ECONOMICS OF RANGELAND SEEDING IN THE CHIHUAHUAN DESERT

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Abstract

Data from six years of seeding trials from the Jornada Experimental Range were used to develop relationships for seedling establishment as a function of soil moisture, soil temperature, and seedbed preparations. These relationships were integrated into an economic evaluation of expected net present value based on probabilities of the occurrence of various environmental conditions. The analysis shows that seeding is not feasible as a financial investment in the region. However, when seeding is considered necessary for other reasons, the least cost native plant species is blue grama (*Bouteloma gracilis*) with no seedbed preparation and the least cost introduced plant species is Lehmann lovegrass (*Eragrostis lehmanniana*) with no seedbed preparation. If seeding in the region is to become economically attractive, ways to increase the probability of achieving stand establishment must be found.

Introduction

Natural revegetation on rangelands can take more than 100 years (Allison 1990) and rangeland seeding can increase land productivity by as much as 100 times within 3 years (Herbel, 1983). Seeding therefore has obvious attractions for rangeland managers.

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However, seeding of rangelands in arid climates is dependent on a set of environmental conditions that do not occur with high frequency, so the activity is more risky than in temperate climate areas.

Past research on rangeland seeding in the Southwestern United States has concentrated on seeding methods and timing, seedbed preparation, and suitability of plant varieties (Herbel *et al.*, 1973; Herbel, 1972a, 1972b; Herbel and Sosebee, 1969; Marietta and Britton, 1989; Merkel and Herbel, 1973; Sosebee and Herbel, 1969; Welch *et al.*, 1962). This body of research establishes the effectiveness of removing unwanted plant competition, selecting plants adapted to the site, and seeding immediately prior to the period when rainfall is most reliable and temperatures are favorable for seedling establishment. The climate cannot be controlled, but some factors that affect success of seeding are controllable.

While some aspects of seeding rangeland are well understood, the main economic problem/issue/question of whether or under what conditions seeding is a feasible economic or financial investment is not understood. No previous work on this issue has been found, probably because of lack of a satisfactory data base. As we contemplated the problem and searched for appropriate data, a set of data from the Jornada Experimental Range in New Mexico, located in the Chihuahuan Desert (Figure 1) was found that provided a means to undertake the research. The objectives of the research were to determine environmental and management conditions necessary to achieve seedling stand establishment in the arid southwest and identify the expected economic/financial returns from seeding.

Methods and Procedures

The analysis proceeded in four primary steps: estimation of (1) relationships describing how environment and management practices affect stand establishment, (2) net income from stand establishment if it is achieved, (3) probabilities of conditions needed for stand establishment, and (4) expected net returns from seeding.

Data

Data for estimating stand establishment relationships were obtained from experiments conducted in six years of seeding trials [Herbel 1961-1966, unpublished rangeland seeding experiment data, Jornada Experimental Range, Agr. Research Service, USDA, N.M. State Univ., Las Cruces, N.M.; summarized in Sosebee and Herbel (1969), Herbel and Sosebee (1969), Herbel (1972a, 1972b), and Herbel *et al.* (1973)]. These data typify all of the Chihuahuan Desert, which covers 450,000 km^2 and covers parts of New Mexico, Arizona, Texas, and Mexico (MacMahon, 1988). The data series included soil types, soil moisture and temperature at different depths, air temperature, seedbed preparation, vegetation cover, and stand establishment from an extensive group of seeding trials.

Data on 14 varieties of plants were grouped into two categories: (1) introduced (non-native) species with rapid establishment{Lehmann lovegrass (*Eragrostis lehmanniana* Nees.), boer lovegrass (*Eragrostis chloromelas* Steud.), old-world bluestem [*Bothriochloa ischaemum* (L.) Keng var. *ishaemum*], and rhodesgrass (*Chloris gayana* Kuneth)} and (2) native (indigenous to the area) species, which occupy a higher successional stage{black grama [*Bouteloua eriopoda* (Torr.) Torr.], sideoats grams [*Boutelous curtipendula* (Michx.) Torr.], tobosa grass [*Hilaria mutica* (Buckl.) Benth.], vine mesquite (*Panicum obtusum* H.B.K.), alkali sacaton [*Sporobolus airoides* (Torr.) Torr.], sacaton (*Sporobolus Wrightii Scribn.*), fourwing saltbush [*Atriplex canescens* (Pursh) Nutt.], bush muhly (*Muhlenbergia porteri Scribn ex* Beal), blue grama [*Boutela gracillis* (H.B.K.) Griffiths], and little bluestem [*Schizachyrium scoparium* (Michx.) Nash]}. All environmental data used in the study were micro-climate data taken at the experimental sites.

