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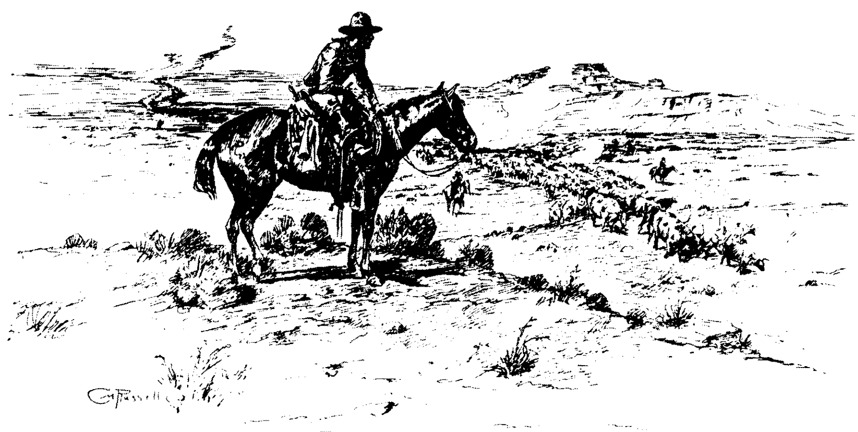

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BOOK REVIEWS

Predator Control in Relation to Livestock Losses in Central Texas

ERWIN W. PEARSON AND MILTON CAROLINE

Abstract

Records of the 1971-76 federal-state Animal Damage Control (ADC) program in central Texas reflected 0.27% annual domestic sheep and goat losses to predators despite intensive control efforts. Sheep and goat numbers decreased, but their value, cattle numbers, and cattle values increased. Losses to coyotes and bobcats were proportionately greatest in brushy, uneven terrain on the periphery of the Edwards Plateau. In 1975, cooperative ADC predator control efforts protected 438,649 (40%) of the sheep and goats on 8,912 km^2 (3,441 mi^2), or 15.5% of the total land area in 21 counties studied at an average cost of 46 cents for each sheep or goat protected. Heaviest losses to predators occurred from October to May when small lambs were present; control efforts were most successful during winters. An estimated cost-benefit ratio to measure the effectiveness of the ADC program was 1:4.5 for 1975. We observed that losses to predators were lowest when annual precipitation was highest; high losses coincided with dry years, which were probably the periods of lowest wild prey abundance.

Increasing sociological and political controversy about predator control from local to Congressional levels has increased the need to evaluate the effectiveness of control efforts. This paper analyzes records from a continuing cooperative federal-state program in 21 Texas counties to evaluate the effects of present control methods in this country's largest and most concentrated sheep and goat-raising area. In other parts of the West, detailed loss studies in three no-control situations and several areas with unmeasured controls have provided views (discussed later) of several aspects of predation. We add to that information by providing some insight from the broad view of a control organization as opposed to individual ranch studies of loses to predators.

Methods

The study area included three counties each of seven levels of sheep density as determined by an earlier study (Pearson 1975). The 21 counties included three having the highest sheep densities in the West in 1972, but also included counties lying adjacent to or near the Edwards Plateau with sparse sheep populations (Tables 1 and 2; Fig. 1). The goal of choosing an orderly band of adjacent counties extending across the Edwards Plateau was not achieved because control records of two or more counties were sometimes irreversibly combined; therefore they could not be treated as separate comparable units. Nevertheless, the sample was probably representative of the seven levels of sheep density in Texas and the Southwest.

When records were first examined, rough calculations indicated that, where present, about as many angora goats were killed by predators as were sheep; consequently, data for goats and sheep were combined. Furthermore, since control methods protected both species (nearly one-third were goats), it was not possible to evaluate the program without considering both goats and sheep.

Similarly, because records of predation by bobcats *(Lynx rufus)* and costs to control them could not be separated from similar records for coyotes *(Canis latrans)*, costs of control were combined for the two species. Except in a few areas, control operations were directed primarily at the coyote.

Calendar year 1971 was chosen to represent conditions for the year preceding the presidential ban on use of toxicants for predator control (Executive Order No. 11643, February 8, 1972), and 1973 and 1974 were chosen to reflect conditions after the ban. However, ADC personnel collected the ADC-protected area data for 1975-76 (Table 2) when it became obvious that biased conclusions were being drawn from incomplete data such as unknown numbers of sheep and goats as well as unknown land areas being protected by ADC operations. The ADC-protected area data for 1975-76 present the most complete portrayal of the Texas predator control program.

Records of ADC do not include all livestock losses because ADC operations are not under signed agreements to control predators for all livestock owners. Also, field workers who answer control requests normally apply controls, but usually do not have time to make extensive searches for later losses. Therefore, these data include only a partial listing of losses that occur in spite of controls.

Costs of conducting the cooperative control program in 1975

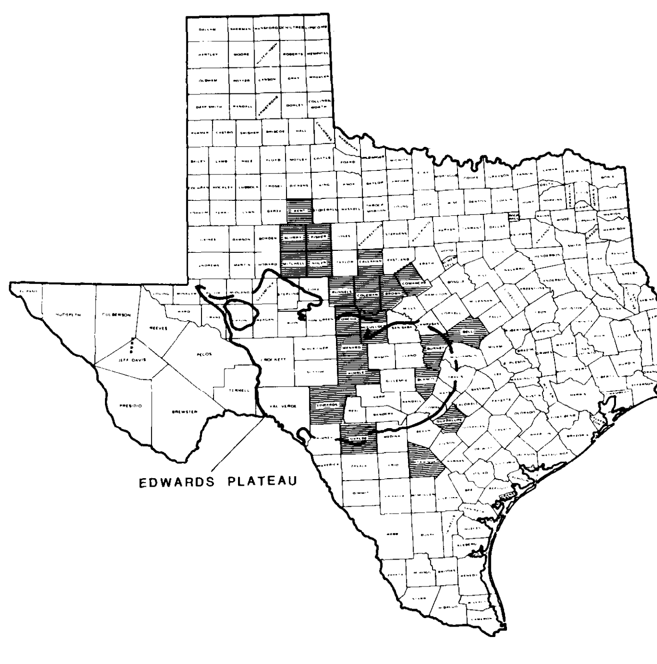

Fig. 1. *The 21 counties in the Edwards Plateau (outlined) study area, Texas (after Teer et al. 1965, p 7).*

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Authors thank Martin Popelka of the Denver Wildlife Research Center, while stationed in Uvalde, Texas, for copying the detailed figures from the 1971, 1973, and 1974 ADC records, and district supervisors and field assistants who gathered additional 1975-76 data. All information in this paper was obtained from ADC records unless indicated otherwise. Authors also thank D.S. Balser, Patricia A. Chamberlain, G.E. Connolly, S.B. Linhart, and R.D. Nass for their editorial assistance.
Manuscript received November 23, 1979.

Table 1. Combined numbers of sheep and goats in 1971, 1974, and 1976, cattle numbers, percent changes from 1971 in 1974 and 1976 (in parenthesis), and values in seven selected sheep density areas of the Edwards Plateau region, Texas,[1] on January 1 in 1971 and 1976.

Counties in density category (1972 sheep/km²)[1]	Sheep and goats[2] 1971	1974	1976	Cattle[2] 1971	1976	1976 values[2] Sheep and goats	All cattle
Concho, McCulloch, Menard (62.8)	502,000	487,000 (-3.0)	410,000 (-18.3)	92,000	117,000 (27.2)	$12,352,500	$ 18,135,000
Coleman, Kimble, Runnels (27.9)	403,000	281,570 (-30.1)	243,950 (-39.5)	138,000	158,000 (14.5)	6,897,550	24,490,000
Blanco, Edwards, Nolan (14.0)	380,000	297,000 (-21.8)	223,600 (-41.2)	86,000	125,000 (45.3)	5,435,900	19,375,000
Brown, Burnet Uvalde (18.2)	363,000	237,000 (-34.7)	168,900 (-53.5)	162,000	171,000 (5.6)	4,321,600	26,505,000
Bell, Comanche, Mitchell (5.8)	84,315	38,200 (-54.7)	33,630 (-60.1)	144,000	221,000 (53.5)	963,970	34,255,000
Callahan, Guadalupe, Scurry (1.1)	11,365	5,000[3] (-56.0)	5,270[3] (-53.6)	137,000	168,000 (22.6)	155,130	26,040,000
Atascosa, Fisher, Kent (0.3)	2,985[3]	910[3] (-69.5)	770[3] (-74.2)	141,000	187,000 (32.6)	23,130	28,985,000
TOTALS (19.1)	1,746,665	1,346,680 (-22.9)	1,086,120 (-37.8)	900,000	1,147,000 (27.4)	$30,149,780	$177,785,000

[1]From Pearson, 1975.
[2]From *Texas Livestock Statistics;* average values in 1976 were $31.50 for each sheep, $19 per goat, and $155 for cattle.
[3]Numbers under 1,000 per county not given, so estimated from weights of wool or mohair given, or obtained from county Extension agents by M. Popelka.

included only salaries and expenses of the professional field control workers. An estimate of additional supervisory and state office costs is presented later to offer a tentative economic portrayal of all costs compared with the benefits derived from the predator control program.

Results and Discussion

Emphasis on predator research at the Denver Wildlife Research Center has been placed on the study of coyote-sheep relationships because interactions between these two species have included the greatest economic and sociological considerations and controversies in animal damage control. Tables 1–5 contain most of the applicable facts and calculated data on which this paper is based; an understanding of them is necessary for an objective understanding of the Texas ADC program.

The 21-county study area included 30.5% of the Texas sheep and goat population in 1971 and 31.1% in January 1976 (Texas Livestock Statistics 1971 and 1975). Following a national trend (Pearson 1975, Gee and Magleby 1976), the sheep and goat population dropped 39.0% from 1971 to 1976 in the total state, and 37.8% in the 21-county study area (Table 1). The value of all sheep and goats in the study area increased more than 31% despite the decrease in numbers between 1971 and 1976.

Cattle numbers and values are listed in Table 1 because information from several states in the West indicates that calf losses to coyotes have been increasing. In addition, other studies have

Table 2. Comparisons of tri-county region and ADC-protected area data in seven selected sheep density areas of the Edwards Plateau region, Texas, 1972 and 1976.

Counties in density category (1972 shee/km²)	Tri-county region data: Area in km²	Sheep and goats/km² 1976	ADC-protected area data, 1975–76: Sheep and goat numbers	Sheep and goats/km²	% of sheep and goats protected[1]	% loss to predators 1975	Square kilometers protected	% of counties protected
Concho, McCulloch, Menard (62.8)	7,729	53.0	143,335	79.8	35	0.02	1,796	23.2
Coleman, Kimble, Runnels (27.9)	9,352	26.1	86,290	42.8	35	0.29	2,016	21.6
Blanco, Edwards, Nolan (14.0)	9,627	23.2	89,930	38.8	40	0.26	2,318	24.1
Brown, Burnet, Uvalde (18.2)	9,122	18.5	83,288	37.4	49	0.45	2,224	24.4
Bell, Comanche, Mitchell (5.8)	7,539	4.5	29,197	75.4	87	0.84	387	5.1
Callahan, Guadalupe, Scurry (1.1)	6,408	0.8	6,254	38.4	100	0.66	163	2.5
Atascosa, Fisher, Kent (0.3)	7,744	0.1	355	50.7	46	0.28	7	0.1
Totals or averages	57,521	18.9	438,649	49.2	40	0.27	8,911	15.5

[1]Approximate; January 1 county figures (Table 1) do not always agree with ADC figures that may include herd changes during the fiscal year.

Table 3. Combined numbers of sheep and goats killed by coyotes and bobcats seasonally, 1971 and 1973-75.

Counties in category (1976 sheep & goats/km²)	Years	Sheep and goats killed in: Dec.-Feb.	Mar.-May	June-Aug.	Sept.-Nov.	Totals	4-year totals (%)
	1971	13	0	0	0	13	
Concho, McCulloch,	1973	0	0	6	3	9	364
Menard (53.0)	1974	0	289	19	8	316	(5.8)
	1975	26	0	0	0	26	
	1971	45	120	17	15	197	
Coleman, Kimble,	1973	3	8	45	5	61	870
Runnels (26.1)	1974	61	25	98	174	358	(14.0)
	1975	62	1	149	42	254	
	1971	17	6	0	0	23	
Blanco, Edwards,	1973	21	27	67	26	141	745
Nolan (23.2)	1974	5	268	39	36	348	(11.9)
	1975	18	6	150	59	233	
	1971	408	259	90	20	777	
Brown, Burnet,	1973	736	191	69	75	1071	2712
Uvalde (18.5)	1974	91	157	197	46	491	(43.5)
	1975	44	125	62	142	373	
	1971	46	79	36	197	358	
Bell, Comanche,	1973	48	61	2	157	268	1153
Mitchell (4.5)	1974	40	96	89	58	283	(18.5)
	1975	46	8	31	159	244	
	1971	5	8	0	0	13	
Callahan, Guadalupe,	1973	0	0	12	0	12	336
Scurry (0.8)	1974	4	26	236	4	270	(5.4)
	1975	16	0	17	8	41	
	1971	10	17	0	9	36	
Atascosa, Fisher,	1973	0	0	6	0	6	55
Kent (0.1)	1974	0	0	10	2	12	(0.9)
	1975	0	0	0	1	1	
	1971	544	489	143	241	1417	
	1973	808	287	207	266	1568	6235
Totals (18.9)	1974	201	861	688	328	2078	(100)
	1975	212	140	409	411	1172	
Totals of 4 years		1765	1777	1447	1246	6235	
% of 4 year totals		28.3	28.5	23.2	20.0	100.0	

shown that when sheep numbers decreased, many sheep ranchers turned to raising cattle (Stevens 1971; Pearson 1975; Stevens and Hartley 1976). In the 21 counties, cattle numbers increased 27.4% between 1971 and 1976 (Table 1), and calf losses also reportedly increased in 1975 (Table 4).

In 1975 about 15.5% of the land in this area of concentrated sheep and goat-raising was under written agreement with ADC for possible control work to protect about 40% of the sheep and goats in the 21 counties (Table 2). It is unlikely that other sheep and goat ranchers' control efforts would be as intensive as those of the federal cooperative program. A separate study of those ranches would be necessary to determine the extent of their controls and losses. An early draft of a USDA study (Gum et al. 1978) indicated that ranchers using cooperative federal control programs generally had lower predator losses than did other ranchers, but the lack of basic, factual data often prevented clear, well-founded conclusions.

The percent reduction by ranchers of numbers of sheep and goats from 1971 to 1976 was generally far less in counties having high sheep and goat populations than in counties having low populations (Table 1). However, losses to predators (Table 4, Fig. 2) did not follow a similar pattern; largest percent losses to predators occurred in the low- and medium-density sheep- and goat-raising areas, despite more intensive control efforts there. An associated seemingly contradictory finding is that due primarily to intensive control efforts usually more coyotes were taken in counties with few sheep and goats (Table 4, Fig. 2) than in counties with more sheep and goats in which the heavier losses occurred.

Apparent inconsistencies in the seven different livestock density areas are explained by more explicit observations and considerations of geography and habitat. There probably are advantages, such as better predator control, in raising large numbers of sheep and goats near the center of the Edwards Plateau. Sheep and angora goats have been raised for decades in counties with highest sheep and goat densities on and immediately adjacent to the edge of the Edwards Plateau. The concentration of woven wire fencing has impeded the travel of coyotes and has helped maximize control efforts where the centrally located counties "have contained the lowest known densities of coyotes west of the Mississippi" (Anderson et al. 1974). As Anderson et al. (1974) pointed out, however, counties adjacent to the Plateau serve as the first line of defense to prohibit ingress of coyotes into the country most heavily populated with sheep and goats, and coyote controls are used as intensively as funds permit to keep coyote populations as low as possible. The past history of predator control is readily depicted in 1971 when only 13 sheep and goats were killed in the tri-county area with the highest average density of sheep and goats, and only 16 coyotes and 39 bobcats were taken (Table 4) at great expense while about 175,000 animals were being protected.

The counties with highest percentage losses to predators were those with medium- and low-density sheep and goat populations located on the edges and adjacent to the Edwards Plateau. The irregular, brushy terrain is often grazed only by sheep and goats, but it is also good predator habitat; this obviously places livestock in a hazardous position insofar as predation is concerned.

