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Broom snakeweed (*Gutierrezia sarothrae*) dispersal, viability, and germination

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Broom snakeweed achene dispersal was monitored by placing surface-level traps outwards in the cardinal directions from 12 plants and collecting the achenes weekly or bi-weekly from September 1993 until seeds were no longer retained by the plants after 42 wk. About 50% of the achenes dispersed between October and December. Especially high numbers of achenes were dislodged during periods of intense winter winds and rains, with 78% of the seed placed into the east tray and 86% falling within 50 cm of the parent plant. Achene production averaged 3,928 (± 1,146) per plant in 1993 and 2,036 (± 987) per plant in 1994. Achenes collected over time directly from the inflorescence and achenes stored in nylon packets on the soil surface averaged 82% viability during fall and winter. Achene viability declined rapidly in late spring, and few remained viable before the next seed crop. Greenhouse experiments compared the influence of water application interval and water amount on broom snakeweed germination and seedling survival. Treatments consisted of 4 water intervals: daily, 5-d, 10-d, and 15-d intervals; and 4 water amounts: field capacity (1/1 fc), 3/4 fc, 1/2 fc, and 1/4 fc. Germination was 52% at daily 1/1 fc, and no seed germinated at daily 1/4 fc. Data suggest that optimum germination occurs when soils are maintained at a minimum soil matric potential (Ψm) > -180 kPa for at least 4 d. Optimum Ψm for seedling survival appears to range between -300 and -900 kPa, while seedling mortality would generally be expected with a Ψm of > -1800 kPa.

Key words: Seed longevity, seed ecology, seed retention, seedling survival, soil seed reserve, soil matric potential, GUESA.

Broom snakeweed is indigenous to semiarid western rangelands from Mexico to Canada (Lane 1985). In New Mexico, broom snakeweed is considered a major weed problem because it interferes with productivity of desirable forage and often becomes dominant on large tracts of blue grama grasslands, causing substantial economic losses to livestock producers (Carpenter et al. 1990; Torell et al. 1988). Herbicide and burning programs can provide good control, but treatment life is variable because of the cyclic nature of broom snakeweed populations (McDaniel and Duncan 1987).

Broom snakeweed is a short-lived perennial that propagates by seed in years when optimal environmental conditions occur, then subsequently dies from 1 or more factors, including drought (McDaniel 1989), insect infestation (Wangberg 1982), and old age (Jameson 1970). The average life expectancy of broom snakeweed surviving beyond the 1st year is approximately 4 yr, but some plants may live longer than 15 yr (Dittberner 1971). Environmental mechanisms that trigger a mass germination of seeds or factors that result in a major die-off of mature plants are not fully understood, but this information is needed to make sound decisions about broom snakeweed control and management (Torell et al. 1989).

The inflorescences of broom snakeweed are numerous, with 2 to 5 very small heads borne in clusters on short, panicled stalks arranged near the ends of upright stems. Broom snakeweed heads usually contain 2 to 7 ray flowers with yellow corollas, and from 0 to 9 disk flowers (Lane 1985). The seeds from ray florets are brown, roughly cylindrical (from 0.9 to 1.6 mm long and from 0.2 to 0.7 mm wide) and weigh about 0.15 mg per achene. The often infertile disk achene is always smaller than the ray achene. The achenes are pubescent when rows of white trichomes are oppressed to the seed coat in the direction of the pappus. The trichomes act to anchor the achene and enhance soil penetration; presumably, they draw and retain water next to the pericarp (Mayeux 1989). The pappus consist of small white or yellowish erose scales (< 1 mm length) aligned with the axis of the achene. This highly reduced pappus is unlike that found with most members of the tribe Astereae, which usually have a well-developed pappus for wind dispersal (Lane 1985). Thus, broom snakeweed seeds are absent of any specialized structures to facilitate long-range dispersal, and most seeds fall close to the parent plant when dislodged (Osman et al. 1987). Good seed crops may occur every year on some sites, but climatic factors, plant age, and insects generally cause wide fluctuations in seed production from year to year (McDaniel 1989).

By studying broom snakeweed seed ecology, additional insight into the plant's population dynamics can be gained, thereby increasing the opportunity to develop more efficient management strategies. The objective of this study was to investigate the production and dispersal of broom snakeweed achenes and to determine the longevity of achenes retained in the inflorescence and on the soil surface. We also examined achene germination under different water applications to determine soil water requirements for emergence and survival.