Forage Response Model

A response model of seeding stand establishment as a function of both environmental and management variables was developed, based on both conceptual and empirical considerations. The mathematical form of the model was:

$$SE_v = \beta_0\, SR^{\beta_1}\,(SM1+1)^{\beta_2}\,(SM2+1)^{\beta_3}\,(SM3+1)^{\beta_4}\, e^{\beta_5 SB1+\beta_6 SB2+\beta_7 SB3}\, e^{\beta_8 SB4+\beta_9 SB5+\beta_{10} SB6+\beta_{11} ST1+\beta_{12} ST1^2+\beta_{13} ST2+\beta_{14} ST2^2+\beta_{15} ST3+\beta_{16} ST3^2}$$

where SE_v = stand establishment in seedlings/.09 m^2 for species group v; v = I (introduced) or N (native); SR = seeding rate in 1.12 kg/ha; SM1 = soil moisture (% days $\geq$ field capacity, July-Sept.) at the 1.27 cm depth (field capacity is the level of soil moisture adequate to prevent permanent wilting, which varies with soil type, vegetation, and soil and air temp.); SM2 = soil moisture at the 5.08 cm depth; SM3 = soil moisture at the 10.16 cm depth; SBi = seedbed preparation dummy variable, I = 1,....., 6 (SB1 = 1 if seedbed preparation is pits, 0 otherwise; SB2 = 1 if preparation is root plowing, 0 otherwise; SB3 = 1 if preparation is emulsion, 0 otherwise; SB4 = 1 if mulch, 0 otherwise; SB5 = 1 if plastic, 0 otherwise; SB6 = 1 if furrows, 0 otherwise; if SB1 = SB2 = ... = SB6 = 0, there is no seedbed preparation)[2]; ST1 = average maximum soil temperature (°C), July-Sept., at the 1.27 cm depth; ST2 = average maximum soil temp. (°C), July-Sept., at the 5.08 cm depth; ST3 = average maximum soil temp. (°C), July-Sept., at the 10.16 cm depth; and β_I = estimated parameters.

This model specification was developed to be conceptually consistent with hypothesized variable relationships and interrelationships. Stand establishment increases at a decreasing rate as seeding rate and soil moisture increase (marginal productivities of these inputs decrease). Stand establishment increases, then decreases, as soil temperature increases. Seedbed preparation shifts these relationships, and all the variables are interactive in their effects on stand establishment. The model was linearized by logarithmic transformation to facilitate linear regression estimation.

Net Revenue from Stand Establishment

When stand establishment is achieved, the net revenue is measured as the added net revenue from the additional forage minus the added costs associated with the seeding activity. The costs of seeding are

$$TC = SC_v + SB + SO$$

[2] The dummy variables shift the relationship up or down according to the effects of alternative seedbed preparations. Each shift is relative to no seedbed preparation.

where TC = total cost of seeding, SC_v = seed costs, SB = seedbed preparation costs, and SO = seed application costs. In this analysis, SB are based on using farm-type equipment. There is a TC for plant species and each type of seedbed preparation.

Revenue was estimated by converting added grass production from seeding to added livestock (cattle) production. The net revenue generated from one animal unit year (AUY) was calculated as

$$PL = (PS * S) + (PH * H) + (PC * C)$$

where PL = value of livestock marketed per AUY ($143.82), PS = 1987-1991 average market price of a 181-227 kg #1 medium frame steer ($2.22/kg), S = weight of marketable steer calf resulting from added grass production (86.0 kg), PH = 1987-1991 average market price of a 181-227 kg #1 medium frame heifer ($1.88/kg), H = weight of marketable heifer calf from added grass production(52.8 kg), PC = 1987-1991 average market price of a commercial grade 2-4 cow ($1.02/kg), and C = weight of marketable cull cow resulting from added grass production (59.0 kg). Data for these calculations were obtained from Torell *et al.* (1991) and U.S. Department of Agriculture (1987-1991), and are fully explained in Sherwood (1994). The total value of seeding is found by multiplying PL by the total animal units per year that result from a given stand establishment.