Another reason why large numbers of coyotes were killed in those counties having few sheep and goats was the reported need to protect increasing numbers of cattle and calves (Table 1). Coyotes taken to protect cattle are not usually distinguishable from those taken to protect sheep and goats in the same area, and despite large coyote kills, calf losses remained the same or increased (Table 4). Calf losses to coyotes were consistently greatest in counties lying near the Edwards Plateau where the annual coyote abundance survey has continually recorded high coyote densities (Roughton 1976), but where cattle numbers have been about the same as in other areas. It should be emphasized that the loss of a cow or calf usually represents several times the economic loss of a sheep or goat (Table 1).

Seasonal losses generally reflect the availability of lambs, and in the present study differ in varying degrees from most other western states. Because western range lambs are usually born in the spring, losses in most states are highest in spring and summer (Nass 1977; Tigner and Larson 1977). In Texas (and parts of California, Arizona, and other states), many sheep herds are managed to yield large numbers of lambs for market in spring when lamb prices are high. For example, the Texas early lamb crop (for Easter markets) was listed as 770,000 between October 1, 1974, and March 1, 1975, or about half of the 1,500,000 lambs produced in Texas in all of 1974 (Anonymous 1975). Sheep and goat losses to coyotes and bobcats reflect this winter and spring availability; combined seasonal predator losses for 4 years were 56.8% of the production years' total in December through May (Table 3). A study of losses on seven California ranches, all with early lambing, showed that losses from December through March were 94 and 82% of total predator losses in 2 production years (Nesse et al. 1976).

Seasonally, the loss pattern differed in 1973 and 1975, when, with one county's exception, fewer sheep were lost to predators in the first 6 months (33 and 31%, respectively) than during the same period in other years. Table 5 shows the inverse relationship between precipitation (U.S. Weather Bureau 1971–76) and the proportion of predator kills that occurred during the first 6 months of each year, 1971–75. When first half-year precipitation was about normal (1973 and 1975), only one-third of each year's predator kills occurred in the first half-year, even though that was the period of greatest exposure of lambs and kids to predation. In 1971 and 1974, 61% or more of the year's predator kills occurred in the first half-year periods when precipitation was well below normal. Possibly the average and above-average precipitation in 1973 and 1975 produced abundant vegetation for rodent and rabbit populations, which normally respond quickly to increased food availability. In 1971 and 1974, however, inadequate moisture during the first half-years may have curtailed vegetative growth, which in turn produced deficit wild prey populations, thereby causing predators to turn to livestock for food despite the persistent pressure of the predator control program.

These data can only indirectly relate to studies that link predation with natural prey availability. In Nevada, Kauffeld (1977) found that coyote predation on domestic sheep was highest in a study area with the lowest natural prey:predator ratio. In Texas, Gober (1979) recorded luxuriant vegetative growth in 1975 after abundant precipitation in the fall and winter of 1974–75, but poor growth in 1976 and early 1977 when drought conditions persisted. Concurrently he found rodent biomass estimates on the same areas were substantially lower in 1976 and 1977 than in 1975, and that expanding prey populations in 1975 appeared to enhance lamb survival. In 1977 the rate of lamb loss moderated after spring precipitation allowed vegetative response and indirectly encouraged the expansion of alternative prey populations (Gober 1979, p 98). Also, "in 1974, a year when wild prey populations were probably depressed in the Trans-Pecos, ewes on this ranch produced at least an 80% lamb crop at spring docking (468 lambs) but only a 5% lamb crop (25 lambs) survived the autumn shipping"; most lamb losses were reportedly caused by predators (Gober 1979, p 100–101). During the same period Guthrey (1977), also in Texas, reported plentiful rainfall and good production of grasses and forbs in 1975. This contrasted with a droughty period from November 1975 to March 1976 when (p 23) "The higher level of predation on kids and nannies [angora goats] in the untreated [no predator control] pasture in 1976 roughly correlated with alternate prey availability; . . . rodent densities dropped considerably in 1976, . . . and may have played a role in the increased predation of 1976."

Turkowski and Vahle (1977), with rodent trap-catch data obtained annually in December for 22 years in southern Arizona, showed that, "The total rodent populations of the years following

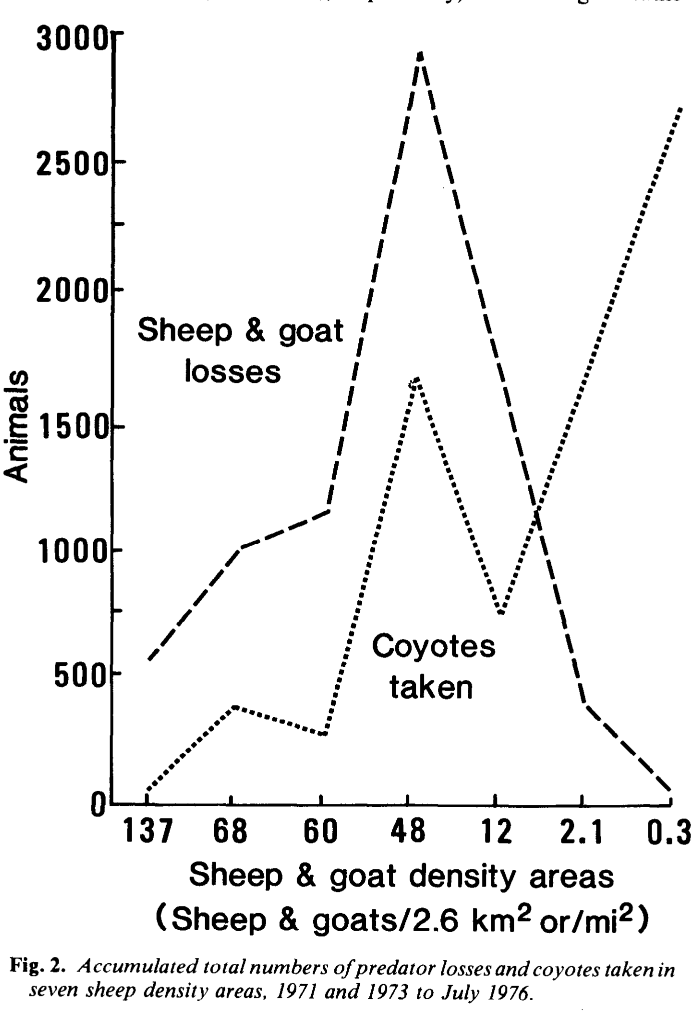

Fig. 2. *Accumulated total numbers of predator losses and coyotes taken in seven sheep density areas, 1971 and 1973 to July 1976.*

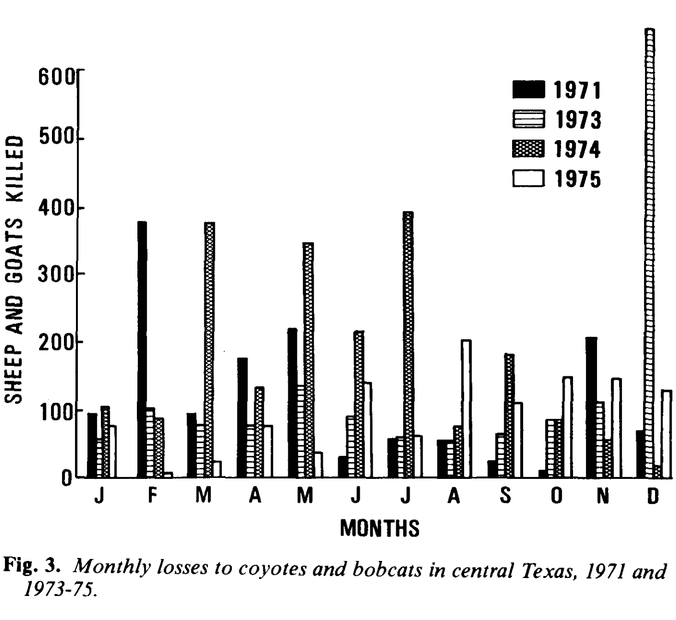

Fig. 3. *Monthly losses to coyotes and bobcats in central Texas, 1971 and 1973-75.*

Table 4. Sheep, goat, and calf losses to coyotes and bobcats, and some predator control costs and results in central Texas.

Counties in density category (1976 sheep & goats/km²)	Years	Losses to coyotes & bobcats: Sheep & goats	Calves	Total	Coyotes & bobcats taken	Coyotes or bobcats taken/sheep, goat, or calf killed	1975 control costs, ADC-protected area[1]	Cost/sheep or goat protected in 1975
Concho, McCulloch, Menard (53.0)	1971	13	0	13	55	4.2		
	1973	9	0	9	29	3.2		
	1974	316	0	316	48	0.2	$ 30,909	$0.22
	1975	26	0	26	49	1.9		
Coleman, Kimble, Runnels (26.1)	1971	197	1	198	208	1.1		
	1973	61	1	62	59	1.0		
	1974	358	2	360	79	0.2	27,159	.31
	1975	254	0	254	57	0.2		
Blanco, Edwards, Nolan (23.2)	1971	23	0	23	88	3.8		
	1973	141	1	142	112	0.8		
	1974	348	1	349	109	0.3	37,119	.41
	1975	233	1	234	146	0.6		
Brown, Burnet, Uvalde (18.5)	1971	777	2	779	532	0.7		
	1973	1071	4	1075	595	0.6		
	1974	491	0	491	447	0.9	52,789	.63
	1975	373	0	373	398	1.1		
Bell, Comanche, Mitchell (4.5)	1971	358	7	365	150	0.4		
	1973	268	4	272	197	0.7		
	1974	283	1	284	246	0.9	27,339	.94
	1975	244	6	250	205	0.8		
Callahan, Guadalupe, Scurry (0.8)	1971	13	1	14	342	24.4		
	1973	12	0	12	324	27.0		
	1974	270	3	273	458	1.7	25,357	4.05
	1975	41	17	58	466	8.0		
Atascosa, Fisher, Kent (0.1)	1971	36	17	53	660	12.5		
	1973	6	13	19	488	25.7		
	1974	12	12	24	747	31.1	1,017	2.86
	1975	1	35	36	707	19.6		
TOTALS (18.9)	1971	1,417	28	1,445	2,035	1.4		
	1973	1,568	23	1,591	1,804	1.1		
	1974	2,078	19	2,097	2,134	1.0	201,689	.46
	1975	1,172	59	1,231	1,924	1.6		
4-year totals		6,235	129	6,364	7,897	1.2		

[1]Obtained for only 1975.

lowest rainfall was about half that following the high rainfall years." Based on the several cited studies, we believe that in 1975, for example, when the previous fall, winter, and spring precipitation was well above average and adequate for the whole year (Table 5), and livestock losses were the lowest of the study (Table 4, Fig. 3), wild prey numbers were probably high and could have produced a buffering effect that reduced sheep and goat losses to predators.

Although there was year-around effort, predator control was generally most successful during winter (Fig. 4) and predators were most difficult to capture during the summer. Of the 6,661 coyotes taken during the main 4 study years, 36, 27, 13, and 24% were taken in the winter, spring, summer, and fall, respectively; this seasonal control was similar for bobcats. Several factors probably contributed to this success pattern, including the fact that naive juveniles normally make up about half of the fall populations (Knowlton 1972). In addition, young coyotes disperse in fall and winter, and are probably more susceptible to capture in strange environments. Also, natural predator foods are becoming scarce, and the predator's wide-ranging, foraging trips come at a time when leafless vegetation makes them more visible to control personnel than in the summer.

Although not shown in tables, costs for reducing coyote populations would be lowest during the winter on areas such as range lambing grounds and early summer grazing pastures where general population reduction is the goal.

Bobcat predation on livestock was erratically significant in only a few counties; 13 sheep or goats were lost to bobcats in Uvalde county in 1971 and 20 in Mitchell County in 1974. However, sheep and goat losses to bobcats increased in 1975; 14 sheep or goats were taken by bobcats in Mitchell County, 22 in Coleman, 40 in Uvalde,

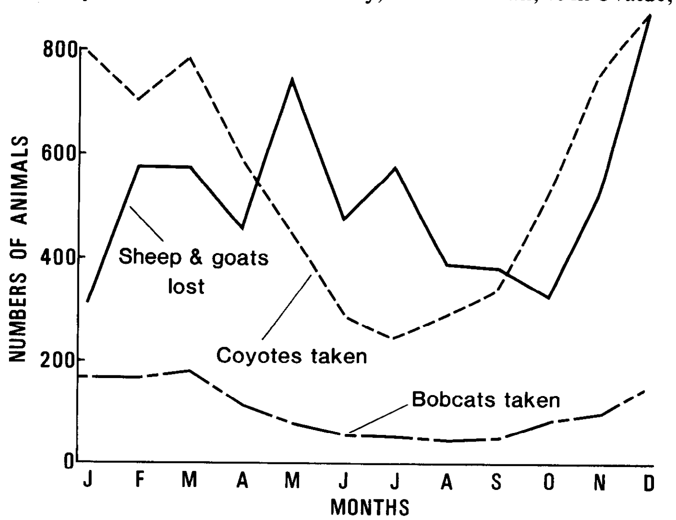

Fig. 4. *Accumulated monthly predator losses and coyotes and bobcats taken in central Texas, 1971 and 1973-75.*

and 100 in Runnels. Of 85 sheep or goats lost to bobcats in the first half of 1976, 77 were taken in Edwards County.

Except in local areas, control operations during the reporting period were seldom directed specifically at the bobcat. It is, however, both easily trapped and usually considered a predator, so it was seldom released. (As recent policy changes have dictated, most bobcats are now being released unless they are causing losses locally.) In addition to predation on lambs and goats, bobcats sometimes take poultry; in 1974, for example, bobcats took 48 chickens and 40 turkeys.

The coyote also destroys more than the sheep, goats, and calves shown in Table 4. For example, in 1974 coyotes reportedly took 714 turkeys, 4 chickens, 15 melons, 1 horse, and 1 deer in the 21 counties.

In 3 of the 4 years of the present study, a proportionally larger number of goats were killed than are represented by their total numbers in the 21 counties. In 1971, 1973, 1974, and 1975, when goats made up 29.3, 33.8, 32.0, and 29.9%, respectively, of the total sheep and goats in the 21 counties, losses to predators were 47.1, 30.6, 33.5, and 52.1% of the total reported sheep and goat losses in those same years. This generally higher percent loss of goats may indicate a preference for goats, or a greater vulnerability of goats because they are smaller than sheep. However, Shelton (1972) indicated that a lower loss of sheep (3.4%) than goats (4.9%) to coyotes might be because sheep were the more valuable species and were given the greater protection. In addition, nannies usually leave their kids behind while they go to water and often while feeding, whereas ewes and lambs remain together most of the time, thereby affording lambs better protection.

Pertinent Information from Other Sources

For most practical purposes, toxicants used for predator control were banned in 1972, and the general belief is that numbers of predators, particularly coyotes, have since been increasing. Some of these are general observations which lack factual evidence of population changes, but ranchers report increasing livestock losses to coyotes as evidence of increasing coyote numbers. In addition, annual reports of the federal ADC program from several states, as well as reports in the *National Wool Grower* magazine (July and December 1974; April, July, November 1975) have indicated that increasing coyote numbers are primarily responsible for increasing livestock losses. Gee et al. (1977), reporting on a survey of about 9,000 sheep producers in 15 western states, indicated that a third of total lamb deaths (728,200) and a fourth of adult sheep deaths (229,400) were attributed to coyotes in 1974; 11.4% of all lambs and 3.4% of all adult sheep were reportedly killed by predators.

Factual evidence of changing coyote numbers come from over 400 (in 1976) coyote survey lines (Linhart and Knowlton 1975) which have been run annually since 1972 in the 17 western states. Roughton (1976) summarized the survey data, which indicated a West-wide 10% increase in coyote numbers between 1972 and 1973, another 10% increase on comparable lines from 1973 to 1974, a 5% decrease from 1974 to 1975, and a 7% decrease from 1975 to 1976. Although there is no clear evidence that valid changes can be detected in areas smaller than entire states, the average coyote index of five comparable lines run in four of the 21 counties in the present study varied greatly. The average index of these five lines increased more than 18% between 1972 and 1973, increased another 20% between 1973 and 1974, decreased nearly 4% from 1974 to 1975, then decreased nearly 21% between 1975 and 1976; in 1976 it was within two points of the beginning (1972) index. The changing coyote population appeared to parallel the losses through 1975, but the 21% decrease in the coyote index between 1975 and 1976 did not reflect the greatly increased losses of 1,544 sheep and goats and 33 calves recorded for the first half of 1976.

Table 5. Inverse relation of precipitation and predator kills as indicated by half-year totals.