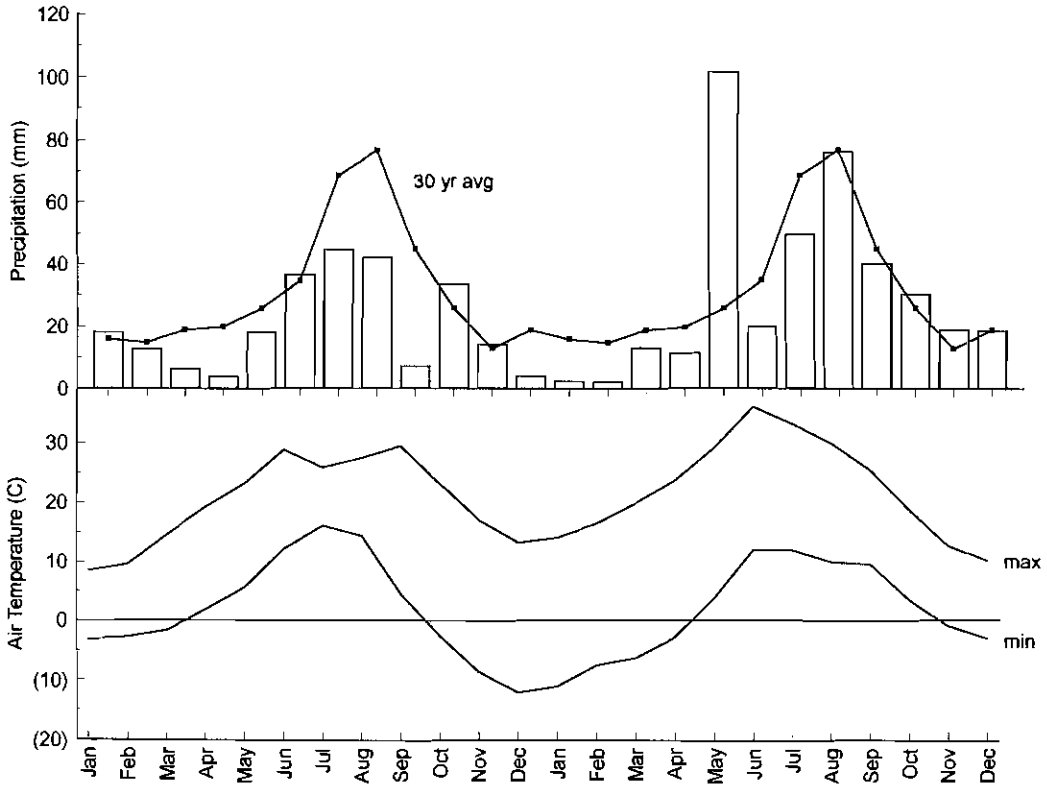

FIGURE 1. Monthly (bar) and long-time (line) average precipitation, and minimum and maximum air temperatures on the New Mexico State University Corona Research Ranch, NM. Time 0 is January 1993.

Materials and Methods

Environmental Setting

This study was conducted on the New Mexico State University Corona Ranch about 25 km east of Corona, NM. Sample plants were selected from 2 study sites, each within 5-ha exclosures, located about 10 km from one another on nearly level terrain at 1,870-m elevation. Rainfall is most common from July to September, and the 397-mm annual average can range from 280 to 510 mm.

Soils are comprised of the Taipa–Dean loam association, which is shallow and underlain by a highly calcareous limestone bedrock. The Taipa loam is a fine-loamy mixed mesic Ustollic Haplargid. The Dean loam is a fine carbonate mesic Ustollic Calciorthid. Vegetation in both exclosures is composed of a moderate stand of broom snakeweed (5 to 10 plants m^{-2}), with blue grama, wolftail (*Lycurus phleoides* H.B.K.), sand dropseed [*Sporobolus cryptandrus* (Torr.)], squirreltail [*Elymus longifolius* (Smith) Gould], and several forb species in the interspaces. Winterfat [*Ceratoides lanata* (Pursh) Howell] and cholla [*Opuntia imbricata* (Haw) DC.] are scattered throughout the area.

Weather in each exclosure was monitored throughout the study by automated stations[1] recording air temperature, soil temperature, relative humidity, windspeed, wind direction and rainfall. Precipitation from January to September 1993 was about 30% below the long-term average and was near or below normal every month until December 1994 (Figure 1). The exception was in May 1994, when rainfall was 115 mm, or 392% above average.

Seed Dispersal

In mid-September 1993, when broom snakeweed was in the early bloom stage, seed traps were installed around 6 similarly sized, healthy, mature plants in each exclosure. Shallow trenches (1 m long by 10 cm wide by 3.2 cm deep) were dug outwards from beneath the plant canopy in the 4 cardinal directions. Collectors made of polyvinyl raingutter were placed in the trenches so that the top edge was even with the ground surface. To retain seed in the traps, an air foil was placed over each collector made of five 0.64-cm by 91-cm wooden dowels secured to metal hardward cloth. Inside each collector, equal-sized (0.025 m^2 surface area) removable compartments, also made of polyvinyl raingutter, divided collectors into 4 distance categories. Water drainage was provided by using fine cloth netting at ends of the compartments and by drilling several 0.5-mm holes in the collector bottom.