The returns from the investment accrue over a future period of time. If seeding is effective, growing conditions are sufficient to maintain a stand, and the resource is managed so as to sustain the stand, there is an added revenue for each future year. The present value of that stream of revenue is

$$PVAP = \sum_{t=1}^{n} \left[VAGP_t / (1+r)^t \right],$$

where PVAP is the present value of added production from the time of seeding to time period n, $VAGP_t$ is added revenue from seeding in year t, and r is the discount rate. There is a PVAP for each level of stand establishment. In this study, stand establishment was classified as excellent (≥ 9 seedlings/.09 m^2; carrying capacity 12 AUY/259 ha), good (7-8 seedlings/.09 m^2; carrying capacity 7.8 AUY/259 ha), fair (4-6 seedlings/,09 m^2; carrying capacity 4.2 AUY/259 ha), poor (1-3 seedlings/.09 m^2; carrying capacity 1.2 AUY/259 ha), and failure (< 1 seedling/.09 m^2; carrying capacity 0 AUY/259 ha). A 3% real discount rate was used and a useful life of the investment of 20 years (n = 20) was used. Four additional assumptions were made: (1) livestock prices are constant in real terms, (2) there are no maintenance costs associated with seeding, (3) the resource is managed so that there is no deterioration through time, and (4) no additional vegetation removal is required.

<u>Probabilities and Expected Returns</u>

The probability of achieving a given stand establishment is determined by the probabilities of soil moisture and temperature conditions occurring that will result in that stand. Probabilities of alternative soil moisture and temperature conditions occurring for excellent, good, fair, poor, and failed stand establishment conditions were estimated directly from the data set; the data provided the observed proportion of time that the conditions necessary for each stand establishment actually occurred.

The expected net present value o a seeding scenario was determined as

$$E(NPVAP_i) = \sum_j NPV_i^j \, (P^j)$$

where $E(NPVAP_i)$ is the expected net present value of additional production, I is the species, NPV_i^j (= PVAP - TC_s) is the net present value for species i with stand establishment j, and P^j is the probability of achieving the SM and ST that will result in stand establishment j. If $E(PVAP_i)$ is greater than zero, the improvement can be considered to be a financially feasible project.

Findings

Estimated parameters for the SEN and SEI stand establishment relationships are shown in Table 1; variables for which the coefficients were not statistically significant were excluded from the predictive equations. These results show the effects of soil temperature at the 5.08 cm depth (ST2), soil moisture at the 1.27 cm depth during the growing season, and seedbed preparation of pits (SB1), asphaltic emulsion (SB3), and mulch (SB4) on stand establishment when seeding arid rangeland at the experimental sites in the Chihuahuan desert. All variables shown were statistically significant at the 95% confidence level.

Asphaltic emulsion (SB3) resulted in a decrease in seedlings established with both introduced and native species, probably because of chemical composition and/or heat absorption. Therefore, it is an economically infeasible seedbed preparation. Pits and mulch increased stand establishment for native species, but had no effect for introduced species. Soil moisture at the 1.27 cm depth had a positive effect on stand establishment for both groups, with the effect larger with native species. Soil temperature at the 5.08 cm depth was optimal at 42.8°C for both native and introduced species; deviation from that temperature in either direction decreased seedlings established. Note that the effects of soil temperature and moisture are interrelated, and that the "windows" for stand establishment are relatively small within the overall range of environmental conditions. For example, Table 2 shows that to achieve an excellent stand establishment of introduced species, no seedbed preparation, SM1 must be between .29 and .89 *and* ST2 must be between 35.5 and 51.1; this combination of conditions was observed to occur only 2% of the time.

Probabilities of achieving the various levels of stand establishment for native species under three seedbed preparation scenarios are shown in Table 3. Note that, in general, seedbed preparation increases the probability of obtaining an excellent stand, but they also increase the probability of a complete failure. Recall that seedbed preparations for introduced species were eliminated because they reduced stand establishment.

Estimated costs of stand establishment for the various species are shown in Table 4. Seedbed preparation and seed drilling costs do not vary with variety, so the costs differ only with the costs of the seed. A complete description of costs is available in Sherwood (1994).