	Difference from normal precipitation (%)		% of total kill of sheep and goats by coyotes and bobcats	
Year	Jan.-June	July-Dec.	Jan.-June	July-Dec.
1971	–45	+63	70	30
1972	–24	+ 6	ND[1]	ND[1]
1973	– 4	+12	33	67
1974	–35	+95	61	39
1975	+ 9	– 2	31	69

[1]ND = no data.

Costs for Control

An estimate of total costs was derived from the 1975-76 data and used to obtain an estimate of the efficiency of the ADC program, sometimes expressed as the cost-benefit ratio. Sources of funds could not be determined at disbursement, but total income for livestock protection in all Texas in fiscal year 1976 ($1,699,255) was one-third federal and two-thirds state and cooperative funding (U.S. Fish and Wildlife Service 1976).

Direct costs for salaries and expenses of ADC field workers in the 21 counties were $201,689 in 1975, or an expenditure of 46 cents for each sheep or goat protected (Table 4). Nass (1977) reported that in Idaho similar predator control funding varied from 60 to 90 cents per adult sheep, plus some additional unknown rancher expenses. His estimates were for adult sheep, whereas those in the present study also include lambs in most instances. A combined total of 1,172 sheep and goats were killed by coyotes and bobcats in 1975 with an estimated average minimum value of $25 each, or a total loss value of about $29,300. These two cost figures—salaries and expenses plus losses—total nearly $231,000, but do not include some likely, but unknown, ranchers' control costs. Some proportional part of the District Supervisors' salaries should also be added, as well as part of the salaries and expenses of the State supervisor's office. Perhaps the 21-county share is $30,000, and the estimated total ADC program cost was about $260,000. This estimate raises the protection cost to 59 cents per sheep.

The benefits are difficult to assess because apparently only 5 years of data (none in Texas) from three studies of sheep herds with no predator control are available (Henne 1975; De Lorenzo and Howard 1976; Munoz 1977; McAdoo and Klebenow 1978) from which base figures can be obtained. These figures may not be completely applicable, but with no better information available, and to have some basis for comparison, we offer the following values: The average annual sheep and lamb loss to predators for 2 complete years of study with no predator control in New Mexico, 2 years in Montana, and 1 summer (113 days) in California was 10.7% (range, 3.8 to 20.8%). In the Montana study (Henne 1975; Munoz 1977), new ewes were added in January of each year which we did not include in figuring total flock numbers because limited predator control was also allowed from October 15–March 14 in the first study year, and more coyote controls were used in the second year. Although coyotes were not taken during the damage season, nine were killed in the first year, and 44 in the second year, so it is likely that the "no-control" designation was not valid for either year. The loss of "new ewes" to predators was low, and would undoubtedly be more than offset by the use of controls in this "no-control" study. Because the New Mexico study area covered only seven sections, neighboring predator control efforts probably biased results downward in that study. The short California study (less than one-third year) undoubtedly also helps to produce a very minimum 10.7% loss figure.

If one applies the 10.7% predator loss to the 438,649 sheep and goats in the ADC-protected areas of the 21 Texas counties, a loss of 46,760 sheep and goats worth about $1,169,000 would be expected if no controls were used. A comparison of this value with the estimate of about $260,000 in control costs plus the value of sheep taken by predators yields benefits equal to about 4.5 times the costs, or a cost-benefit ratio of 1:4.5.

Although no special studies were made to determine the effects of predator losses on the area's economy, Nielsen and Curle (1970), and Nesse et al. (1976) indicated that in studies in Utah and California, respectively, a chain reaction (multiplier effect) in the area economy could cause an area loss of two to four times the combined value of direct losses and control costs. Nielsen and Curle (1970) estimated a total loss to ranchers of $1,320,098, a loss of $3,538,846 to Utah's economy, and total control costs of $213,569. From these data, we estimated an approximate 1:6.2 cost-benefit ratio to the rancher. Thompson (1976) calculated a cost-benefit ratio of 1:3.9 for fiscal year 1975 in California, using an estimated total predatory animal damage loss of $4.7 million that included the value of lost livestock, costs of the control program, and associated projected losses to related industries of manufacturing, processing, and transportation.

The average value placed on sheep and goats lost in the present study ($25) is probably too low, but it provides a minimum loss figure that converts to a plausible cost-benefit ratio. Even so, the 21-county figure of 1:4.5 fell between the 1:3.9 for the California ADC program (Thompson 1976) and the 1:62. for the Utah study (Nielsen and Curle 1970). These three cost-benefit ratios are undoubtedly not as accurate as those that will be derived from an improved data-gathering system being implemented by ADC. However, inasmuch as the three separate studies in different parts of the West yielded somewhat similar figures, they probably are reasonably representative of the returns that can be expected for each dollar spent in the cooperative predator control program.

It is also possible that cost-benefit ratios may vary from one area to another as much as or more than they did in the three examples, due to several factors. Some differences might be attributable to the effects of differences in vegetative cover and topography on the ease of taking livestock by predators, or on the ease of killing predators. Differences by area are interrelated with differences in livestock management that result in large differences in exposure to predation (particularly of sheep and goats), e.g., shed lambing vs. range lambing, and close herding vs. loose herding vs. nonherding in fenced pastures, for example.

Before a more accurate appraisal of livestock-predator problems is possible, it will be necessary to determine reasons for variations in coyote populations from one place to another and from one year to the next, as well as what variations exist in the coyote's wild food supply in relation to livestock losses. From the research standpoint, other studies in coyote behavior and ecology as well as the development of more efficient and environmentally sound control techniques will also be required before a more satisfactory approach to predator management can be made. From a practical control operations standpoint, there is also a need to establish a more consistent and scientifically based federal predator control policy to replace uncertainties in the future of long-range predator management.

Literature Cited

Anderson, T.E., M. Caroline, and J.L. Beavers. 1974. An evaluation of aerial hunting as a means of protecting sheep and goats from coyote and bobcat predation in Uvalde and Kinney Counties, Texas. U.S. Dep. Int., Fish Wildl. Serv., Div. Wildl. Serv. Mimeo. 18 p.

Anonymous. 1975. Texas sheep and lambs on feed and early lamb crop. Texas Crop Livestock Rep. Serv., SRS-U.S. Dep. Agr., Austin. Release: March 18. 2 p.

DeLorenzo, D.G., and V.W. Howard, Jr. 1976. Evaluation of sheep losses on a range lambing operation without predator control in southeastern New Mexico. Final Rep. to U.S. Fish Wildl. Serv., Denver Res. Center, New Mexico State Univ., Las Cruces. 34 p.

Gee, C.K., and R.S. Magleby. 1976. Characteristics of sheep production in the western United States. U.S. Dep. Agr., Econ. Res. Serv., Econ. Rep. No. 345. 47 p.

Gee, C.K., R.S. Magleby, W.R. Bailey, R.L. Gum, and Louise M. Arthur. 1977. Sheep and lamb losses to predators and other causes in the Western United States. U.S. Dep. Agr., Econ. Res. Serv., Agr. Econ. Rep. 369. 41 p.

Gober, D.R. 1979. Factors affecting domestic sheep losses to predators in Trans-Pecos Texas. Ph.D. Diss. Texas A&M Univ., College Station. 119 p.

Guthery, F.S. 1977. Efficacy and ecological effects of predator control in south Texas. Ph.D. Diss. Texas A&M Univ., College Station. 50 p.

Gum, R.L., Louise M. Arthur, and R.S. Magleby. 1978. Coyote control: A simulation evaluation of alternative strategies. U.S. Dep. Agr., Econ., Statist., and Coop. Serv., Agr. Econ. Rep. No. 408. 49 p.

Henne, D.R. 1975. Domestic sheep mortality on a western Montana ranch. MS Thesis, Univ. Montana, Missoula. 53 p.

Kauffeld, J.D. 1977. Availability of natural prey and its relationship to coyote predation on domestic sheep. MS Thesis. Univ. Nevada, Reno. 144 p.

Knowlton, F.F. 1972. Preliminary interpretations of coyote population mechanics with some management implications. J. Wildl. Manage. 36:369-382.

Linhart, S.B., and F.F. Knowlton. 1975. Determining the relative abundance of coyotes by scent station lines. Wildl. Soc. Bull. 3:119-124.

McAdoo, J.K., and D.A. Klebenow. 1978. Predation on range sheep with no predator control. J. Range Manage. 31:111-114.

Munoz, J.R. 1977. Causes of sheep mortality at the Cook Ranch, Florence, Montana, 1975–76. MS Thesis, Univ. Montana, Missoula. 55 p.

Nass, R.D. 1977. Mortality associated with sheep operations in Idaho. J. Range Manage. 30:253-258.

Nesse, G.E., W.M. Longhurst, and W.E. Howard. 1976. Predation and the sheep industry in California, 1972–1974. Univ. California, Davis, Div. Agr. Sci. Bull. 1878. 63 p.

Nielson, D., and D. Curle. 1970. Predator costs to Utah's range sheep industry. Nat. Wool Grower 60:14-16, 22.

Pearson, E.W. 1975. Sheep-raising in the 17 western states: populations, distribution, and trends. J. Range Manage. 28:27-31.

Roughton, R.D. (Coordinator). 1976. Indices of predator abundance in the western United States, 1976. Prog. Rep. U.S. Dep. Inter., Fish Wildl. Serv., Denver Wildl. Res. Center, Colo. 123 p.

Shelton, M. 1972. Predator losses in one flock of sheep and goats. Nat. Wool Grower 62:20-22.

Stevens, D.W. 1971. An economic analysis of Wyoming's sheep industry (1960, 1964, 1968). Univ. Wyoming, Laramie. Agr. Exp. Sta. Bull. 564. June. 64 p.

Stevens, D.W., and D.R. Hartley. 1976. Decline in Wyoming's sheep industry—a partial explanation. Univ. Wyoming, Laramie. Agr. Exp. Sta. Res. J. 104. 42 p.

Teer, J.G., J.W. Thomas, and E.A. Walker. 1965. Ecology and management of white-tailed deer in the Llano Basin of Texas. Wildl. Monogr. 15:7.

Texas Livestock Statistics. Reports for 1971, 1974, and 1975. Texas Crop and Livestock Rep. Serv., P.O. Box 70, Austin. 78767.

Thompson, R.A. 1976. The cost of predator damage control using trapping as the primary technique. Proc. 7th Vertebrate Pest Conf., Monterey, Calif. p. 146-153.

Tigner, J.R., and G.E. Larson. 1977. Sheep losses on selected ranches in southern Wyoming. J. Range Manage. 30:244-252.

Turkowski, F.J., and J.R. Vahle. 1977. Desert rodent abundance in southern Arizona in relation to rainfall. U.S. Dep. Agr., Rocky Mountain Forest and Range Exp. Sta., Forest Serv. Res. Note RM-346. 4 p.

U.S. Fish and Wildlife Service. 1976. Annual report, Texas rodent and predatory animal control service. Fiscal year 1976. Mimeo. 57 p.

U.S. Weather Bureau. 1971-76. Climatological data: Texas. Vols. 76-81.

Soil Ecology of a Lichen Heath at Spitsbergen, Svalbard: Effects of Artificial Removal of the Lichen Plant Cover.

ERLING SENDSTAD

Abstract

The Norwegian MAB project conducted research on the possible effects of overgrazing in winter pastures of the Spitsbergen reindeer *(R. tarandus playtyrhyncus, Vrolik)*. In a 25-m² area of a lichen heath at Svalbard, (79° N, 12° E), the lichen plant cover was artificially removed. This was done to simulate the effects of heavy grazing, resulting in the disapperance of the lichens. The experiment resulted in a significant decrease in total soil respiration. A corresponding effect was found on the population development of the *Collembola* species *Hypogastrura tullbergi* (Schaffer). This species may, therefore, be a good indicator as to the long-term effects on soil microflora. It is also shown that the population development of the different *Collembola* species is not regulated through *Aranea* predation. The removal of the lichen plant cover did effect a decrease in the soil content of organic matter and macronutrients.

The lichen heaths of Spitsbergen (Brattbakk and Rønning 1978) represent important pastures for the Spitsbergen reindeer. Ruminant grazing has, however, in many areas of marginal rangeland, resulted in overgrazing, and consequently in increased run-off and ultimately in soil erosion and loss of nutrients (Lusby 1970, Rauzi and Hanson 1966). In areas where the potential of plant production exceeds the rate of decomposition, plant production will be regulated through the availability of essential nutrients. In such systems, it is the activity of the decomposers that regulates the whole system's productivity (Macfayden 1962 a).

In relation to these statements, it has been shown that reindeer, through their total grazing effect, i.e. ingestion and trampling, dislodged 68% of the lichens present during one summer season (Peagu 1970). In this case after one summer of grazing, 15% of the lichens were considered unusable because of trampling by reindeer (Pegau 1970). Trampling may further result in increased bulk density and consquently in decreased porosity of the soil (Smeins 1975). This may result in a reduced ability of water to penetrate into the soil. Consequently the surface run-off is increased (Rauzi et al. 1968).

These changes in the properties of vegetation and soil are also reflected in the decomposer activity in the soil. It has been shown that heavy grazing may cause a decline in soil respiration (Howard and Howard 1976) and also a reduced abundance of microbial grazers such as the *Collembola* (Willard 1973). It has also been recorded that changes in rates of decomposition affect the litter layer (Welch and Raws 1964).

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These general statements may be of considerable concern to the management of the reindeer population on an arctic island such as Spitsbergen. This population relies during the winter on pastures that are extremely vulnerable, both as a consequence of the lichen plant cover and the concentrated run-off of melt water in the spring.

A subproject of the Norwegian "Man and the Biosphere" (MAB) programme has, therefore, been concerned with the immediate effects on soil ecology caused by an artificial removal of the lichen heath.

Methods

The lichen heath tested is located close to Ny Alesund in Spitsbergen (79° N, 12° E). The lichen cover is dominated by *Cetraria delisei;* this range type is described by Brattbakk and Rønning (1978) from the point of view of plant sociology.

On this site an area 25 m² was cleared of lichens. The effects on total soil respiration were registrated by an infra red gas analyser. The respiration studies were conducted at +5° C and 32% water content of the soil samples, in a static experimental procedure. The respiration rates are calculated as mg CO_2/m²hr and concern the total respiration of soil samples with a diameter of 5.5 cm and 3 cm deep.

From corresponding samples, soil arthropods were extracted in a high gradient extractor (MacFayden 1962 b). Data are here given as mean estimates based on twelve replicas in each sample.

The experiment started in the summer 1976 and has been recorded up until the end of the summer 1979.