Seeds were collected from the traps weekly or biweekly beginning in September 1993 until little flower material remained on the plants the next summer, i.e., 1 flowering season. The contents in each compartment were emptied into separate plastic bags and labeled by plant number, direction, and distance. In the laboratory, flower and seed material was separated from other debris using a No. 16 (0.1168 cm) and No. 50 (0.0297 cm) U.S.A. standard sieve and then examined under a scope. Mature achenes rerained in the capitula were counted separately from rhose dispersed individually. Lane (1985) reported that both ray and disk achenes were viable; however, disk achenes we examined were always sterile. Therefore, when we use the term 'achenes',

we are referring to ray achenes only. We noted signs of insect feeding on achenes, particularly during fall collections; thus, those obviously damaged by herbivory were counted separately from undamaged achenes.

Dispersal data were first analyzed in a nested structure by analysis of variance (SAS 1990), to compare achenes in traps collected from the 2 study sites. Because there were no differences between sites, data were combined and analyses run to compare seed numbers captured at different distances and directions from broom snakeweed plants. When the analysis of variance indicated a significant difference, means were compared by Fisher's Protected LSD test using the 5% probability level.

Seed Production and Retention

To determine seed production and retention within the inflorescence, 6 randomly selected broom snakeweed plants within each exclosure were harvested bi-weekly from October 23, 1993, to August 10, 1994, and near mid-month from October 20, 1994, to June 15, 1995. Plants were clipped carefully near the soil surface to avoid dislodging seed. Then each plant was bagged separately and transported to the laboratory to be oven dried for 24 h at 50 C. The dried plants were hand threshed to loosen the achenes and to remove the inflorescences from the stems. The remaining fine litter and capitula were subsequently pulsed twice in a seed scarifier to further loosen achenes. Final separarion of achenes from chaff was made using 2 sieves (No. 7 clipper screen and No. 120 seedburo) and a pneumatic seed cleaner[2] with the air blower set at 8.0 mm and turned on twice for 10 s. The number of achenes in a 0.2 g subsample of the seed fraction was counted and extrapolated to estimate total achene number per plant. When achene recovery from a plant was low (< 200 achenes per plant), an actual count was made. Differences in achene number per plant over the various collecrion dates were analyzed as a completely randomized design with site by sample date by plant as the error term. Means were separated using Fisher's Protected LSD test at the 5% level of probability.

Seed Viability

Viability tests were conducted shortly after achenes were separated from the inflorescences (time 0) using tetrazolium (TZ) analysis procedures similar to those described by Thill et al. (1985). A random subsample of 40 achenes per plant (6 plants per site and sample date) were placed inside a 5-cm petri dish on filter paper saturated with distilled water. Achenes were allowed to imbibe for a minimum of 4 h; then, using a dissecting scope, those containing an embryo were separated from those obviously without an embryo to determine the percentage of nondeteriorated achenes (achenes with embryo/total achenes × 100). Nondeteriorated achenes were dissected near the apical end, below the pappus, and placed in a 1% aqueous solution of TTC (2,3,5,-triphenyl tetrazolium chloride) for 8 h (Tetrazolium Committee of Association of Official Seed Analysts 1970). Following the soaking period, achenes with a red-stained embryo were used to calculate percentage ner viability (viable achene/total in TZ test × 100). To examine seed longevity, the remaining achenes from cach collecrion dare were stored either in the laboratory or in the field before testing by TZ analysis. Laboratory-stored achenes were placed in 5- by 10-cm manila envelopes and maintained at room temperature (ca. 25 C) before testing at 3, 6, 9, 12, and 18 mo (40 × 5 test). Field-stored achenes were inserted into 5- by 5-cm mesh nylon packets sealed with metal paper clips to keep out herbivorous insects and returned to the Corona Ranch. The packets were placed on the soil surface under a 1.75-cm wire mesh cage until retrieved later for testing after 3, 6, and 9 mo (40 × 3 test) of storage. Because previous reports by Mayeux and Leotta (1981) indicated broom snakeweed seeds are most likely to germinate on the soil surface rather than at buried depths, seed was not buried. Laboratory and field viability data were analyzed separately as split-plot experiments, with site the main plot treatment, and plants within site the main plot sampling unit. Collection time by storage regime was the subplot treatment; seed packets were the subplot sampling unit. Data were analyzed using SAS general linear model procedures (SAS 1990) to produce analysis of variance tables and contrast rests to compare field and laboratory storage effects at the 5% level of probability.

