochia from either set of pots. Oxalate levels were almost a whole percent lower in the salt-watered treatment. the nutrient treatments had little effect on oxlate. The treatments had little effect on TDN in either

Table 24. Effect of soil applied plant nutrients on yield and composition of kochia (greenhouse pot study) when water contained 14 g NaCl per liter, 1985

Treatment kg/ha		Dry Weight g/pot	Protein %	Oxalate %	TDN %	Alkaloid rating
Potassium	45	3.54	22.5	4.75	80.3	3.4
	90	5.51	20.8	4.35	83.3	4.0
	135	3.81	21.0	4.43	83.4	3.2
Sulfur	90	4.83	21.3	4.48	83.0	3.4
	180	4.03	20.9	4.46	84.7	3.8
	270	4.39	22.2	4.65	81.4	4.2
Magnesium	180	4.85	22.6	4.72	78.7	3.8
	360	6.05	21.1	4.33	84.4	3.6
	540	4.76	21.7	4.43	77.4	4.2
Calcium	180	5.85	20.8	4.35	83.1	3.8
	360	5.34	22.0	4.55	84.2	3.4
	540	5.34	22.5	4.75	86.2	3.8
Phosphorus	45	4.16	20.5	4.33	79.7	3.4
	90	3.81	22.1	4.14	74.4	4.0
	135	5.22	21.2	4.38	83.4	4.2
Check	0	5.93	20.6	4.29	84.2	3.2
LSD .05		2.36	2.6	0.50	8.3	0.8
CV, %		38.60	9.5	8.90	8.0	17.0

set, however, the general TDN level of kochia was considerably higher in the salt treated pots than in the nonsalt watered pots. The alkaloid levels of kochia were not appreciably affected by treatments.

SUMMARY AND CONCLUSIONS

Kochia scoparia has been established as a very drought tolerant and productive forage crop. However, toxicity to grazing livestock sometimes develops due to accumulation of an, as yet, unidentified alkaloid or alkaloids. A field test for alkaloids involving Dragendorff's reagent has been developed to be semiquantitative and is being used as a screening device. Slow but definite progress is being made toward selecting for lower alkaloid levels in kochia.

At the beginning of this project, it was thought that the kochia plant contained high amounts of oxalates that were toxic to cattle. Plants low in oxalate content were selected for several generations. Although no lines were developed that were true breeding for low oxalate, progress was made in lowering the oxalate content in several selected lines. As the project developed, it was concluded that alkaloids were probably the major toxins involved.

Several phenotypic characteristics were observed and studied but none were isolated in a true breeding line. The identification and purification of marker gene(s) are needed for detecting crosses. All attributes under study were somewhat sensitive to different environments.

Greenhouse trials have confirmed that kochia is very salt tolerant, thriving in brackish water up to one-third the salt content of sea water. Thus, kochia has high potential as a forage crop to utilize the vast quantities of underground brackish water in New Mexico.

It was concluded that work should be continued toward selection of lower alkaloid strains of kochia as well as for increased leafiness and vigor.

BIBLIOGRAPHY

Ayres, A. D. 1952. Seed germination as affected by moisture and salinity. Agron. J. 44:82-84.

Baker, L. O. 1974. Growth and water use efficiency of seven annual plant species. Proc. W. Soc. Weed Sci. (Abstract) 27:73-74.

Bell, J. M., Bowman, G. H., and Coupland, R. T. 1952. Chemical composition and digestibility of forage crops grown in central Saskatchewan with observations of kochia species. Sci. Agric. 32:463-473.

Burns, R. E. 1964. Field screening of lupines and other plants for alkaloid content. Agron. J. 56:246.

Davis, A. M. 1973. Protein, crude fiber, tannin, and oxalate concentrations of some introduced Astragalus species. Agron. J. 65:613-615.

Dickie, C. W., and Berryman, J. R. 1979. Polioencephalomalacia and photosensitization associated with Kochia scoparia consumption in range cattle. J. Amer. Vet. Med. Assoc. 175:463-465.