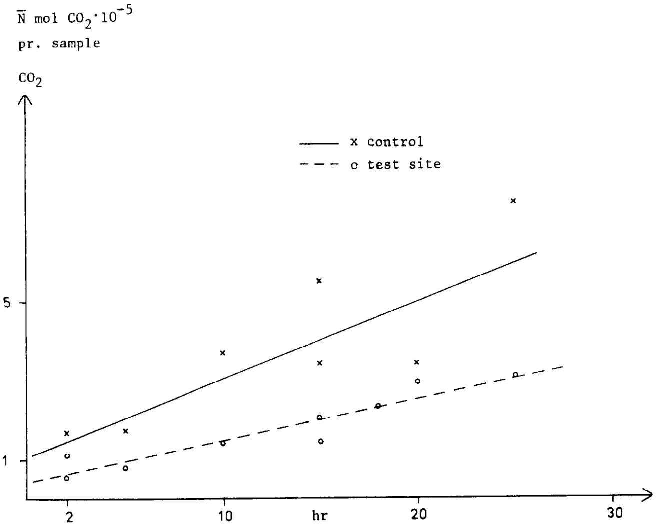

Fig. 1. *Rates of respiration in the natural lichen heath and in a test site where the lichens were removed in 1976. Respiration data is from the summer, 1978. Respiration temperature +5° C.*

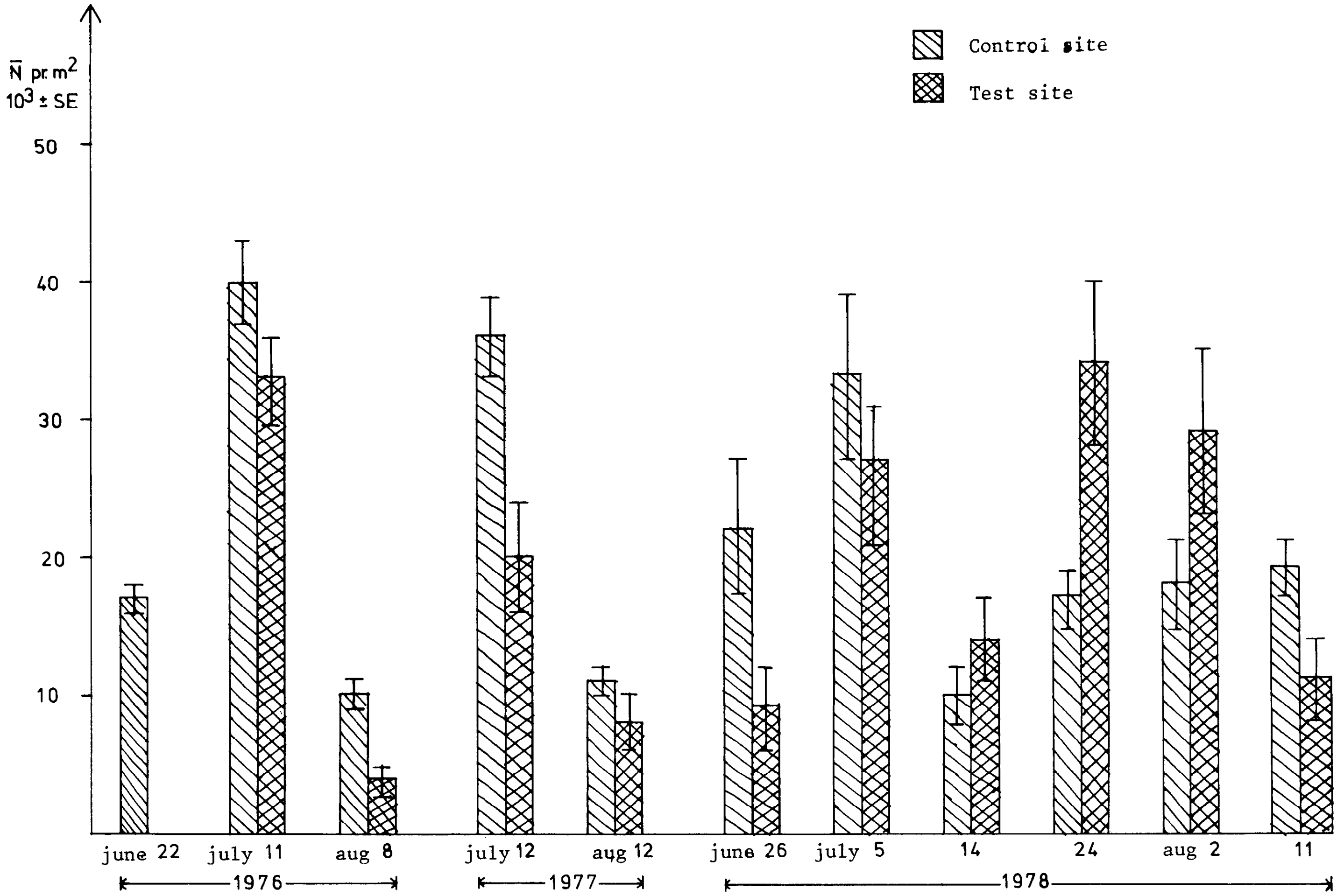

Fig. 2. *Number of* Collembola *(±SE) in the control and the test site. Test site; the lichen cover removed.*

Results

Soil respiration in a natural (control) site of the lichen heath, during summer 1978, is estimated to have been between 40–96 mg $CO_2/m^2/hr$ at 5° C and 32% H_2O. This estimate gives the limits of the 95% confidence interval. This estimate is comparable to data given by Billings et al. (1977). There, total soil respiration in more humid soils in Alaska was estimated to produce 75–300 mg $CO/^2/m^2/hr$ over the summer season.

The effect on soil respiration of removing the lichens is shown in Figure 1.

Figure 1 shows a significant decrease in total soil respiration (significant at the 10% level). The mean estimate declined from 68 mg $Co/_2/m^2/hr$ in the control area to 35 mg $Co_2/m^2/hr$ in the treatment area.

As an indication of the effects on the soil zoological community, the results from the study of *Collembola* are shown in Figure 2. It can be seen that initially there was a decrease in *Collembola* abundance. From the end of the 1977 summer, an increased *Collembola* abundance was found, however.

When the data in Figure 2 are divided into individual species, it is demonstrated (Fig. 3) that the removal of the lichens has produced different effects for each of the two dominating *Collembola* species at the site: *Folsomia quadrioculata* (Tullberg) and *Hypogastrura tullbergi* (Schäffer). These two species account for about 95% of total *Collembola* abundance at the site.

The total effect of removing the lichen plant cover on soil erosion are shown in Table 1. A decrease in the content of organic matter and macronutrients after 4 years is demonstrated.

Discussion

These results clearly demonstrate that a severe grazing intensity that totally alters the plant cover may also severely affect the ecology of the soil. It is shown that the removal of the lichens resulted in a 50% decrease in soil respiration. This, I am inclined to conclude, will affect the rates of release of essential nutrients for further plant production.

The effects of the experiment on the two *Collembola* species (Fig. 3) might also have a reasonable explanation. The decreasing species, *H. tullbergi,* is known to be a fungi grazing animal (Addison 1977). While the representatives of the genus *Folsomia* are reported to be primary decomposers (Whittaker 1974).

The results therefore indicate that the soil biota live together in complex relationships. It may be concluded that, while *F. quadrioculata* in many ways may be unaffected or even negatively affected by an actively growing soil microflora, the other species *H. tullbergi* may turn out to be a relatively good indicator of the long-term activity of the soil microflora in these areas. These kinds of indicators in connection with soil ecology might be useful because the measurement of long term microbial activity is difficult and extremely time consuming.

Table 1. Chemical content of soil. Data after 4 years of exposure. Data are mean estimates, each based on a mixed sample from five replicas.

Parameters Test site	Dry matter (%)	Loss of ignition (%)	N (Kjeldal) (%)	P (%)
Control	64.9	16.3	0.72	0.063
Lichen cover removed	66.8	12.8	0.32	0.056

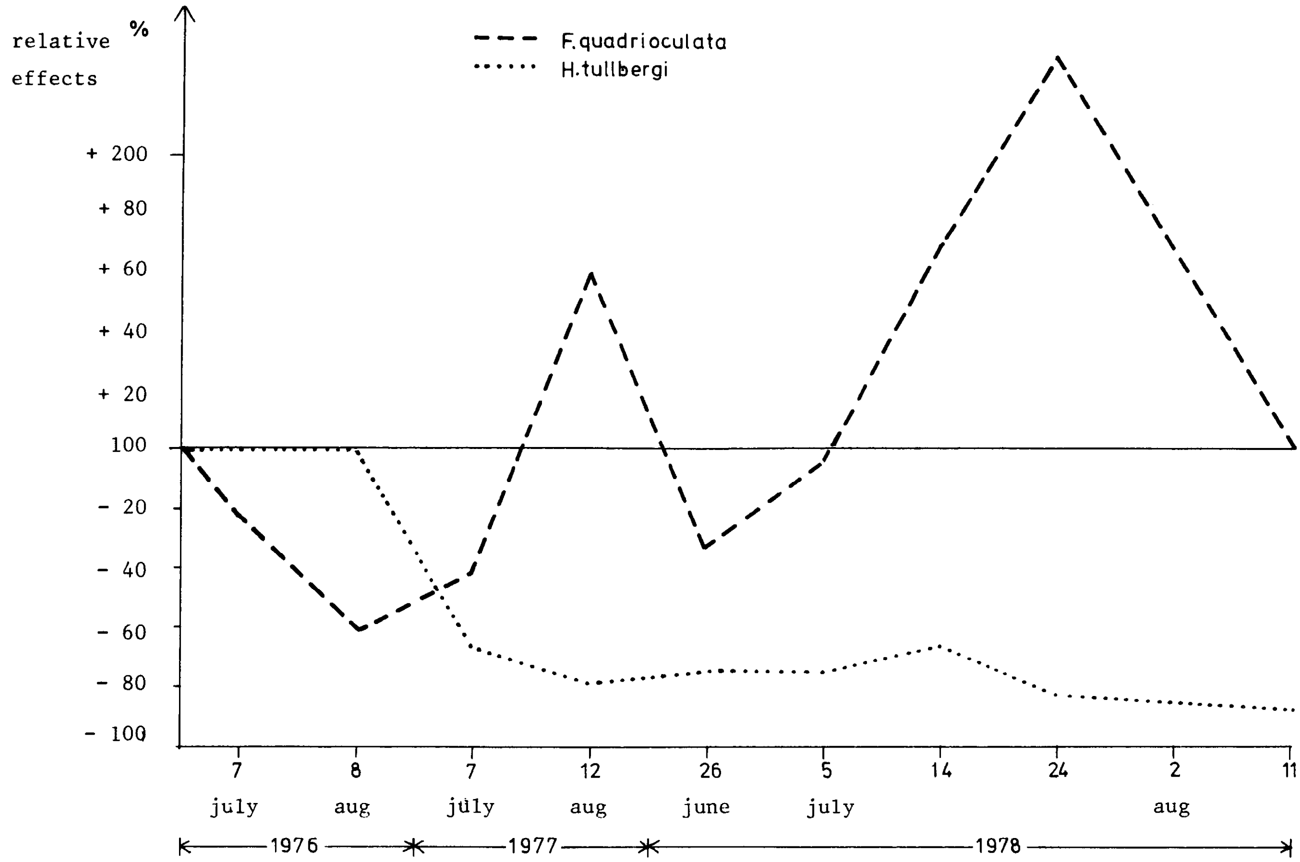

Fig. 3. *Relative effects of an artificial removal of the plant cover for two dominating* Collembola *species of the lichen heath.*

The use of biological indicators is, however, a complex matter. It may be argued that the results merely are a consequence of different responses to predation, or changes in the abiotic environment.

As to the effect of predation on soil animals, a theoretical predation pressure by *Aranea* has been calculated for the test site (Hegstad 1978). Here, it is shown that *Aranea* is only able to utilize 1% of the standing crop of *Collembola.* It therefore seems reasonable to conclude that the population development of the *Collembola* is not influenced by *Aranea* predation.

As to the question whether the variation in *Colembola* abundance in this experiment is a direct result of alterations in the abiotic environment, some data pertinent to the problem are shown in Table 2.

As can be seen, the water content does not vary significantly. There is however a slight decrease in the soil water content at the test site. Further, there are some differences in the mean temperature for the summer season. The temperatures have increased on the ground level where the lichens were removed, that is, on the test site. On the other hand, temperatures deeper in the soil profile have decreased. These results probably reflect the variations in the total heat flux on the black soil surface on the test site, in contrast to the insulated surface on the control site. It is unlikely that these relatively small changes in the abiotic environment directly should affect the population development of the *Collembola* species. If, however, the slight decrease in the water content nevertheless affects the *Collembola* abundance, the two dominating species should respond in the same way. Correspondingly, if the variations in soil temperature directly affect the population development of the different *Collembola* species, the variations should be most beneficial for the more typical surface dweller, *H. tullbergi.* Since the two dominating *Collembola* species respond to the changes in the abiotic environment in the opposite way, I am apt to conclude that the explanation may be found in their biotic environment.

Table 2. Mean temperatures and water content of the soil in the lichen heath, summer season 1978.

Climatic factors	Control site	Test site
Water content %±S.E.	35.5±2.3	32.9±3.2
Mean temperature at ground level (°C)	6.8	8.0
Mean temperature at -2 cm level in the soil (°C)	9.3	8.4

In this context it is of interest to understand the functional relationship within the soil detritus food chain. Based on biomass estimates (Sendstad 1977, 1978), it is possible to calculate the energy the *Collembola* need to consume, in order to maintain their biomass (Reichle 1969). The food consumption of the *Collembola* community is calculated according to the formula:

$$y = a \bullet x^b$$

where:

y = cal. consumed/specimen/day.
x = cal. content/specimen
a = 0.071
b = 0.725 (Reichele 1969).

The results corrected for a temperature range between +5 and +15° C, Q_{10} = 1.60 (Harding and Stuttard 1974) are shown in Table 3.

These estimates of microbial grazing may be compared to data for the microbial biomass at the site. Based on the assumption that 1 Kcal is needed to produce 0.12×10^{-3} kg microbial mass (Odum 1971), it is possible to calculate the microbial production of the site during the active growing season. Soil respiration of the lichen heath is estimated or to be approximately 432 Kcal/m²/year

Table 3. Food consumption in the *Collembola* community of an unaffected lichen heath at the Brögger peninsula, Spitsbergen. Data given for +5 and +150° C.

Species	Food consumed
F. Quadrioculata	12.0 - 19.1 Kcal $M^{-2}year^{-1}$
H. tullbergi	0.7 - 1.1 Kcal $m^{-2}year^{-1}$
Other *Collembola*	1.2 - 2.0 Kcal $m^{-2}year^{-1}$
Σ*Collembola*	13.3 - 22.2 Kcal $M^{-2}year^{-1}$

(Sendstad 1978). If a root respiration of approximately 50% is assumed, then 216 Kcal/m^2/yr is liberated by the heterotrophic food chain each year. This implies that approximately 26 g microbial mass have been produced on this site. In energy terms this means approximately 130 Kcal. Compared to the data given in Table 3, it can thus be seen that the *Collembola* ingests between 11% and 17% of the microflora production.

The *Collembola* community is estimated to represent about 70% of the total detritovores/fungivores invertebrate biomass of the unaffected lichen heath (Sendstad 1978). If the data for *Collembola* consumption are extrapolated to the whole fungivores/detritovores biota, the total ingestion of these invertebrates may be estimated to be between 16% and 24% of the microbial production. It is still an open question whether this grazing intensity has any regulating effect on the activity of the soil microflora. These results do, however, show that the heterothropic foodchain in the soil, in a complicated way, may be affected by artificial changes in the plant cover.

It is finally demonstrated that a removal of the plant cover does promote an overall, loss of organic matter and macronutrients from the pastures (Table 1). Whatever the reasons for these effects, these losses will eventually decrease the potential for plant production. A comprehension of the total effects caused by a destruction of the lichen plant cover must consequently be based on a long-term understanding of soil erosion, combined with an understanding of soil ecology at the site.

The long-term goal of this kind of research will be to see at what level of ruminant grazing intensity, an abnormal rate in the release of nutrients may be experienced, and at what corresponding state we then find the soil heterotrophic food chain. The state of art of soil ecology does not permit us to make any firm statement about the effects of reindeer overgrazing in the arctic tundra. The present data do indicate, however, that we have to be aware of the possibility of a whole spectrum of interactions between the reindeer and its environment.

Literature Cited

Addsion, J.A. 1977. Population dynamics and biology of *Collembola* on Truelove Lowland. *In:* L.C. Bliss (ed.) Truelove Loweland Devon Island, Canada: A High Arctic Ecosystem. The University of Alberta Press. 714 p.

Billing, W.D., G.R. Peterson, G.R. Shaver, and A.W. Trent. 1977. Root growth, respiration, and carbon dioxide evolution in an arctic tundra soil Arctic and Alpine Res. 2:129-137.

Brattbakk, I. and O.I. Rϕnning. 1978. Rikt planteliv langt mot nord. Forskningsnytt 8:44-51. (in Norwegian).

Harding, D.J.L., and R.A. Stuttard. 1974. Microarthropods. *In:* C.H. Dickenson and G.J.F. Pugh (eds.) Biology of Plant Litter Decomposition. Part 2. Academic Press. 489-532.

Hegstad, A. 1978. Edderkopper pa Svalbard, Hovedfagsoppgave i spesiell Zoologi. Univ. i. Trondheim. Unpublished theses, in Norwegian. 115 p.

Howard, P.J.A., and D.M. Howard. 1976. Respiration, litter nutrients, and soil organic matter in grazed and ungrazed upland limestone grassland. Merlewood Res. and Dev. Pap. No. 67. 12 p.

Lusby, G.C. 1970. Hydrological and biotic effects of grazing vs. nongrazing near Grand Junction, Colorado. J. Range Manage. 12:83-87.

MacFayden, A. 1962a. Energy flow in ecosystems and its exploitation by grazing. *In:* D.J. Crisp (ed.) Grazing in Terresetrial and Marine Environments. The British Ecological Society, Blackwell. 322 p.

MacFayden, A. 1962 b. Improved funnel-type extractors for soil arthropods. J. Ecol. 30:171-184.

Odum, E.P. 1971. Fundamentals of Ecology. 3rd edition, Philadelphia. London. Toronto. 574 p.

Pegau, R.E. 1970. Effect of reindeer trampling and grazing on lichens. J. Range Manage. 23:95-97.

Rauzi, R., and C.L. Hanson. 1966. Water intake and runoff as affected by intensity of grazing. J. Range Manage. 19:351-356.