Germination

Germinarion experiments were conducted in a greenhouse on the New Mexico State University campus in Las Cruces, NM. Soil obtained from the Corona Ranch was sieved through a 5-mm screen and pasteurized for 24 h at 80 C. Plastic pots (16.5 cm diam) with filter paper placed over the drainage holes contained 1,700 g of sieved soil. In the 1st greenhouse experiment (April 2 to May 20, 1994), laboratory-stored achenes collected in October 1993 were used. In a 2nd greenhouse experiment (November 10 to December 20, 1994), laboratory-stored achenes from both October 1993 and October 1994 seed lots were used. Germination results with 1993 seed were the same for both greenhouse trials, so 1993 data were pooled for final analyses. The experiment was analyzed as a completely randomized design with a 2 (1993 and 1994 seed source) by 4 (water amounts) by 4 (water intervals) factorial arrangement of treatments. Pressure plate analysis (Rawls et al. 1982) conducted by the NMSU soils laboratory indicated that the water content was at field capacity (fc) when the soil matric potential (Ψm) was −30 kPa. Subsequent water amounts were 3/4 fc (−71 kPa), 1/2 fc (−314 kPa), and 1/4 fc (−3967 kPa). Water intervals were either 1 d, 5 d, 10 d, or 15 d. Six pots were randomly assigned to each treatment, and 10 achenes from each year's seedlot were equally spaced on the soil surface with forceps. A wire was laid down the middle of each pot to separate seedlots. Germinates were recorded daily; germination was considered successful when cotyledons emerged. Pots were weighed before and after each water application and whenever a new germinant was noted. Using procedures described by Klute (1986), a moisture release curve was developed to determine Ψm in each por through time. A negative exponential regression analysis was used to predict achene germination (averaged over pots) versus the Ψm using the general form:

$$Y = a + be^{-cx} \quad [1]$$

The dependent variable (Y) was broom snakeweed germination. The independent variable (x) defines Ψm at germination. The parameter c defines the exponential rate at

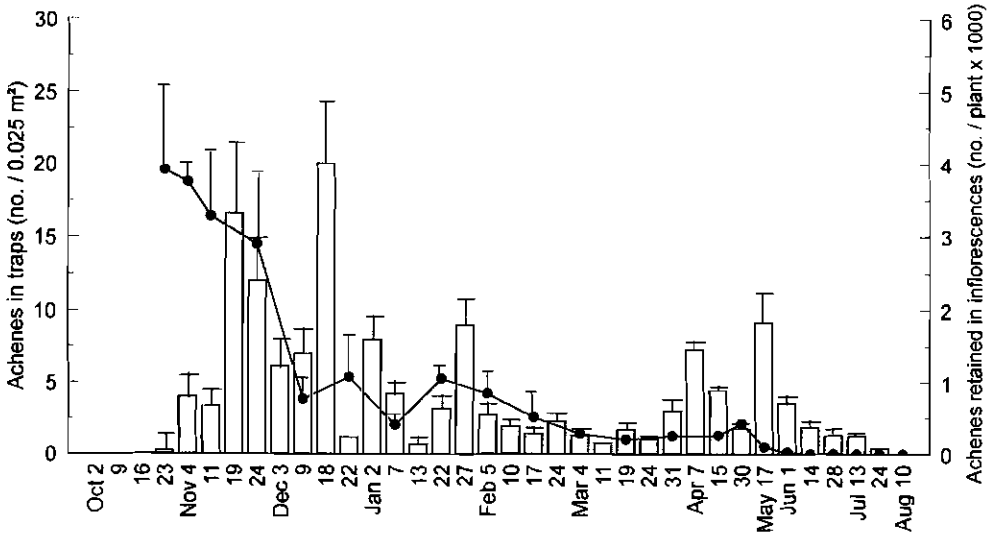

FIGURE 2. Broom snakeweed achenes recovered in 1-m long seed traps (bar graphs with standard error) with 1 end underneath the canopy and extending out in 4 cardinal directions from the parent plant. Achenes in traps are based on means by sample date across distance and direction from 6 plants in 2 exclosures during the 1993–1994 dispersal period. Achenes recovered from the inflorescence (line graph with standard error) are based on the means by sample date for 6 other plants collected within each exclosure.

which Ψm suppresses broom snakeweed germination. The curve is convex to the origin throughout the relevant range.

Results and Discussion

Seed Dispersal

In our study area, the majority of broom snakeweed's yellow, indeterminate flowers developed from mid-August until early October, when minimum air temperatures fell near freezing (Figure 1). During the week preceding the 1st recovery of achenes in the traps on October 23, 1993, the average minimum air temperature dropped below freezing (−3.3 C); this probably triggered the narrow involucre bracts to loosen and allowed dispersal to begin. Achenes were continually collected in traps for 42 wk, at which time dried shoots attached to flowers finally disintegrated (Figure 2). Cessation of dispersal roughly coincided with the development of new flower buds the next season. The rate of dispersal was a function of the number of mature achenes retained in the involucre and the presence or absence of climatic influences such as high winds and precipitation. The stiff floral stalks vibrate in the wind and cause achenes near the center of the head to disperse 1st while achenes pressed against floral bracts are dislodged later. Two precipitation events (mostly snow, accumulating at 10 and 7 mm, respectively) accompanied by high winds (maximum wind speeds of 12.4 m s^{-1} between November 11 and 19 and 14.1 m s^{-1} between December 9 and 18) preceded the highest recovery of total achenes. Relatively low numbers of achenes were collected from traps when no precipitation event occurred and when preceding maximum wind speeds were less than 9.2 m s^{-1} (data not shown). A relatively high number of achenes were recovered after an intense rain preceded sampling on May 17, 1994. Apparently the velocity of raindrops or hail striking inflotences and stems caused achenes to dislodge.