Estimated livestock production, revenues, and discounted income streams for each stand establishment scenario are shown in Table 5. Further adjusting for investment (seeding) costs and the probabilities of the various outcomes occurring, the expected net present values are shown in Table 6. Note that none of the species under any of the seedbed preparation scenarios yielded a positive expected net revenue. This indicates that seeding in these arid environments are not viable as financial investments. Put another way, the practice would have to be justified on other grounds (*e.g.*, erosion control, wildlife habitat, etc.) to be economically feasible. If the decision is made to engage in seeding under the conditions of this study, the results show that the least cost alternatives are Lehmann lovegrass, an introduced species, and blue grama, a native species, both with no seedbed preparation.

Conclusions

Seeding in the Chihuahuan Desert does not appear to be financially viable as an investment if the objective is livestock production. If seeding is deemed desirable for other reasons, the least costly alternatives among the species tried are Lehmann lovegrass and/or blue grama, both with no seedbed preparation. Additionally, the overall negative financial returns suggest that proper care of these fragile resources so as to avoid the need for seeding is likely the best economic alternative; *i.e.*, management so as to maintain the resource in a sustainable productive state provides greater financial returns that depleting the resource, then restoring it.

Prospects for improving the investment potential for seeding projects in these types of environments must revolve around altering the probabilities of stand establishment. Ways in which those probabilities might be altered are development of new seeding techniques and/or seedbed preparation, developing more reliable predictions of climate conditions that affect soil moisture and temperature, and development of new varieties for the existing environmental conditions.

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Table 1. Regression estimates for stand establishment for introduces (SEI) and Native (SEN) species.

Variable	Estimated coefficient	Standard Deviation	t-ratio at .05 level
Introduced Species (dependant variable - ln SEI)			
Constant	-63.381	70112	-8.912
Sb3	-1.937	0.135	-14.324
Ln (SM1 + 1)	2.281	0.658	3.461
ST2	1.199	0.131	9.148
$ST2^2$	-0.0055	0.0006	-9.113
n + 71, d.f. = 66, adjusted R^2 = 0.7834, F = 64.20			
Native Species (dependent variable - ln SEN)			
Constant	-37.532	5.016	-7.478
SB1	0.449	0.124	3.628
SB3	-1.039	0.105	-9.857
SB4	1.232	0.266	4.638
Ln (SM 1 + 1)	2.115	0.353	5.994
ST2	0.722	0.097	7.462
$ST2^2$	-0.0030	0.0004	-7.174
n = 142, d.f. = 135, adjusted R^2 = .686, F = 52.426			

Table 2. Combinations of SM1 and ST2 that achieve stand establishment levels of excellent, good, fair, and poor for introduced species, no seedbed preparation.

SEI-seedlings/ .09 m^2	SM1[1]- soil moisture (units) 1.27 cm depths	ST2[2]- soil temp.(^{0} C) 5.08 cm depth	Probability
Excellent stand ≤ 9	$.29 \leq SM1 \leq .89$	$35.5 \leq ST2 \leq 51.11$	0.02
Good $7 \leq$ stand ≤ 8	$.26 \leq SM1 \leq .92$	$37.17 \leq ST2 \leq 51.94$	0.10
Fair $4 \leq$ stand ≤ 6	$.20 \leq SM1 \leq .98$	$32.22 \leq ST2 \leq 53.79$	0.04
Poor $1 \leq$ stand ≤ 3	$.09 \leq SM1 \leq .93$	$29.72 \leq ST2 \leq 53.06$	0.08
Failure < 1			0.76

[1]Measured as the proportion of days that SM1 is greater than or equal to field capacity.
[2]Measured as the average maximum soil temperature during the growing season (July-September).

Table 3. Combinations of SM1 and ST2 that achieve stand establishment levels of excellent, good, fair, and poor for native species, by seedbed preparation.