Rauzi, F., C.L. FLy, E.J. Dyksterhuis. 1968. Water intake on midcontinental rangeland as influenced by soil and plant cover. U.S. Dep. Agr. Tech. Bull 1390. 58 p.

Reichele, D.E. 1969. Energy and nutrient metabolism of soil and litter invertebrates. *In:* P. Duvigneaud (ed.) Productivity of Forest Ecosystems. Ecology and Conservation. Proc. Bryssel Symp. 1969. Paris: Unesco 1971. 465-477.

Sendstad, E. 1977. Notes on the *Collembola* communities in some major plant-sociological associations at Spitsbergen, Svalbard. Norw. J. Ent. 23:143-148.

Sendstad, E. 1978. Økologiske studier pä Svalbard II. Freinbeiter, erosjon, jorbunnsϕkologiske prosesser. SINTEF rapport Nr. STF21 A78162. (in Norwegian) 47 p.

Smeins, F.E. 1975. Effects of livestock grazing on runoff and erosion. Watershed Management Symp., Logan, Utah. 267-274.

Welch, D., and M. Raw 1964. The early effects of excluding sheep from high level grasslands in the north pennines. J. of Anim. Ecol. 1:281-300.

Whittaker, J.B. 1974. Interactions between fauna and microflora at tundra sites. *In:* A.J. Holding & al. (ed.) Soil Organisms and Decomposition in Tundra, ed. A.J. Holding et al., Stockholm. 183:196.

Willard, J.R. 1973. Soil invertebrates and minor insects III *Collembola.* Population and Biomass. Matador Proj. Tech. Rep. No. 19.

Widden, P. 1977. Microbiology and decomposition on Truelove Lowland. *In:* L.C. Bliss (ed.) Truelove Lowland, Devon Island, Canada A High Arctic Ecosystem. The Univ. of Alberta Press. 714 p.

Authors Omitted

Authors' names were inadvertently omitted for the article entitled "Seasonal Vegetative Establishment and Shoot Reserves of Eastern Gamagrass" in the July 1981 issue. They are *C.L. Dewald* and *Phillip L. Sims*. Our apologies.

Insects Associated with Broom Snakeweed [*Xanthocephalum sarothrae*] and Threadleaf Snakeweed [*Xanthocephalum microcephala*] in West Texas and Eastern New Mexico

D.E. FOSTER, D.N. UECKERT, AND C.J. DELOACH

Abstract

Immature and adult insects representing 8 orders, 86 families, and 338 species were collected from broom snakeweed *(Xanthocephalum sarothrae)* or threadleaf snakeweed *(X. microcephala)* in the western half of Texas and eastern New Mexico during 1976 and 1977. Most of the 46 sampling locations were visited three times each year. Insects were collected by hand, sweep net, or D-Vac. The aboveground vegetation of 30 plants and the root systems of 10 plants were sampled at each location during most visits. Immature forms were determined by rearing or association. Several native insect species inflict damage to broom snakeweed and threadleaf snakeweed, including a leaf-tying moth, *(Synnoma lynosyrana)*, a weevil *(Myrmex* sp. nr. *lineata)*, roundheaded borers *(Crossidius discoideus* and *Crossidius pulchellus)*, a flatheaded borer *(Agrilus gibbicollis)*, and two species of mealybugs *(Phenacoccus helianthi* and *Eriococcus cryptus)*.

Broom snakeweed [*Xanthocephalum sarothrae* (Pursh) Britt. & Rusby], also known as perennial broomweed, turpentine weed, or slinkweed, occurs over much of western North America from Saskatchewan to northern Mexico, whereas threadleaf snakeweed [*Xanthocephalum microcephala* (DC.) A. Gray] is found in western Colorado, southern Utah, Nevada, California, western Texas, and north-central Mexico (Solbrig 1960). These species infest extensive areas of rangeland in the western half of Texas and eastern New Mexico. Both species are relatively short-lived, perennial half-shrubs. Although populations of both species are cyclic and often increase on rangeland in response to overgrazing or drought (Ragsdale 1969; Stoddart et al. 1975), their abundance is not a definite indicator of overgrazing (Vallentine 1971). Both broom snakeweed and threadleaf snakeweed are toxic to cattle, sheep, goats, and other animals (Sperry et al. 1964). Abortion or the delivery of dead or small, weak calves is the most common manifestation of snakeweed poisoning in cattle. It may affect up to 60% of the pregnant cows pastured on sandy soils infested by these weeds (Dollahite and Anthony 1956; Sperry et al. 1964). Economic loss resulting from the toxic properties of broom snakeweed is compounded by apparent severe competition with desirable forage plants. Ueckert (1979) reported that forage production increased by 324% (2,201 kg/ha) during the second growing season after removal of broom snakeweed.

Several approaches to control of snakeweed have been explored with mixed results. Burning during June has successfully controlled broom snakeweed in New Mexico (Dwyer 1967). Chemical control has been erratic (Sosebee et al. 1979). One largely unexplored strategy of control is the use of insects, both native and exotic, either alone or in conjunction with other control techniques. Andres (1971) suggested that the conservation and augmentation of endemic phytophagous insects are feasible and advantageous in many cases.

Species of *Xanthocephalum* native to South America (Solbrig 1966) harbor a number of insect species potentially useful for biological control of this genus in other countries[1]. Before the search for exotic insects is far advanced, a thorough understanding of the native arthropod fauna of broom snakeweed and threadleaf snakeweed is essential. No extensive survey of insects associated with broom snakeweed or threadleaf snakeweed has been previously attempted. Lavigne (1976) reported on several insects associated with broom snakeweed in northern Colorado. A few contributions dealing with specific insects have also been reported (Falkenhagen 1978; Penrose 1973; Powell 1976). This study was initiated to gather base line data on the distribution, seasonal occurrence, and relative abundance of insects associated with broom snakeweed and threadleaf snakeweed in west Texas and eastern New Mexico and to identify native species that exercise some degree of natural control and warrant more extensive study.

Methods and Materials

During 1976 and 1977 the insect faunas associated with broom snakeweed and threadleaf snakeweed were studied at 46 sites in the Rolling Plains, High Plains, Edwards Plateau, and Trans-Pecos vegetative zones of Texas as defined by Gould (1975), and in adjacent areas of eastern New Mexico (Table 1). Most localities were visited three times each year to collect insects along with data on their abundance and activity. Collections were made during the spring, summer, and fall at a time when the host-plants were in their early vegetative, mature vegetative, or flowering stages, respectively.

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Table 1. Insects collected from broom snakeweed and threadleaf snakeweed in western Texas and eastern New Mexico.

Species collected	Collection site[a]	Relative frequency[b]	Stage collected[c]	Collection method[d]	Growth stage of host[e]	Species of host[f]
Coleoptera						
Alleculidae						
Hymenorus densus LeC.	4	R	A	D	B	M
Anobiidae						
Tricorynus gibbulum (Fall)	24	O	A	D	EV	S
Xyletinus sp. nr. *lugubris* LeC.	6	R	A	D	B	S
Anthicidae						
Anthicus nr. *scabriceps* LeC.	36	R	A	D	EV	S
Ischyropalpus sp.	39	R	A	D	EV	S
Notoxus spp.	18,24,26,27,31	O	A	D,S	MV,B	S
Anthribidae						
Trigonorhinus limbatus (Say)	8,45	C	A	D	B	S
T. spp.	2,11,15,31,40,42	C	A	D,S	EV,MV,B	S
Bruchidae						
Acanthoscelides aequalis (Sharp)	8	R	A	D	B	M
A. compressicornis (Schaef.)	38,44	R	A	D	EV	S
A. obrienorum Johnson	2	R	A	D	B	S
A. schrankiae (Horn)	10,27,36,42	O	A	D,H	EV,B	S
Algarobius prosopis (LeC.)	11,14,18,19,26	C	A	S,D	MV,B	M,S
Merobruchus julianus (Horn)	10	R	A	H	B	M
Mimosestes amicus (Horn)	2,6,10,14,15,16, 18,19,20,23,26	C	A	D,S	MV,B	M,S
M. protractus (Horn)	15,29,36	O	A	D,S	MV,B	M,S
Sennius morosus (Sharp)	10,15,26	O	A	D,S	MV,B	M,S
Stator limbatus (Horn)	1,20	R	A	D	B	M,S
S. pruininus (Horn)	1,12,20	R	A	D	B	M,S
Zabrotes spectabilis Horn	39	O	A	D	EV	S
Buprestidae						
Acmaeodera scalaris Mann.	1,2,18,26	O	A	D	B	S
Agrilus gibbicollis Fall	1,11,12,31,36, 41,43,45	C	L,P,A	D,R,S	EV,MV,B	S
A. sp.	4	R	A	D	B	M
Cantharidae						
Chauliognathus discus LeC.	7	O	A	D	B	S
C. marginatus Fab.	1	R	A	D	B	S
C. scutellaris LeC.	10,20,40	C	A	D,H	EV,B	M,S
Trypherus sp.	6	R	A	D	B	S
Carabidae						
Philophuga viridis Dej.	2	R	A	D	B	S
Cerambycidae						
Crossidius discoideus (Say)	10	O	L,P,A	D,H	MV,B	S
C. pulchellus LeC.	1,8,12,20,26	C	L,P,A	D,S,H,R	EV,MV,B	S
Placosternus difficilis (Chev.)	3	R	A	S	B	M
Chrysomelidae						
Altica foliacea LeC.	26,40	R	A	D,S	EV,B	S
Babia tetraspilota LeC.	38,42	R	A	D,S	EV,B	S
Chaetocnema pulicaria Melsh.	15,31,36	O	A	D,S	MV,B	S
Chlamisus sp. nr. *foveolatus* (Knoch)	15,26,28,29,38 40,41	C	L,A	D,S,H	EV,MV,B	S
Colaspoides sp.	27	R	A	D	B	S
Coscinoptera mucorea (LeC.)	44	R	A	D	EV	S
Cryptocephalus amatus Hald.	11	R	A	D	EV	S
C. brunneovittatus Schaef.	12	R	A	D	EV	S
C. cerinus cerinus White	22	O	A	D	EV	S
C. confluens Say	4	R	A	D	B	M
C. spp. *spurcus-cerinus* complex	6,22,27,29	C	L,A	D,S,H	EV,MV,B	S
Diabrotica longicornis longicornis (Say)	10	R	A	D	B	S
D. tricincta (Say)	10,11,20	O	A	D,S	MV,B	S
D. undecimpunctata howardi Barber	2,10,20	C	A	D,H	B	M,S
Diachus auratus (Fab.)	1,2,45	C	A	D	B	S
Distigmoptera apicalis Blake	39	C	A	D	EV	S
Epitrix sp. nr. *hirtipennis* (Melsh.)	14	R	A	S	MV	M
Euryscopa pilatei Lac.	15	R	A	S	MV	M
Exema mormana Karren	8	R	A	D	B	M
Gastrophysa dissimilis (Say)	36	R	A	D	B	S
Glyptina cerina (LeC.)	26	O	A	D	B	S
G. spuria LeC.	8,12,17	C	A	D	B	M
Monoxia apicalis Blake	5	O	A	D	EV	S
M. puberula Blake	3,17,19,20,46	C	L,A	D,H	EV,MV,B	S
Pachybrachys nero Bowditch	1,4,5,6,11,14,15 20,21,29,31,36 41,43,44	C	A	D,S	EV,MV,B	M,S

Table 1. Continued.

Species collected	Collection site[a]	Relative frequency[b]	Stage collected[c]	Collection method[d]	Growth stage of host[e]	Species of host[f]
P. vau Fall	11,21,23,28,29, 42	C	A	D,S	EV,MV,B	M,S
P. sp.	12,33	R	A	D	B	S
Phyllotreta sp.	12	R	A	D	B	S
Saxinis knausi Schaef.	11	R	A	D	EV	S
S. sp.	43	R	A	D	EV	S
Systena blanda (Melsh.)	11,21,22,24,31 36,39	C	A	D,S	EV,MV	S
Zygogramma disrupta Rogers	41	R	A	D	EV	S
Cleridae						
Enoclerus laetus (Klug)	28	C	L,P,A	D,H,S,R	EV,MV,B	S
E. coccineus (Schenk.)	23,24,29	C	L,P,A	H,S,R	EV,MV,B	S
Phyllobaenus discoideus (LeC.)	10	R	A	D	EV	S
Coccinellidae						
Anovia virginalis (Wickham)	16	R	A	D	B	S
Diomus debilis (LeC.)	24	R	A	D	EV	S
Hippodamia convergens Guerin	10,12,14,25,38, 45	C	L,A	D	EV,MV,B	S
Hyperaspidius comparatus Casey	28	O	A	D	EV	S
H. insignis Casey	14	R	A	D	MV	M
Hyperaspis fimbriolata (Melsh.)	18,35	R	A	D	EV	S
H. lateralis Mulsant	18,43	R	A	S	MV	S
Olla abdominalis (Say)	5	O	L,A	D	EV	S
Psyllobora renifer (Casey)	24,44	O	L,A	D	EV	S
Nephus (Scymnobius)intrusus Horn	41,43	R	A	D	EV	S
Sycmnus ardelio Horn	18,21,28	C	A	D,S	EV,MV	M,S
S. creperus Muls.	40	R	A	D	EV	S
S. horni Gorham	11,20,23,40	C	A	D,S,H	EV,MV,B	S
S. loewii Muls.	21,26,36,40	C	A	D,S	EV,MV,B	S
S. pallens LeC.	42	R	A	S	MV	S
Zagloba hystrix Casey	15,43,45	R	A	D,S	EV,MV	M,S
Curculionidae						
Anthonomus decipiens LeC.	8,14,18,38,40, 42,44	C	A	D,S	EV,MV,B	M,S
A. sp. nr. *decipiens* LeC.	10,14,19	O	A	D,S	B	M
A. tenuis Fall	12,46	C	A	D	EV,MV,B	S
Apion amaurum Kissinger	3,28,40,44	C	A	D,S	EV,MV	S
A. impunctistriatum Smith	1,8	R	A	D	B	M,S
A. sp.	1,2,5,6,8	C	A	D	EV,B	M,S
Centrinaspis sp.	2,6	C	A	D	B	S
Cylindrocopturus sp.	1	R	A	D	B	S
Dorytomus brevicollis LeC.	11	R	A	S	MV	S
Epimechus curvipes Dietz	12,39,43,45	C	A	D	B	S
E. sp.	21,22,23,26,28 29,31,33,35,36	C	A	D,S	EV,MV,B	S
E. sp.	5,38,44	R	A	D	EV	S
Minyomerus laticeps (Casey)	45	R	A	D	EV	S
M. sp.	5,15,17,22,28 31,33,35,39	C	A	D,S	EV,MV,B	M,S
M. sp.	21,26	O	A	D,S	EV,MV	S
Mitostylus setosus (Sharp)	5,6,11,20,27,44	C	A	D,S,	EV,MV,B	S
M. tenuis Horn	1,38,41	C	A	D	EV	S
Myrmex lineata (Pascoe)	10,21	R	A	D	B	S
M. sp. nr.*lineata* (Pascoe)	3,4	C	L,P,A	D,S,R	B	M
M. sp.	23	R	A	S	MV	S
Ophryastes latirostris LeC.	39	R	A	D	EV	S
O. sp.	20,31	R	A	D	EV,B	S
Pantomorus elegans (Horn)	31	R	A	D	EV	S
P. obscurus (Horn)	44	R	A	D	EV	S
Peritaxia sp.	24	R	A	D	EV	S
Sibinia sp.	42	R	A	S	B	S
Smicronyx lutulentus Dietz	5,6	O	A	D,S	EV,MV,B	S
S. sordidus LeC.	1,15,26	O	A	D	MV	S
S. spretus Dietz	10,14,16,18 19,20	C	A	D	B	M,S
S. tesselatus Dietz	38	R	A	D	EV	S
S. sp. nr. *pleuralus* Casey	43	R	A	D	EV	S
S. spp.	15,31,36,41,44	O	A	D,S	EV,MV,B	M,S
Tychius sp.	39	R	A	D	EV	S
Dermestidae						
Cryptorhopalum balteatum LeC.	2	R	A	D	B	S