Most achenes recovered in traps (91%) dispersed individually from the inflorescence. Achenes dispersed within the head were rarely totally encapsulated by bracts and were usually immature and undeveloped; thus, it is not likely that capitula dispersal, as suggested by Mayeux and Leotta (1981), is a significant mechanism to promote seed dormancy in broom snakeweed. Insect herbivory affected 7% of total seed recovered. However, insect activity was especially high in the first 4 wk of collection, when most achenes in the traps were noted as immature and damaged by herbivory (Figure 3). Weevils (*Anthoromus tenuis*) and an unidentified species of *Microlepidopteran* were often recovered from collection compartments underneath the plant during this time. Foster et al. (1981) described these and other insects as flower and seed eaters. Difference in seed predations in the inflorescence compared to on the ground was not compared in this study, but research in this area seems warranted. A decline in achenes damaged by herbivory coincided with increasingly colder minimum temperatures in the fall, but ground-dwelling herbivores such as ants, were noted in the collectors throughout the study.

Without specialized structures to facilitate dispersal, the majority of broom snakeweed achenes fell directly beneath or near the canopy margin (Table 1). This pattern agrees with Osman et al. (1987), who reported that most broom snakeweed seedlings occur within 30 cm of the parent plant. Achenes recovered beyond 75 cm from a plant were mostly without a developed embryo (data not presented). The dispersal pattern of achenes towards the east was expected because storms in this region typically move in from the Pacific and Gulf Coast, creating winds from the southwest. A similar dispersal pattern with big sagebrush seed being skewed to the east was reported by Young and Evans (1989).

Broom snakeweed's dispersal distance is atelechory (Ellner and Shmida 1981; Pijl 1982); most achenes probably remain near where they land after dislodging. Plant litter and unevenness of the soil surface may impede wind and water transport after seeds are on the ground. Mayeux (1983) reported broom snakeweed germination decreases as burial depth increases. Thus, seed that falls into soil cracks or those

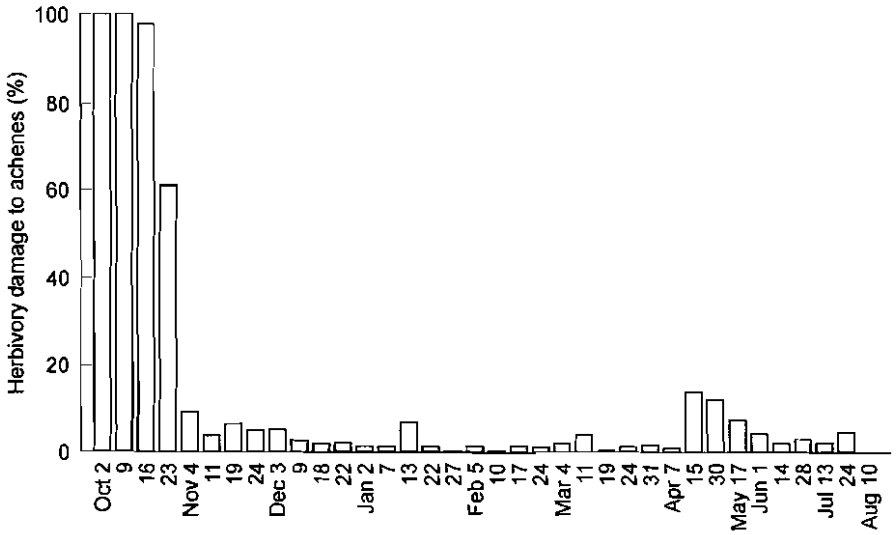

FIGURE 3. Herbivory damage to broom snakeweed achenes recovered from traps during the 1993–1994 dispersal period.

covered by soil movement may be removed from the pool of potential progeny. We did not examine biological dispersal, but animals large enough to brush against a plant can feasibly affect dispersal either by causing stems to eject achenes by a whipping motion or by achene trichomes attaching to the animal's coat and possibly transporting the seed out of the area (Mayeux 1989).