SEN-- seedlings/ 0.09 m²	SM1[1]-- soil moisture, 1.27 cm. depth	ST2[2]-- soil temp. (C⁰) 5.08 cm. depth	Probability
----------No Seedbed preparation----------			
Excellent - stand $\geq$ 9	.34 $\leq$ SM1 $\leq$ .91	35.56 < ST2 < 53.06	0.00
Good - 7 $\leq$ stand $\leq$ 8	.28 $\leq$ SM1 $\leq$ .96	33.33 < ST2 < 53.06	0.12
Fair - 4 $\leq$ stand $\leq$ 6	.19 $\leq$ SM1 $\leq$ .90	30.56 < ST2 < 50.28	0.06
Poor - 1 $\leq$ stand $\leq$ 3	.04 $\leq$ SM1 $\leq$ 1.0	22.28 < ST2 < 53.33	0.57
Failure - < 1			0.25
----------Seedbed preparation--pits----------			
Excellent - stand $\geq$ 9	.24 $\leq$ SM1 $\leq$ .84	32.22 < ST2 < 48.89	0.14
Good - 7 $\leq$ stand $\leq$ 8	.20 $\leq$ SM1 $\leq$ .89	30.33 < ST2 < 50.00	0.03
Fair - 4 $\leq$ stand $\leq$ 6	.12$\leq$ SM1 $\leq$ .96	28.89 < ST2 < 52.22	0.06
Poor - 1 $\leq$ stand $\leq$ 3	.10 $\leq$ SM1 $\leq$ .34	27.89 < ST2 < 30.56	0.22
Failure - < 1			0.55
----------Seedbed preparation--mulch----------			
Excellent - stand $\geq$ 9	.12 $\leq$ SM1 $\leq$ .97	28.61 < ST2 < 52.22	0.24
Good - 7 $\leq$ stand $\leq$ 8	.09$\leq$ SM1 $\leq$ 1.00	27.78 < ST2 < 53.06	0.15
Fair - 4 $\leq$ stand $\leq$ 6	.14 $\leq$ SM1 $\leq$ .34	28.89 < ST2 < 30.86	0.00
Poor - 1 $\leq$ stand $\leq$ 3	.05 $\leq$ SM1 $\leq$ .27	26.11 < ST2 < 28.33	0.00
Failure - < 1			0.61

[1]Measured as the % of days that SM1 is greater than or equal to field capacity.
[2]Measured as the average maximum soil temperature (C⁰) during the growing season (July - Sept.).

Table 4. Estimated costs associated with rangeland seeding.

Seed Variety	Seed costs[1]	Seedbed prep.- farm equipment[2]	Drilling costs[3]
Native species	----------------------------	--------$/.4047 ha--------	----------------------------
sideoats grama	11.00	6.50	6.75
tobosa grass	40.00	6.50	6.75
vine mesquite	23.00	6.50	6.75
sacaton (giant)	26.00	6.50	6.75
alkalai sacaton	20.00	6.50	6.75
black grama	40.00	6.50	6.75
fourwing saltbush	12.00	6.50	6.75
bush muhly	40.00	6.50	6.75
blue grama	8.00	6.50	6.75
little bluestem	11.00	6.50	6.75
Introduced species			
lehmann lovegrass	5.75		6.75
boer lovegrass	13.00		6.75
old world bluestem	11.00		6.75
rhodesgrass	7.25		6.75

[1] The assumed seeding rate was 2.24 kg/ha. for native and 1.12 kg/ha. for introduced species (average seeding rates within the data).

[2] Average custom rate (Curtis & Curtis Seed Co., Clovis, NM, and Richardson Seed Co, Lubbock, TX, Mar. 1992) for the use of farm type equipment to do similar work as that required for rangeland seedbed preparation; the cost is the same for pits and mulch.

[3] Average custom seeding rate for rangelang grasses in the semi-arid desert region of West Texas.

Table 5. Annual returns generated.

Stand Establishment	Carrying Capacity[1] AUY/259 ha	Annual Revenue	Present value of income over 20 years at discount rate 3%	7%
		--------------------------$/259 ha--------------------------		
Excellent	12.00	1,726	25,676	18,283
Good	7.80	1,122	16,689	11,884
Fair	4.20	604	8,987	6,399
Poor	1.20	173	2,566	1,828
Failure	0	0	0	0

[1]Assumed to also represent the change in carrying capacity.

Table 6. Expected net present values of seeding arid ranges, 3% discount rate; selected grasses.