Table 1. Continued

Species collected	Collection site[a]	Relative frequency[b]	Stage collected[c]	Collection method[d]	Growth stage of host[e]	Species of host[f]
Elateridae						
Conoderus vespertinus (Fab.)	26	R	A	D	EV	S
Megapenthes sp.	43	R	A	S	MV	S
Lathridiidae						
Melanophthalmus sp.	36,42	O	A	D,S	EV,B	S
Meloidae						
Epicauta ferruginea (Say)	6	C	A	D	B	S
E. spp.	2,26,28	C	A	D,S	MV,B	M,S
Zonitis atripennis (Say)	2	R	A	D	B	S
Melyridae						
Amphivectura sp.	24	R	A	D	EV	S
Attalus lecontei Champ.	45	R	A	D	EV	S
Collops balteatus LeC.	1	R	A	S	B	S
C. confluens LeC.	36	R	A	S	MV	S
C. limbellus G. & H.	28	R	A	D	B	S
C. punctatus LeC.	36	R	A	S	MV	S
C. quadrimaculatus (Fab.)	18,36,40	O	A	D,S,	MV,B	S
C. vittatus (Say)	36,38,40	O	A	D,S	MV,B	S
Hypebaeus spp.	6,15,24	O	A	D,S	EV,MV,B	M,S
Trichochrous spp.	4,10,12,14,20	C	A	D	B	M,S
Mordellidae						
Diclidia sp.	24	R	A	D	EV	S
Mordella melaena Germar	40	O	A	D	B	S
Mordellistena spp.	15,24,31,36, 38,42	O	A	D	EV	M,S
Pedilidae						
Eurygenius sp.	45	R	A	D	MV	S
Phalacridae						
Olibrus sp.	42	R	A	D	EV	S
Phalacrus spp.	23,41,42,45	O	A	D	EV,B	S
Scarabaeidae						
Cotinis mutabilis (G. & P.)	2	R	A	D,S	B	S
Diplotaxis subangulata LeC.	17,35	O	A	D	B	M,S
Scolytidae						
Dendrocranulus sp.	41	R	A	S	MV	S
Tenebrionidae						
Bothrotes canaliculatus acutus LeC.	1	R	A	S	B	S
B. plumbeus plumbeus (LeC.)	10,16,20,37,	O	A	D,H	B	M,S
B. sp.	3	R	A	S	B	M
Eleodes extricatus (Say)	17,25	R	A	D	EV	M,S
E. fusiformis LeC.	29	R	A	D	EV	S
E. obsoleta (Say)	26	O	A	D,S,H	EV,MV,B	S
E. tricostata (Say)	37,41	R	A	D	EV,B	S
Eusattus reticulatus (Say)	20	R	A	D	B	M
Metoponium nr. *cognitum* Casey	28	R	A	D	EV	S
Steriphanus spp.	18,31	R	A	D,S	EV,MV	S
Collembola						
Sminthuridae						
Sminthurus sylvestris Banks	31,33,42	R	N,A	D,S	EV,MV,B	S
Diptera						
Anthomyiidae						
Hylemya sp.	1	R	A	S	MV	S
Bibionidae						
Dilophus sp.	35,38	R	A	D,S	EV,B	S
Calliphoridae						
Cochliomyia macellaria (Fab.)	2	C	A	D	B	S
Cecidomyiidae						
Asphondylia sp.	38,44	R	L,A	R,D	MV,B	S
Rhopalomyia sp.	12	C	L	R	EV	S
Chamaemyiidae						
Leucopis sp.	45	R	A	D	B	S
Chloropidae						
Chlorops 5-punctatus Lw.	15	R	A	D	EV	M
C. n. sp.	1	R	A	D	MV	S
C. n. sp.	15	C	A	S	MV	M
Conioscinella nuda (Adams)	28,40	R	A	D,S	EV,MV	S
Meromyza sp.	20	R	A	D	B	S
Neodiplotoxa pulchripes (Lw.)	36	R	A	D	EV	S
Opetiophora straminea Lw.	40	R	A	D	EV	S
Siphonella nigripalpis (Mall.)	6,11,28,35,44	O	A	S	MV,B	S
Thaumatomyia glabra (Mg.)	21	R	A	S	MV	S

Table 1. Continued

Species collected	Collection site[a]	Relative frequency[b]	Stage collected[c]	Collection method[d]	Growth stage of host[e]	Species of host[f]
Ephydridae						
Paralimna punctipennis (Wied.)	36	R	A	S	B	S
Lauxaniidae						
Camptoprosopella inaequalis Shewell	11,29,31,36	O	A	D,S	EV,MV	S
Otitidae						
Tritoxa cuneata Loew	40	R	A	S	B	S
Sarrophagidae						
Blaesoxipha sp.	28	R	A	S	MV	S
B. sp.	28	R	A	S	MV	S
Ravinia derelicta (Walker)	1,20	R	A	S	MV,B	M,S
R. iherminieri (R. & D.)	29	R	A	D	EV	S
R. planifrons (Ald.)	26,29	R	A	S	MV	S
Senotainia rubriventris Macq.	18	O	A	D,S	EV,MV,B	S
Sepsidae						
Sepsis neocynipsea Melander & Spuler	11,18,36,42	O	A	D,S	EV,MV,B	S
Stratiomyiidae						
Eulalia sp.	1	R	A	D	B	S
Nemotelus sp.	1,33	R	A	D,S	MV,B	S
Syrphidae						
Allograpta exotica (Wied.)	43	R	A	S	MV	S
Toxomerus marginatus (Say)	1,10,26,38,44	C	A	D,S	MV,B	S
Tachinidae						
Leucostoma sp.	15	R	A	S	MV	M
Microchaetina sp.	20	R	A	D	B	M
Paradidyma sp.	10	R	A	D	B	S
Prosenoides sp.	11	R	A	D	MV	S
Schizactia sp.	42	R	A	S	B	S
Siphophyto sp.	11	R	A	S	MV	S
Sitophaga sp.	18	R	A	S	MV	S
Tephritidae						
Euarestoides acutangulus (Thoms.)	2	R	A	D	B	S
Neaspilota sp.	15,42	R	A	D,S	EV,MV	M,S
Trupanea actinobola (Lw.)	4,6,33,38,39,43 44	C	A	D,S	MV,B	M,S
T. signata Foote	39,43	R	A	D	B	S
Therevidae						
Psilocephala sp.	42	R	A	S	B	S
Hemiptera						
Lygaeidae						
Xyonysius californicus (Stal)	8,45	C	A	D	B	M,S
Miridae						
Coquillettia mimetica Osborn	20	O	A	D	B	S
Pentatomidae						
Mecidea major Sailer	8	R	A	D	B	M
Rhopalidae						
Liorhyssus hyalinus (Fab.)	8	C	A	D	B	M
Tingidae						
Corythucha morrilli Osborn & Drake	18	R	N,A	D	B	S
Homoptera						
Acanaloniidae						
Acanalonia invenusta Doering	11,12,15,26,42	C	A	D,S	EV,MV,B	M,S
A. parva Doering	1	C	A	D	B	S
Aphidae						
Aphis gutierrezis (Pack & Knowlton)	28,42	C	N,A	D,H,S	MV,B	S
Dactynotus zerogutierreziae (Smith & Knowlton)	15,25,27,39,40	C	N,A	D,H,S	EV,MV,B	S
Cercopidae						
Clastoptera lincatocollis Stal	2,18,20,26,28	O	N,A	D,S	MV,B	M,S
Cerococcidae						
Cerococcus artemisiae (Ckll.)	33,39	C	N,A	H	EV	S
Cicadellidae						
Aceratagallia sanguinolenta (Prov.)	39,43	R	A	D	B	S
A. uhleri (VanDuzee)	11,12,14,17,19 22,23,26,27,28 31,36,38,39,40 42,44,45	C	N,A	D,S	EV,MV,B	S
Acinopterus bakeri Lawson	2,38,44	R	A	D	B	S
Athysanella argenteola (Uhler)	6,29,36,40,42	O	N,A	D,S	EV,MV,B	S
A. clavata Ball & Beamer	40,43,44	O	N,A,	D,S	EV,MV B	S
Balclutha guajanae (DeLong)	1	R	A	D	B	S

Table 1. Continued

Species collected	Collection site[a]	Relative frequency[b]	Stage collected[c]	Collection method[d]	Growth stage of host[e]	Species of host[f]
B. neglecta (DeLong & Davidson)	11,15,26,29 33,36	O	N,A	D,S	EV,MV,B	M,S
*B.*sp.	1	R	A	D	B	S
Ceratagallia bigeloviae (Baker)	1,11,15,18,21, 24,26-29,31,33, 35,36,38,39,40- 44,45	C	N,A,	D,S	EV,MV,S	S
Chlorotettix spatulatus Osborn & Ball	1,40,43,44	R	A	D,S	EV,MV,B	S
C. sp.	2	R	A	D	B	S
Ciminius sidanus (Ball)	1	R	A	D	B	S
Cuerna arida Oman & Beamer	24	R	A	D	EV	S
C. costalis (Fab.)	38	R	A	D	EV	S
C. obesa Oman & Beamer	10,11,29,31,36	C	N,A	D,S	EV,MV,B	S
C. striata (Walker)	11,20	O	N,A	D,S	EV,MV,B	S
Driotura vittata Ball	15,23,24,28,29 33,35,36	C	N,A	D,S	EV,MV,B	M,S
D. vittata nigra Lawson	29,31,33	O	N,A	S	MV	S
Empoasca alboneura Gillette	5,6,11,15,18,21- 23, 26-29, 31, 33, 35, 36, 39,40,42	C	N,A	D,S	EV,MV,B	M,S
E. mexicana Gillette	12	C	N,A	D	EV,MV,B	S
Exitianus exitiosus (Uhler)	20,27,29,33,44	O	N,A	D,S	EV,MV,B	S
Flexamia abbreviata (Osborn & Ball)	36	R	A	D	EV	S
F. flexulosa (Ball)	39,40	R	A	D,S	EV,MV	S
Gillettiella labiata (Gillette)	29	C	A	D	EV	S
Graminella sonora (Ball)	14,19,36	R	N,A	D	B	S
Graphocephala marathonensis (Olsen)	12	C	A	D	EV	S
Gyponana delta Ball	15,22,23,31,35, 36,40,42,43	C	N,A	D,S	EV,MV,B	M,S
Keonolla dolobrata (Ball)	2,15	C	A	D	MV,B	S
Norvellina pulchella (Baker)	4	R	A	D	B	M
Opsius stactogalus Fieber	36	R	A	S	B	S
Polyamia sp.	1	R	A	D	B	S
Psammotettix sp.	31	R	A	S	MV	S
Scaphytopius irroratus (VanDuzee)	12	R	A	D	MV	S
Stirellus bicolor (VanDuzee)	1,6,15,26	R	N,A	D,S	EV,MV,B	M,S
Stragania bisignata Ball	20,23,26	O	N,A	D,S	EV,B	S
S. robusta (Uhler)	1,39,43	R	A	D	MV,B	S
Texananus latipex DeLong	15,26,28,33	O	N,A	D	EV	M,S
Tinobregmus vittatus VanDuzee	43	R	A	D	EV	S
Xerophloea peltata (Uhler)	26,36,40	O	N,A	D	EV,B	S
Cixiidae						
Cixius sp.	23	R	A	S	B	S
Oecleus nolinus Ball & Klingenberg	35	R	A	D	EV	S
Oliarus sp.	27	R	A	S	B	S
O. sp.	1	R	A	D	B	S
Delphacidae						
Bostaera nasuta Ball	6,26	R	A	D,S	EV,B	S
Dictyopharidae						
Scolops grossus Uhler	36	R	A	S	B	S
S. pungens (Germar)	10,14,27,33,42	R	N,A	S	MV,B	M,S
Eriococcidae						
Eriococcus cryptus Ckll.	5,11,18,27-29, 33,40,41,42	C	N,A	H	EV,MV	S
E. sp. possibly *dubius* Ckll.	35	C	N,A	H	EV	S
Flatidae						
Mistharnophantia sonorana Kirkaldy	6,15,18,26	R	N,A	D,S	EV,MV,B	M,S
Issidae						
Fitchiella rufipes Lawson	40	R	A	D	EV	S
Hysteropterum sepulchralis Ball	24	R	A	D	EV	S
Kerriidae						
Tachardiella glomerella (Ckll.)	5	O	A	H	EV	S
Kinnaridae						
Oeclidius nanus VanDuzee	4	R	A	D	B	M
Margarodidae						
Steatococcus townsendi (Ckll.)	6,16,18,26,33	C	N,A	H	EV,MV,B	M,S
Membracidae						
Micrutalis calva (Fitch)	15	R	A	S	MV	M
Spissistilus festinus (Say)	12,15,20,24,40	C	N,A	D,S	EV,MV,B	M,S
Stictopelta marmorata Goding	27,36	R	A	S	B	S

Table 1. Continued

Species collected	Collection site[a]	Relative frequency[b]	Stage collected[c]	Collection method[d]	Growth stage of host[e]	Species of host[f]
Vanduzea laeta Goding	15,27,36	R	N,A	S	MV,B	M,S
Pseudococcidae						
Chorizococcus sp.	33,,39	O	N,A	H	EV	S
Phenacoccus gossypii Town. & Ckll.	31	C	N,A	H	EV	S
P. helianthi (Ckll.)	33,39,40,42	C	N,A	H	EV	S
Spilococcus sp.	42	O	N,A	H	EV	S
Psyllidae						
Craspedolepta gutierreziae (Klyver)	11,15,21,27,28	C	N,A	D,S	EV,MV,B	M,S
C. sp.	42	R	N,A	S	B	S
Heteropsylla taxana Crawford	11,12,22,23 26-29,31,36	C	N,A	D,S	EV,MV,B	S
Kuwayama medicaginis Crawford	24,27,29	O	A	D,S	EV,MV,B	S
Rhinopsylla dimorpha Caldwell	40,24	O	A	S	B	S
Trioza diospyri Ashmead	26	R	A	D	EV	S
Hymenoptera						
Andrenidae						
Perdita ignota Ckll.	15,20,28,40	O	A	D,S	EV,MV,B	M,S
P. sp. nr. *lacteipennis* Swenk & Ckll.	15	R	A	S	MV	M
P. sp. nr. *stottleri* Ckll.	10	R	A	D	B	S
Pseudopanurgus sp.						
Anthophoridae						
Exomalopsis sp.	2	R	A	D	B	S
Melissodes sp. nr. *verbesinarum* Ckll.	14	"	A	D	B	S
Apidae						
Bombus sonorus Say	6	R	A	S	B	S
Argidae						
Schizocerella pilicornis (Holmgren)	35	R	A	S	B	S
Bethylidae						
Holepyris sp.	23	R	A	D	EV	S
Parasierola sp.	15,24	R	A	D	EV	M,S
Colletidae						
Hyaleus sp.	14	R	A	D	B	S
Cynipidae						
Alloxysta sp.	23	R	A	D	EV	S
Figitidae						
Melanips	44	R	A	S	MV	S
Formicidae						
Camponotus vicinus Mayr	31	C	A	H	EV	S
Conomyrma insana (Buckley)	21,23,26,29 33,35,43	C	A	D,S	EV,MV,B	S
Crematogaster punctulata Emery	6,15,21,26,27, 33,36,38,43,44	C	A	D,S,H	EV,MV,B	MS
Forelius foetidus (Buckley)	23,26,31	R	A	S	EV,MV	S
Iridomyrmex pruinosus (Roger)	26,27,3340-42	C	A	D,S	EV,B	S
Leptothorax pergandei Emery	23,26,43	O	A	D,S	EV,MV,B	S
Monomorium minimum (Buckley)	41	O	A	D	EV	S
Myrmecocystus depilis Forel	18,26	R	A	D	B	S
M. mimicus Wheeler	6,26,31	O	A	D,S	MV,B	S
Novomessor cockerelli André)	!%	R	A	S	MV	M
Paratrechina sp.	27,43	R	A	D,S	EV,MV	S
Pheidole sp.	26,29,33,43	O	A	D,S	EV,MV	S
Pogonomyrmex rugosus Emery	29,33	O	A	D,S	EV,MV,B	S
Solenopsis aurea Wheeler	35	O	A	DEV	S	
S. xyloni McCook	23	R	A	D	EV	S
Halictidae						
Agapostemon texanus Cresson	26	O	A	S	B	S
Dialictus clematisellus (Ckll.)	11O	A	S	MV	S	
D. sp. nr. *hunteri* (Cwfd.)	2	R	A	D	B	S
D. sp.	24,27	R	A	D	EV	S
Halictus (Scladonia) tripartitus (Ckll.)	43	R	A	D	EV	S
Megachilidae						
Ashmeadiella bucconis (Say)	40	R	A	S	B	S
Megachile texana Cresson	6	R	A	D	B	S
Mutillidae						
Pseudomethoca sp.	31	R	A	D	EV	S
Pompilidae						
Anoplius sp.	18	R	A	D	EV	S
Episyron snowi Viereck)	6	R	A	D	B	S
Psorthaspis macronotum cressoni Bladley	6	R	A	D	B	S