Seed Production

Individual broom snakeweed plants are capable of producing thousands of seeds (Ragsdale 1969), but there is considerable variation in seed production among plants, populations, and years (Pieper and McDaniel 1989). Of 12 plants randomly sampled for seed production near the beginning of dispersal in October 1993, the number of achenes counted ranged from 116 to 14,414 per plant and averaged 3,928 achenes per plant (± 1,146) (data not presented). A similar sample of 12 plants in October 1994 indicated a range from 25 to 8,921 achenes per plant and a mean of 2,036 (± 987). Broom snakeweed achene production may have been reduced in 1993 and 1994 in our study area because precipitation was below normal during flowering both years (Figure 1). Under very dry conditions, broom snakeweed typically ceases to flower, whereas in wetter years, the plant flowers profusely (Pieper and McDaniel 1989). Besides a lack of soil water, flowering is negatively influenced by old age, poor plant vigor, high shrub density, and insect feeding (McDaniel 1989). For example, Parker (1985) nored the obligate feeding snakeweed grasshopper [*Hesperotettix viridis* (Thomas)] completely defoliated threadleaf snakeweed (*Gutierrezia microcephala*) in localized areas, which resulted in no flowering or seed production in certain years.

TABLE 1. Number of broom snakeweed achenes recovered from seed traps located beneath the canopy edge outwards to 1 m in 4 cardinal directions. Achenes were collected at 2-wk intervals from October 1993 through August 1994. Each value in the table is the average using seed collections from 12 plants on the New Mexico State University Corona Ranch.

Achenes trapped by cardinal direction				Achenes trapped by distance from plant			
East	North	South	West	0–25	25–50	50–75	75–100
No. of achenes per 0.025 m^{-2}							
11.2a[a]	1.9b	1.0b	0.7b	8.4a	3.9b	1.5bc	0.6c

[a] Means with the same letters by cardinal direction or by distance from plant do not differ significantly at the 0.05 level.

Seed Retention and Viability

The percentage of nondeteriorated achenes obtained from the inflorescence during the first 6 mo after dispersal began in October was nearly twice as high for the 1993 seedlot as compared to the 1994 seedlot, or 74% versus 32%, respectively (Table 2). The difference in percentage nondeteriorated achenes between seedlots was probably related to the relative vigor of broom snakeweed each year during flowering and seed maturation. During the summer of 1994, the highest average air temperatures on record occurred in Corona, which, coupled with low precipitation, resulted in less flower production than observed in 1993 (data not presented). The differences in the quality of achenes produced during these 2 years was partially reflected in the relative weights of nondeteriorated achenes, which were 41% higher (per 100 achenes) in October 1993 compared with October 1994. These data suggest that broom snakeweed achene development and the subsequent rate of deterioration may be influenced by climatic conditions and inherent differences between seedlots.

Broom snakeweed achenes stored on the soil surface in packets decayed little during fall and winter months (October to March) for the 1993 and 1994 seedlots (Table 2). Achenes retrieved from the packets after mid-May were often seedless pericarps in various stages of decomposition, regardless of storage time. The pericarp was often covered with fungi, but it is not known whether deterioration was a result of snakeweed seed physiology or the effects of microbial decay. The timing and rate of rapid deterioration of achenes on the soil surface were similar to that observed with achenes collected from the inflorescence both years (Ta-

TABLE 2. Percentage of nondeteriorated achenes obtained directly from the inflorescences (time 0) and after storage on the soil surface for 3, 6, and 9 mo. Data ate averaged from 12 plants collected from 2 locations on the New Mexico State University Corona Ranch beginning in October 1993 and 1994.

1993 seedlot					1994 seedlot				
	Time in months					Time in months			
Sample date	0	3	6	9	Sample date	0	3	6	9
	%					%			
Oct. 11	69	72	62	11	Oct. 22	36	42	42	0
Oct. 29	73	76	22	3					
Nov. 11	80	79	1	0	Nov. 5	45	44	40	0
Nov. 23	94	92	5	3	Nov. 24	50	47	36	0
Dec. 9	78	79	2	0					
Dec. 22	78	78	3	0	Dec. 17	49	46	18	0
Jan. 7	74	88	1	0					
Jan. 22	91	91	2	0	Jan. 28	25	24	12	0
Feb. 5	74	64	18	0					
Feb. 19	71	7	3	0	Feb. 23	26	14	0	0
Mar. 4	56	6	0	0					
Mat. 18	67	5	0	0	Mat. 9	25	34	0	0
Mar. 31	61	6	0	0					
Apr. 15	62	4	0	0	Apt. 14	18	14	0	0
Apr. 30	37	0	0	0					
May 17	10	0	0	0	May 15	7	0	0	0
Jun. 1	19	0	0	0					
Jun. 14	6	0	0	0	Jun. 15	0	0	0	0
Jun. 28	45	0	0	0					
Jul. 13	0	0	0	0	Jul. 15	0	0	0	0
Jul. 24	21	0	0	0					
Aug. 10	0	0	0	0					
LSD (0.05)	19	14	16	6		17	15	12	NS

ble 2). Most of the 1993 achenes (98%) deteriorated within the inflorescence and on the soil surface between April 30 to June 15, whereas the majority of 1994 achenes (96%) deteriorated between April 15 to May 15. These results indicate that the majority of broom snakeweed achenes are nor long-lived and that only a small proportion of the original number of seeds persist into the next production year. Other rangeland shrub species in the Asteraceae family, such as big sagebrush (*Artemisia tridentata* Nutt.) (Young and Evans 1989), also produced prolific but short-lived seed crops that rarely persist for more than a year.