Species	Expected Net Present Values		
	No Seedbed Preparation	Pits	Mulch
	---------------$/.4047 ha---------------		
Native species			
sideoats grama	- 11.53	- 15.90	- 10.73
tobosa grass	- 40.53	- 44.90	- 39.73
vine mesquite	- 23.53	- 27.90	- 22.73
sacaton (giant)	- 26.53	- 30.90	- 25.73
alkalai sacaton	- 20.53	- 24.90	- 19.73
black grama	- 40.53	- 44.90	- 39.73
fourwing saltbush	-12.53	- 16.90	- 11.73
bush muhly	- 40.53	- 44.90	- 39.73
blue grama	- 8.53	- 12.90	- 7.73
little bluestem	- 11.53	- 15.90	- 10.73
Introduced species			
lehmann lovegrass	- 8.26	---------	---------
boer lovegrass	- 15.51	---------	---------
old world bluestem	- 11.53	---------	---------
rhodesgrass	- 9.76	---------	---------

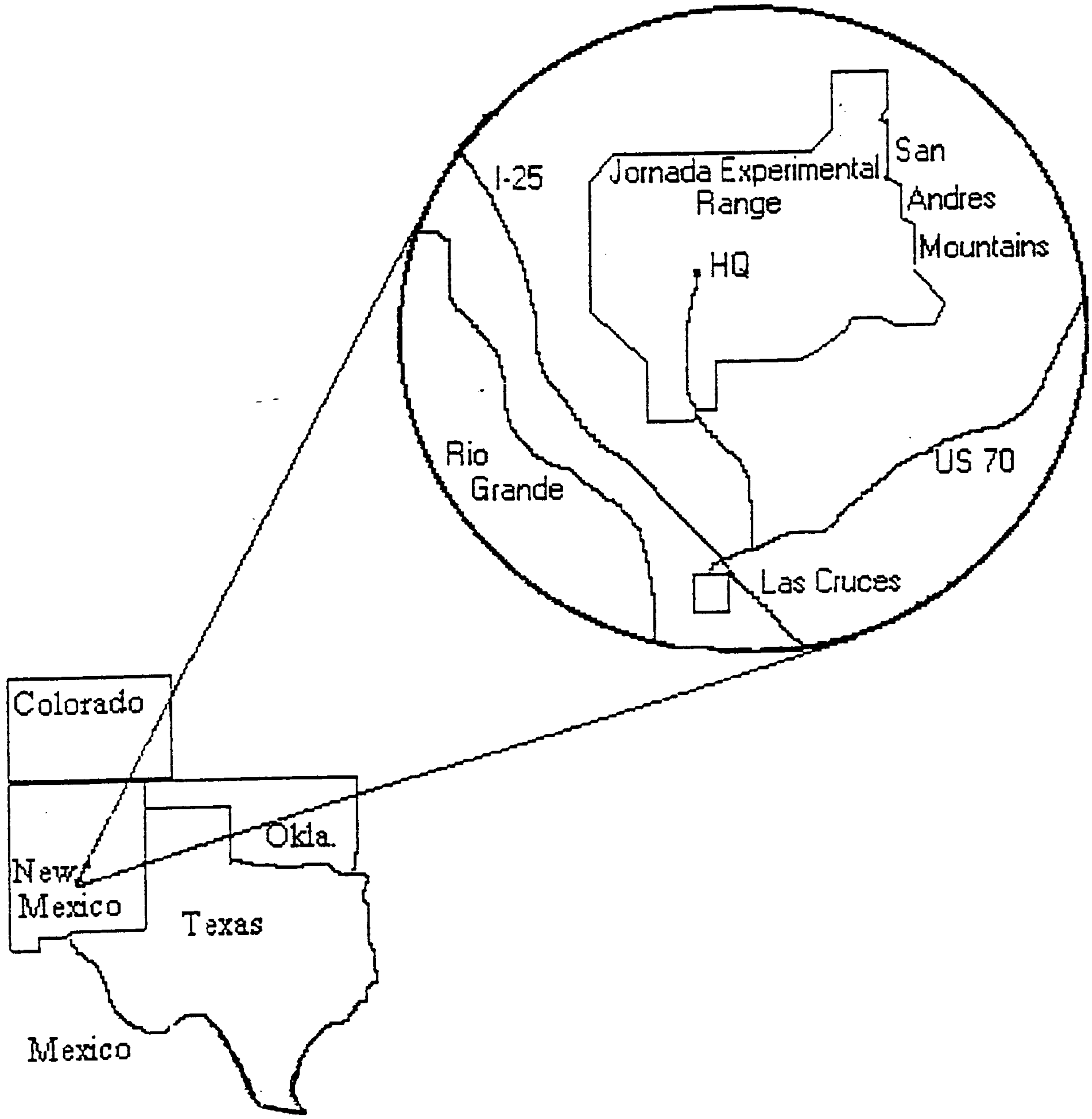

Figure 1. Jornada Experimental Range.