Table 1. Continued

Species collected	Collection site[a]	Relative frequency[b]	Stage collected[c]	Collection method[d]	Growth stage of host[e]	Species of host[f]
Sphecidae						
Cerceris sp.	26	"	A	S	MV	S
Oxybelus sp.	18	R	A	D,S	B	S
Tiphiidae						
Paratiphia mitchelli Allen	10,20,23	R	A	D,S	B	S
Lepidoptera						
Arctiidae						
Cisthene tenuifascia (Harv.)	2	R	A	D	B	S
Geometridae						
Eubaphe unicolor (Robinson)	2R	A	D	B	S	
Melanochroia chephise (Cram.)	1	R	A	D	MV	S
Pergama radiosaria (Hulst)	1	R	L	R	EV	S
Tornos scolopacinarius (Gn.)	45	C	L	R	EV	S
Noctuidae						
Acontia sp.	1	C	A	D	MV	S
Spragueia jaguaralis Hmpsn.	2	R	A	D	MV	S
Sesiidae						
Carmenta prosopis (Edw.)	6	R	A	D	B	S
Tortricidae						
Synnoma lynosyrana Walsingham	14-19,21,23,24	C	L,P,A	D,H,S,R	EV,MV,B	M,S
Yponomeutidae						
Atteva punctella (Cramer)	2,3	C	A	D	B	M,S
Neuroptera						
Hemerobiidae						
Micromus subanticus (Walk.)	23,24,29,40	R	A	D	EV	S
Chrysopidae						
Chrysopa carnea Steph.	23,26	R	A	D	B	S
Mantispidae						
Mantispa sayi Bks.	3	R	A	S	B	M

[a]1=15 m. WSW, Uvalde, Maverick Co., TX; 2=10 m. E, Del Rio, Val Verde Co., TX; 3=20 m. W, Del Rio, Val Verde Co., TX; 4=4 m. W, Comstock, Val Verde Co., TX; 5=13 mi. E, Dryden, Terrell Co., TX; 6=14 m. N, Dryden, Terrell Co., TX; 7=34 m. N, Dryden, Terrell Co., TX; 8=2 m. W, Iraan, Pecos Co., TX; 9=28 m. E, Marathon, Brewster Co., TX; 10=20 m. E, Marathon, Brewster Co., TX; 11=9 m. E, Marathon, Brewster Co., TX; 12=6 m. E, Alpine, Brewster Co., TX; 13=1 m. N, Alpine, Brewster Co., TX; 14=33 m. SW, Fort Stockton, Pecos Co., TX; 15=8 m. W, Crane, Crane Co., TX; 16=22 m. W, Crane, Crane Co., TX; 17=7 m. S, Monahans, Ward Co., TX; 18=5 m. W, Pyote, Ward Co., TX; 19=13 m. S, Pecos, Reeves Co., TX; 20=22 m. S, Van Horn, Culberson Co., TX; 21=13 m. W, Van Horn, Hudspeth Co., TX; 22=22 m. W, Van Horn, Hudspeth Co., TX; 23=10 m. S, Cornudas, Hudspeth Co., TX; 24=6 m. W, Cornudas, Hudspeth Co., 25=3 m. E, Jal, NM, in Andrews Co., TX; 26=4 m. N, Jal, Lea Co., NM; 27=14 m. E, Seminole, Gaines Co., TX; 28=12 m. NE, Lovington, Lea Co., NM; 29=2 m. E, Milnesand, Roosevelt Co., NM; 30=1 m. S, Melrose, Curry Co., NM; 31=6 m. N, Fort Sumner, De Baca Co., NM; 32=12 m. SE, Santa Rosa, Guadalupe Co., NM; 33=10 m. E, Tucumcari, Quay Co., NM; 34=2 m. W, San Jon, Quay Co., NM; 35=8 m. S, Channing, Oldham Co., TX; 36=1 m. E, Four Way, Moore Co., TX; 37=14 m. E, Crosbyton, Crosby Co., TX; 38=14 m. SE, Guthrie, King Co., TX; 39=3 m. S, Wilson, Lynn Co., TX; 40=2 m. N, Justiceburg, Garza Co., TX; 41=2 m. W, Noodle, Jones Co., TX; 42=12 m. SW, Patricia, Dawson Co., TX; 43=16 m. N, San Angelo, Tom Green Co., TX; 44=4 m. E, Barnhart, Irion Co., TX; 45=15 m. N, Ozona, Crockett Co., TX; 46=26 m. N, Deming, Grant Co., NM.
[b]R=rare, O=occasional, C=common
[c]N=nymph, L=larva, P=pupa, A=adult
[d]D=D-Vac, S=sweep net, H=hand collecting, R=rearing
[e]EV=early vegetative, MV=mature vegetative, B=bloom
[f]S=*Xanthocephalum sarothrae*
M=*Xanthocephalum microcephala*

Immature and adult insects were collected by hand or with the aid of a D-Vac® insect vacuum or sweep net. D-Vac and sweep net collections were made by sampling the aboveground portion of 30 plants at each site. Hand collected samples included both aboveground and belowground portions of 10 plants from each location. The roots and stems of hand-sampled plants were opened and examined. Infested plant tissues were returned to the laboratory for rearing. Wherever possible, immature stages were reared on greenhouse plantings of the appropriate host. In some instances immature stages were identified by association.

The relative abundance of various insect species at each site was categorized as common, occasional, or rare. Insects ranked as common were relatively abundant and usually present on a majority of the host-plants sampled. Occasional occurrence was indicative of species that occurred at low population densities and usually occurred on a limited number of host-plants. Rare insects were those encountered at a given locality only infrequently.

Results and Discussion

Specimens of 338 species of insects from 8 orders and 86 families were collected from broom snakeweed and threadleaf snakeweed in western Texas and eastern New Mexico along with data on their distribution, seasonal occurrence and abundance (Table 1).

The phytophagous habits of several insect species were particularly devastating to their hosts and apparently resulted in localized reduction in abundance of these weeds. Among these, *Synnoma lynosyrana* Walsingham, a leaf tying tortricid moth associated with broom snakeweed in California (Powell 1976), was responsible for defoliating populations of both snakeweed species in localized areas in the Trans-Pecos vegetation zone. Larvae of an unidentified weevil, *Myrmex* sp., bore extensively in the roots of broom snakeweed while the larvae of *Myrmex ventralis* Van Dyke damaged the roots of threadleaf snakeweed. Two cerambycid species, *Crossidius discoideus* (Say) and *Crossidius pulchellus* LeC., infested nearly 100% of broom snakeweed plants at several locations. A widely distributed buprestid, *Agrilus gibbicollis* Fall, bored extensively under the bark of broom snakeweed. One mealybug species, *Phenacoccus helianthi* (Ckll.), occurred on the foliage, stems, and roots of both snakeweed species, whereas another, *Eriococcus cryptus* Ckll., was abundant on the roots of broom snakeweed.

Because specialists in Orthoptera and two families of Hymenoptera, Braconidae and Ichneumonidae, were unavailable to make identifications, representatives of these groups are not included in Table 1, although one grasshopper species, *Hesperotettix viridis* (Thomas), is known to be specific to snakeweed and a few closely related plants (Mulkern et al. 1969). All specimens collected as part of this study were deposited in the collections of the Texas Tech University Museum; the Blacklands Conservation Research Laboratory, U.S. Dep. Agr., Agr. Res. Serv., Temple, Texas; or the National Museum of Natural History.

[2]The following specialists identified insects upon which this study was based: D.M. Anderson, S.W.T. Batra; OL.L. Flint, R.H. Foote, D.C. Ferguson, R.J. Cagne, R.D. Gordon, J.M. Kingsolver, J.P. Kramer, P.M. Marsh, W.N. Mathis, A.S. Menke, D.R. Miller, C.W. Sabrosky, D.R. Smith, T.J. Spilman, G.C. Steyskal, M.B. Stoetzel, F.C. Thompson, R.E. White, D.R. Whitehead, and W.W. Wirth, Systematic Entomology Laboratory, ARS, U.S. Dep. Agr., Beltsville, Md.; J.F.G. Clark, R.C. Froeschner, and W.N. Mathis, National Museum of Natural History, Washington, D.C.; W.F. Barr, University of Idaho, Moscow; H.R. Burke, Texas A&M University, College Station; T.D. Eichlin, SEL, Sacramento, Calif.; D.L. Wray, North Carolina Department of Agriculture, Raleigh.

Literature Cited

Andres, L.A. 1971. The suppression of weeds with insects. Tall Timbers Conference on Ecol., Anim. Control and Habitat Manage. 3:185-195.

Dollahite, J.W., and W.V. Anthony. 1956. Experimental production of abortion, premature calves and retained placentas by feeding a species of perennial broomweed. Texas Agr. Exp. Sta. Progr. Rep. 1884.

Dwyer, D.D. 1967. Fertilization and burning of blue grama grass. J. Anim. Sci. 26:934.

Gould, F.W. 1975. Texas plants: a checklist and ecological summary. Texas Agr. Exp. Sta. 129 p.

Falkenhagen, T.J. 1978. Root-boring insects of *Gutierrezia sarothrae,* M.S. Thesis, Univ. Arizona, Tucson. 57 p.

Lavigne, R.J. 1976. Rangeland insect-plant associations on the Pawnee site. Ann. Entomol. Soc. Amer. 69:753-63.

Mulkern, G.G., K.P. Pruess, H. Knutson, A.F. Hagen, J.B. Campbell, and J.D. Lambley. 1969. Food habits and preferences of grassland grasshoppers of the North Central Great Plains. N. Dak. Agr. Exp. Sta. Bull. 481:1-32.

Penrose, R.L. 1973. A biosystematic study of the genus *Crossidus* north of Mexico (Coleoptera: Cerambycidae). Ph.D. Diss., Univ. of Idaho, Moscow. 397 p.

Powell, J.A. 1976. Host plant preference, mating and egg development in *Synnoma lynosyrana* (Lepidoptera: Tortricidae). Pan-Pac. Entomol. 52:1-12.

Ragsdale, B.J. 1969. Ecological and phenological characteristics of perennial broomweed. Ph.D. Diss., Texas A&M Univ., College Station. 138 p.

Solbrig, O.T. 1960. Cytotaxonomic and evolutionary studies in the North American species of *Gutierrezia* (Compositae). Contrib. Gray Herbarium 188. 63 p.

Solbrig, O.T. 1966. The South American species of *Gutierrezia* Contrib. Gray Herbarium. 197:3-42.

Sosebee, R.E., W.E. Boyd, and C.S. Brumley. 1979. Broom snakeweed control with tebuthiuron. J. Range Manage. 32:179-182.

Sperry, O.E., J.W. Dollahite, G.O. Hoffman, and B.J. Camp. 1964. Texas plants poisonous to livestock. Texas Agr. Exp. Sta. Bull. 1028. 59 p.

Stoddart, L.A., A.D. Smith, and T.W. Box. 1975. Range Management. 3rd ed. McGraw-Hill Book Co., Inc., New York. 532 p.

Ueckert, D.N. 1979. Broom snakeweed: effect on shortgrass forage production and soil water depletion. J. Range Manage. 32:216-220.

Vallentine, J.F. 1971. Range Development and Improvements. Brigham Young Univ. Press, Provo, Utah. 516 p.

Growth and Phenological Development of Rough Fescue in Interior British Columbia

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Abstract

Growth and phenological development of rough fescue *(Festuca scabrella)* in interior British Columbia have been documented for a 3-year period. The plants began growing around mid-April and normally ceased growing in late June. Culm growth began in late May and ceased at approximately the time leaf growth ceased. However, leaf and culm elongation ceased before the plants reached their full weight. Rough fescue headed out between May 14 and June 10 and seed shattering occurred between July 13 and July 24. Seed head production per plant was variable from year to year. Fall regrowth occurred in September one year, in October another year, and not at all the other year.

Rough fescue *(Festuca scabrella)* is an important forage species on 1,275,000 ha of grasslands in interior British Columbia, providing up to 10% of the dry matter yield of the *Agropyron-Poa* or middle grasslands zone and up to 50% of the dry matter yield of the *Agropyron-Festuca* or upper grasslands zone (Tisdale 1947). Rough fescue requires a mesic environment and is therefore most abundant on north and east facing slopes.

As rough fescue is a palatable forage and has an extensive fibrous root system for holding soil, it may be advisable to manage it as the key species when it makes up more than 15% of the total plant composition (Hodgkinson and Young 1973). Traditionally the middle and upper grasslands of interior British Columbia have been utilized for spring and fall grazing. To help resource managers make the best use of these rough fescue ranges, we have conducted experiments to document the growth characteristics and the resistance to herbage removal of rough fescue. In this paper we describe the pattern of vegetative and reproductive growth of rough fescue at two sites of interior British Columbia. Possible relationships between growth and environmental parameters are also considered.

Materials and Methods

Study Areas

The Hamilton exclosure, fenced in 1931, is located 70 km south and 26 km east of Kamloops, B.C., on a 49% southeasterly slope at an elevation of 1,158 m, and has a Black Chernozemic (Haploboroll) soil with a sandy loam texture. The East Mara exclosure, fenced in 1938, is located 5 km west of Kamloops, B.C., on a 20% northeast slope at 854 km elevation and has a Black Chernozemic (Haploboroll) soil with a sandy loam texture (McLean and Tisdale 1972).

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Environmental Measurements

Rain gauges, and monthly thermographs (model 251C or 252C Wilh. Lambrecht Ltd., Gottingen, West Germany) housed in Stevenson screens, were maintained at each site from April 1 to October 31 to monitor rainfall and air temperature. Soil temperature was sampled at 10 and 50 cm depths, biweekly from April to October and periodically throughout the winter with a battery operated telethermometer (model 43TE, Yellow Springs, Inst. Co. Inc., Yellow Springs, Ohio). Soil samples, from gravimetric moisture content determination, were collected biweekly from April to November at 5 and 25 cm depths.

Vegetative Growth Measurements

Each year 30 rough fescue plants at a site were identified with labelled stakes. Yield at each site was determined by harvesting 20 plants to a 5-cm stubble at weekly intervals during the plant growth period. The 20 plants were divided into two groups of 10 plants. Plant tissue from the 10 plants within a group was bulked, dried at 80° C and weighed.

In addition to determining the pattern of biomass accumulation, 10 of the 30 plants were randomly chosen to determine the pattern of leaf and culm growth. Average leaf and culm length, measured from ground level, were recorded weekly for each of the 10 plants. When the culm was not visible the length of the outermost leaf sheath was measured, as it would represent the upper limit for the culm length.

Reproductive Growth Measurements

An additional 30 plants were labelled at each site and used to observe flowering and seed production. The dates of developmental stages (boot, head, flower, and seed) were visually estimated. The boot stage occurred when seed heads were enclosed by the leaf sheath. Early heading was defined to be when 10% of the heads from all plants had come out of the boot, and full heading was defined to be when 90% of the heads were out of the boot. Early flowering was defined to be when 10% of the heads were flowering and full flowering was defined to be when 90% of the heads were flowering. At the end of the flowering the anthers discolored and dried up. Seed development was evaluated by estimating the dates when 50% of the seeds were in the milk, dough, ripe, and shattering stages. To quantitatively evaluate reproductive growth, the number of heads per plant were counted for each of the 30 plants. Numbers of tillers and basal areas per plant were also determined to evaluate whether or not the number of heads per plant was related to plant size.

Results

Environmental Conditions

East Mara is a warmer site than Hamilton (Table 1). September and October air temperatures in 1972 were cooler than during 1971 and 1973 at both sites. May and June average daily air temperatures were lower during 1972 than during 1971 or 1973 at Hamilton. At East Mara, April and May air temperatures were lower in 1972 than in 1971 or 1973.

Table 1. Air temperature and precipitation at two interior British Columbia sites during 1971, 1972, and 1973.