When percentage viability data (TZ test) were analyzed, no interactions or main effects attributable to study area were observed, but initial net viability was higher for the 1993 seedlot (95%) compared with the 1994 seedlot (83%) (data not presented). Net viability of achenes collected from the inflorescence or stored on the soil surface was similar through time when compared by recovery date within a sample year (October to August) (Figure 4). During both study years, achenes exhibited a pronounced periodicity of viability, as seeds were always most viable when recovered during fall and winrer (October ro April) but declined sharply late in spring (May to July). A similar periodicity of viability was not observed for achenes stored in the laboratory for 2 yr, which agrees with Mayeux and Leotta (1981), who reported that viability of broom snakeweed achenes remain unchanged after 4 yr of laboratory storage.

Results from the viability study suggest that it may be possible to severely reduce broom snakeweed from rangeland with conventional control methods, provided the environmental conditions necessary for germinarion do not occur for 1 to 2 yr after a parent plant population is eliminated. This agrees wirh observations that once broom snakeweed is controlled by herbicide spraying and seedlings do not establish within 2 yr, treatment life is likely long-lived (McDaniel and Duncan 1987). However, if even a small proportion of the original parent population survives and continues to produce seed, the weed population may eventually reestablish.

Germination

When percenrage germination data were analyzed, no interactions or main effects due to seedlots were observed. Achenes watered to field capacity had the highest percentage

TABLE 3. The influence of water amount (fraction of field capacity) and water interval (summed over seedlots and testing dates) on percentage germination of broom snakeweed achenes.

	Germination[a]			
	Fraction of field capacity			
Water interval	1/1	3/4	1/2	1/4
Day	%			
1	52a	38b	6d	0
5	35b	18c	1	0
10	23c	3d	0	0
15	23c	4d	1	0

[a] Means followed by the same letters are not significantly different at the 5% level of probability according to Fisher's Protected LSD rest. Where letters do not appear, no significant differences were found.

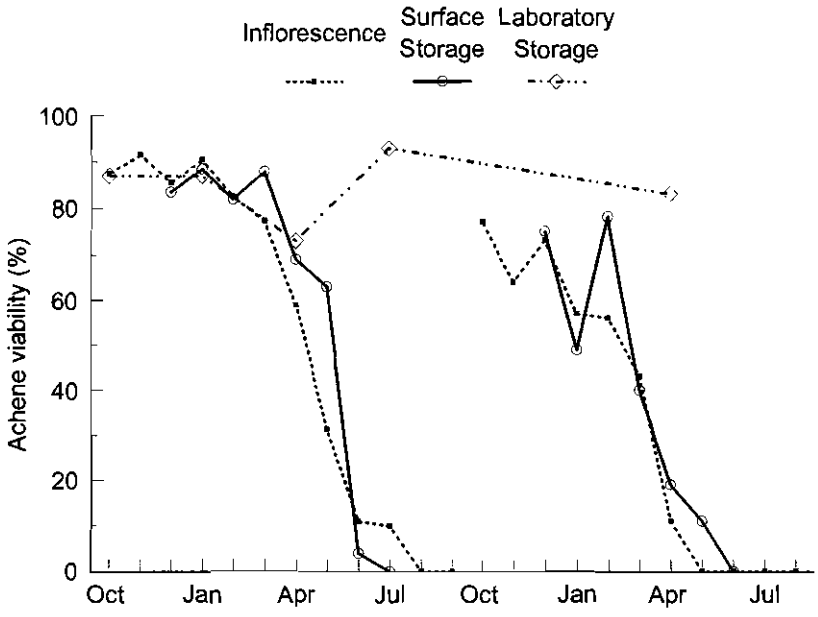

FIGURE 4. Percentage net viability of broom snakeweed achenes recovered from inflorescences and after storage on the soil surface and in the laboratory during the 1993–1994 and 1994–1995 dispersal periods.

of germination (33%) when averaged over seedlots, trial dates, and water intervals (Table 3). No achenes germinated when water was applied at 1/4 fc, and few achenes germinated when pots were watered to 1/2 fc. A higher percentage of achenes germinated (24%) when watered daily than when watered at 5-, 10-, or 15-d intervals, regardless of water amount. Germination generally decreased proportionally as water interval lengthened and water amount decreased. Achenes watered daily to 1/1 fc had the highest percentage of germination (52%). Achenes watered daily to 3/4 fc had the same percentage of germination as achenes watered at 5-d intervals to 1/1 fc (average 37%). Percentage of germination was not different for achenes watered to 3/4 fc at 5-d intervals and achenes watered to 1/1 fc at 10-d and 15-d intervals (average 21%).