Durham, R. M., and Durham, J. W. 1979. Kochia: its potential for forage production. Arid land plant resources. In Proceedings of the International Arid Lands Conference on Plant Resoures, Texas Tech University, July 1979.

Dye, W. B. 1956. Chemical studies of Halogeton glomeratus. Weeds 4:55-59.

Erickson, E. L., and Moxon, A. L. 1947. Forage from kochia. South Dakota Agric. Exp. Sta. Bull. 384.

Fuehring, H. D. 1983, 1984, 1985. A selective breeding program to improve the water efficiency and nutritive acceptability of kochia as a forage and grazing crop. In Annual Reports, New Mexico State Univ. Agric. Sci. Center at Clovis.

Fuehring, H. D. 1980. Kochia as a forage crop. Eighth Annual Texas Beef Conference Proceedings. Amarillo, Texas, pp. 1-3.

Fuehring, H. D., Finkner, R. E., Oty, Gary W. 1986. Yield and composition of kochia forage as affected by salinity of water and percent leaching. Technical Completion Report, Project No. 1423623. New Mexico Water Resources Research Insititute Report No. 199.

Galitzer, S. J., and Oehme, F. W. 1978. Kochia scoparia (L.) Schrad toxicity in cattle: A literature review. Vet. Hum. Toxicol. 20:421-423.

Governor's Council of Economic Advisors. 1977. Water: key to New Mexico's future. New Mexico Business, September 1977, pp. 3-17.

Hanson, E. G. 1967. Influence of irrigation practices on alfalfa yield and consumptive use. New Mexico State Univ. Agric. Exp. Sta. Bull. 514.

Helmerick, R. H., and Pfeifer, R. P. 1954. Differential varietal responses of winter wheat germination and early growth to controlled limited moisture conditions. Agron. J. 46:560-562.

High Plains Study Council, 1982. A summary of results of the Ogallala aquifer regional study with recommendations to the secretary of commerce and congress. In response to the directives of Public Law 94-587 90, Stat. 2943.193.

Kiesling, H. E., et al. 1984. Nutritive value and toxicity problems of kochia for yearling steers. New Mexico State Univ. Agric. Exp. Sta. Res. Rep. 546.

Lansford, Robert R, and Sorensen, Earl F. 1971. Planted cropland acreage in New Mexico in 1969 and 1970. In New Mexico Agriculture--1970. Edited by J. R. Gray and H. R. Stucky. New Mexico State Univ. Agric. Exp. Sta. Res. Rep. 195.

Lansford, Robert R., et al. 1980. Sources of irrigation water and irrigated and dry cropland acreages in New Mexico, by county, 1974-1979. New Mexico State Univ. Agric. Exp. Sta. Res. Rep. 422.

Powell, L. M., and Pfeifer, R. P. 1956. The effect of controlled limited moisture on seedling growth of Cheyenne winter wheat selections. Agron J. 48:555-557.

Sherrod, L. B. 1971. Nutritive value of Kochia scoparia. I. Yield and chemical composition at three stages of maturity. Agron. J. 63:343-344.

Shull, C. A. 1951. Measurement of the internal forces of seeds. Trans. Kansas Acad. Sci. 27:65-70.

Sperry, O. E., et al. 1965. Texas plants poisonous to livestock. Texas Agric. Exp. Sta. Bull. B-1028, p. 30.

Thimann, K. V. 1954. The physiology of growth in plant tissues. Amer. Sci. 42:589-606.

Uhvits, Rachel. 1946. Effect of osmotic pressure on water absorption and germination of alfalfa seeds. Amer. J. Bot. 33:279-285.

Williams, T. V., Snell, R. S., and Ellis, J. F. 1967. Methods of measuring drought tolerance in corn. Crop Sci. 7:179-182.

Woldeghebriel, Abraham. 1983. Potential of Kochia scoparia plant for animal feed and its oxalate potency. A dissertation submitted to Graduate School, New Mexico State University.