Broom snakeweed percentage of germination was negatively and inversely related to the soil Ψm at germination (Figure 5). When data were combined over years, water intervals, and amounts, 72% of the variability in percentage germination was attributed to variation in soil Ψm. As expected, the estimated curve exhibits a rapid decline in germination as soils become drier. The curve is steepest near 0 when germination is highest and flattens when germination declines below about 10%. Averaged across all experiments, 91% of achenes germinated when soil Ψm remained > -180 kPa for at least 4 d (data not shown).

The majority of propagules survived the greenhouse experiments in the daily 1/1 fc (76%), the daily 3/4 fc (58%), and the 5-d 1/1 fc treatments (64%). Few survived under the other water amounts (data not presented). Seedlings that died under the daily 1/1 fc regime died mostly from damping off fungus. This may partially explain why low-lying areas that periodically retain standing water in snakeweed communities are usually void of the shrub. Seedling mortality in treatments other than when watered daily 1/1 fc occurred when soil Ψm averaged -1853 ($\pm$ 364) kPa. Seed-

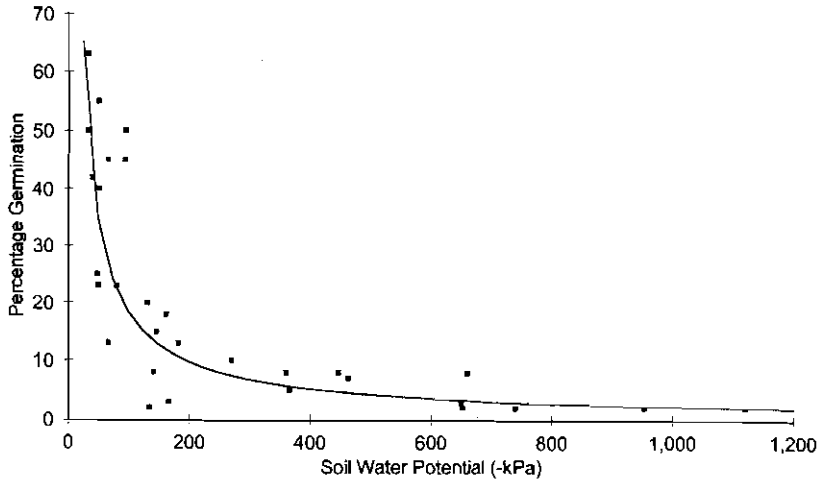

FIGURE 5. Actual (symbol) and predicted (line) percentage germination of broom snakeweed under changing soil matric potentials. Predicted germination values were determined using Equation 1 ($\hat{Y} = 1164.14 - 0.90\ e^{-cx}$, $r^2 = 0.72$, and $n = 30$).

ling mortality under drying soil conditions should be expected to vary depending on the age and condition of the seedling at the time of stress.

These results suggest that optimal broom snakeweed germinarion occurs when water is applied frequently and saturates the soil. Field observations of broom snakeweed germination from 1990 rhrough 1995 on the Corona Ranch closely correspond with these findings (Carroll 1994). During this 5-yr period, precipitation during the 2nd quarter (April through June) was near or below normal every year except 1992 and 1994, when rainfall was above normal and 63% of broom snakeweed seedlings eounted during this study emerged (Carroll 1994). Under field conditions, low daily precipitation (< 25 mm) for 1 or several days is probably insufficient to result in successful germination. We suspect a higher amounr of precipitation (> 25 mm) that keeps the soil surface wet for several days is necessary for germination. Besides soil water, conditions conducive to optimal germination include seed placement near the soil surface (Mayeux 1983) and an alternating air temperature regime between 10 to 20 C (Kruse 1970). For mass germination on rangeland, it appears these conditions in central New Mexico must culminate before mid-May, after which time seed viability declines dramatically. The optimal culmination of these events elsewhere must be adjusted to localized conditions. These generalizations need to be tested over a wide range of environmental conditions where broom snakeweed is a dominant species.

Sources of Materials

[1] Automated Stations, Campbell Scientific, Inc., 815 W 1800 N, Logan, UT 84321-1784.

[2] Pneumatic seed cleaner, E. L. Erickson Products, Brookings, SD.

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Nomenclature: Broom snakeweed, *Gutierrezia sarothrae* (Pursh) Britt. & Rusby GUESA; Blue grama, *Bouteloua gracilis* (H.B.K.) Lag. *ex* Griffiths.

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