Measurement	Site	Year	Months Apr.	May	June	July	Aug.	Sept.	Oct.	
										Mean for May to Oct
Average daily temperature (° C)	Hamilton	1971	—	9	11	15	19	10	6	12
		1972	—	2	6	14	17	9	3	8
		1973	4	8	11	14	17	11	4	9
	East Mara	1971	7	12	13	18	22	12	7	14
		1972	3	11	15	18	20	11	6	14
		1973	7	13	15	19	21	15	7	15
										Total for May to Oct.
Total rainfall (cm)	Hamilton	1971	—	2.9	5.3	0.8	1.6	1.6	3.7	15.9
		1972	—	2.2	6.2	1.6	4.2	1.8	2.5	18.5
		1973	0.4	1.5	2.6	0.2	0.5	1.8	3.0	10.0
	East Mara	1971	—	3.0	4.2	2.1	1.7	1.8	1.0	13.7
		1972	0.9	2.5	4.5	3.1	3.2	1.9	0.9	17.1
		1973	0.3	1.9	3.0	0.4	0.9	2.3	2.1	11.0

Soil temperatures, at 10 cm, were generally lower at Hamilton than at East Mara (Fig. 1). Soil temperature began to increase at about the same time in April at both sites but it decreased sooner in September at Hamilton. East Mara had higher summer soil temperatures, especially during June, than Hamilton. During winter the Hamilton soil froze at 10 cm but not at 50 cm, whereas East Mara soil did not freeze at 10 or 50 cm (50 cm data not shown). At East Mara mid-April soil temperature was higher in 1973 than in 1971 or 1972 and September-October soil temperatures were lower in 1972 than in 1971 or 1973.

Total rainfall during May to October was highly variable from year to year at both Hamilton and East Mara (Table 1). Hamilton received more rain than East Mara in 1971 and 1972. May and June rainfall was least in 1973 at both sites.

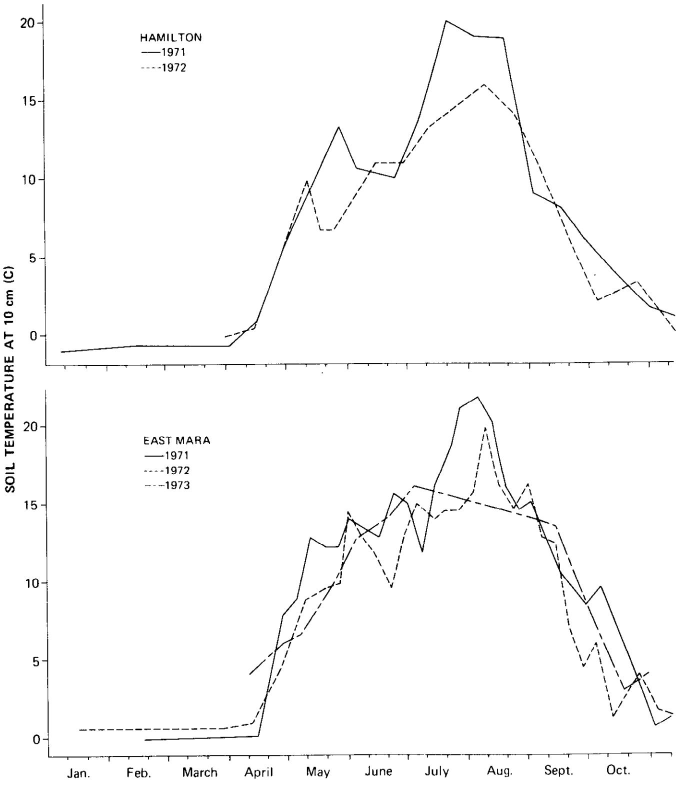

Fig. 1. *Soil temperature at a depth of 10 cm for Hamilton during 1971 and 1972 and for East Mara during 1971, 1972, and 1973.*

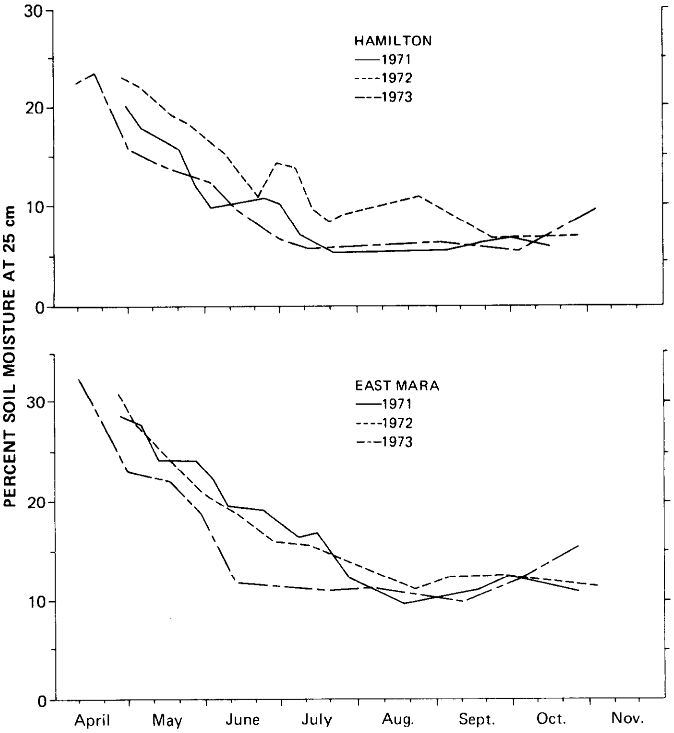

Fig. 2. *Soil water content at a depth of 25 cm for Hamilton and East Mara during 1971, 1972, and 1973.*

Soil water content was maximum in the spring (April) and then decreased during the summer (Fig. 2). Soil water content decreased most rapidly from April to June or July and then less rapidly during the rest of the summer and fall. Summer and fall rains were not sufficient to return the soil water content to the early spring values. However, the soil was fully recharged with water following snow melt in April. Soil water content at 5 cm reflects the rainfall pattern, and so is highly variable during the year (data not shown). Therefore, soil water content at 25 cm was used for comparison of sites and years. At East Mara and Hamilton, September had a lower soil water content in 1973 than in 1971 or 1972 (Fig. 2); whereas, October soil water content was higher in 1973 than in 1971 or 1972. In general the soil water content was lower in 1973 than in 1971 or 1972 at both sites. The higher soil water content at East Mara likely reflects the soil clay content there and not that it has more available water than Hamilton.

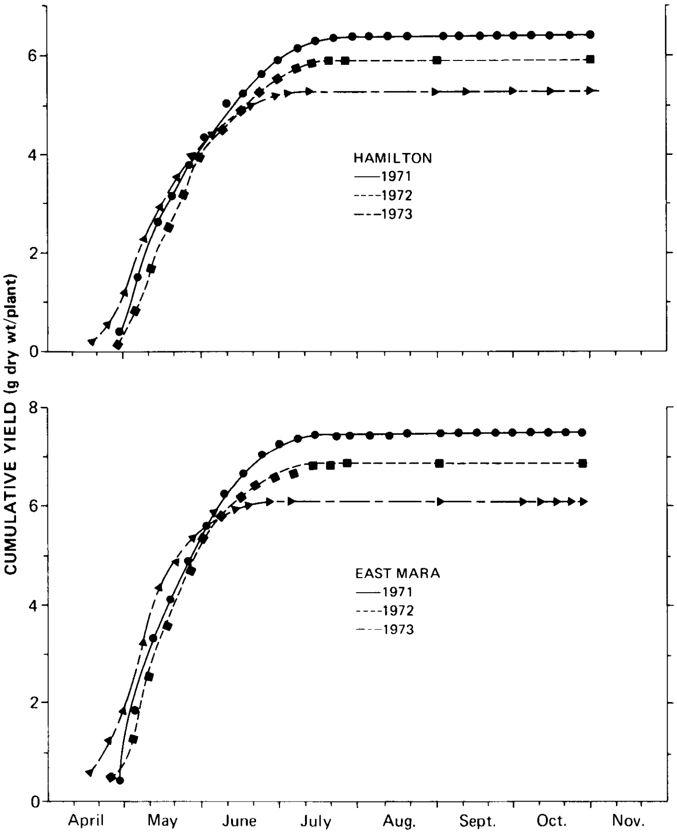

Fig. 3. *Cumulative yield at Hamilton and East Mara during 1971, 1972, and 1973. Value are $\bar{x}$ for two groups of plants each containing 10 plants. $LSD_{.05}$ equalled 0.4 g, 1.0 g, and 0.7 g during 1971, 1972, and 1973, respectively.*

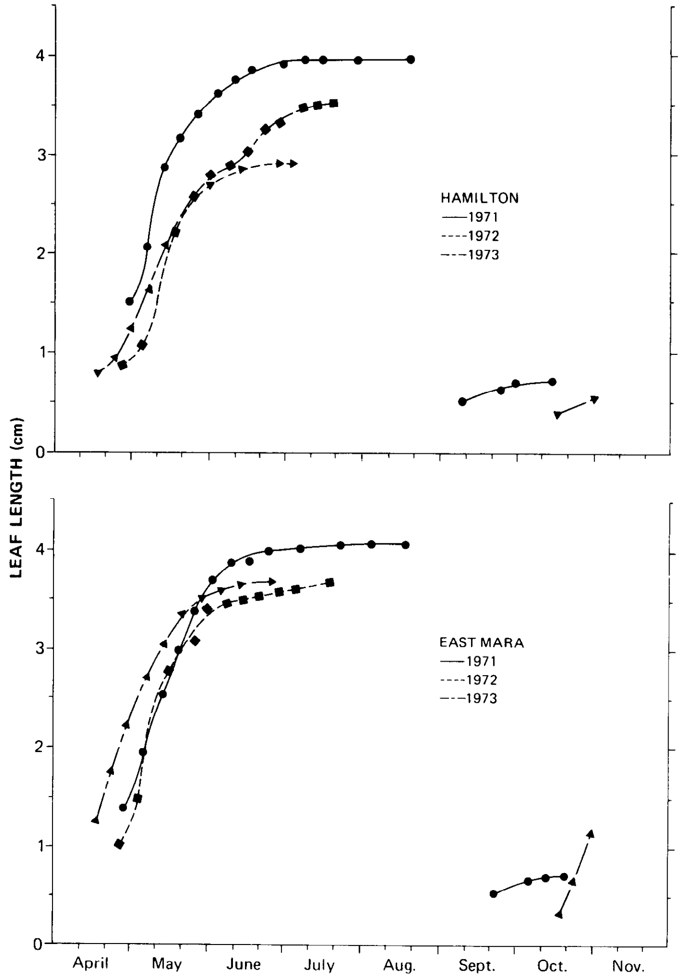

Fig. 4. *Growth in leaf length at Hamilton and East Mara during 1971, 1972 and 1973. Values are $\bar{x}$ for 10 plants. At Hamilton $LSD_{.05}$ equalled 1.5 cm, 1.5 cm, and 1.5 cm during 1971, 1972, and 1973, respectively, and at East Mara $LSD_{.05}$ equalled 2.2 cm, 1.3 cm, and 1.6 cm during 1971, 1972, and 1973, respectively.*

Vegetative Growth

Weight

Date of growth initiation in the spring was estimated by extrapolating the growth curves presented in Fig. 3 to zero yield. Visible growth began during the period April 10 to 25 at both sites (Fig. 3). At Hamilton growth was initiated earlier in 1973 than in 1971 or 1972. At East Mara growth occurred earliest in 1973 and latest in 1971. Soil temperature at 10 cm depth and at the time of growth initiation was 2.9 ± 0.9° C at East Mara and 2.6 ± 0.1° C at Hamilton.

Total yield was greater at East Mara than at Hamilton (Fig. 3). At both sites most growth occurred in 1971 and least growth in 1973. In this experiment, where yield was measured, no fall regrowth occurred.

Leaf Length

Extrapolating leaf length curves to zero length suggests that leaf growth was initiated between April 1 and 15 (Fig. 4). This period for growth initiation is slightly earlier than the period estimated from yield data. However, it is more difficult to extrapolate the leaf data because the initial portions of the curves are not as linear as was observed for the yield data. Generally, rough fescue initiates growth within 7 to 10 days of April 15 at both study locations. The specific date within this period varies with year. There is no indication that growth initiation occurs at a different time at East Mara than at Hamilton, despite the fact that Hamilton is 304 m higher in elevation. Ranking of final leaf length for sites and years corresponds to ranking of final yield with the exception that leaf length at East Mara was the same in 1972 and 1973, whereas yield was larger in 1972 than in 1973.

Cessation of leaf length growth was estimated by two methods (Table 2): (1) visual field observations, and (2) measuring leaf length and estimating when the leaves reached their final length by determining on which date each year the average leaf length was significantly different from the final length using Duncan's multiple range test. The measuring technique estimated that leaf growth ceased from 1 to 2 weeks before it was visually observable in the field. Soil water content at 25 cm when leaf growth ceased was 20 ± 2% at East Mara and 12 ± 2% at Hamilton.

In the leaf length experiment, fall regrowth was observed to occur in 1971 and 1973 at both sites (Fig. 4). In 1971 the regrowth began in September, whereas in 1973 regrowth began in October. This suggests that the lack of regrowth in the yield experiment was due to the clipping.

Culm Length

At both East Mara and Hamilton culm elongation was detected in 1972 (Fig. 5). The 10 plants used in this experiment were not a sufficiently large enough number to detect the low rates of seed head production which occurred during other years (Tables 2 and 3). Culm elongation in 1972 was initiated between May 26 and 31 at East Mara and May 18 and 25 at Hamilton. The soil water content at 25 cm was 22% at East Mara on May 26 and 19% at Hamilton on May 18.

Reproductive Growth

Rough fescue reached the full head stage of development during the period May 25 to June 10 at Hamilton, and during the period May 14 to 24 at East Mara (Table 2). Rough fescue was in full flower during the period June 6 to 24 at Hamilton and the period June 5 to 9 at East Mara. Seeds reached the ripe stage during July 5 to 22 at Hamilton and July 3 to 14 at East Mara. Seed shattering occurred during July 5 to 24 at Hamilton and July 3 to 17 at East

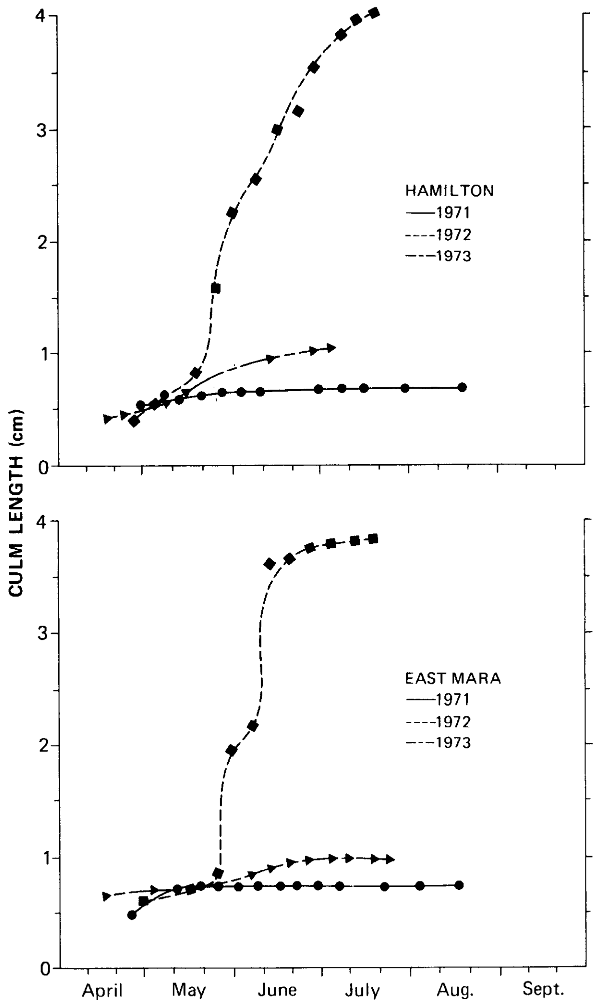

Fig. 5. *Growth in culm length at Hamilton and East Mara during 1971, 1972, and 1973. Values are $\bar{x}$ for 10 plants. At Hamilton $LSD_{.05}$ equalled 1.4 cm, 5.0 cm and 3.9 cm during 1971, 1972, and 1973, respectively, and at East Mara $LSD_{.05}$ equalled 0.4 cm, 7.6 cm, and 1.0 cm during 1971, 1972, and 1973, respectively.*

Mara. These results demonstrate that heading occurs earlier at East Mara than at Hamilton, but that seed ripeness and shattering occur during the same period at both sites. Therefore, initial development of reproductive organs occurs more slowly at Hamilton than at East Mara but later development of reproductive organs occurs more rapidly at Hamilton than at East Mara.

Number of heads per plant varied dramatically from year to year (Table 3), making it impossible to detect small differences in number of heads per plant. Thus the only statistically significant difference was the high seed head production at Hamilton in 1972. However, the complete lack of head production at both sites in 1974 probably reflects a real difference compared to 1972 and 1973. Number of tillers and basal area per plant indicate that differences in heading were not due to difference in plant size (Table 3).

Discussion

Growth initiation in the spring may be related to soil temperature. Because soil temperatures in the spring were similar at both sites, it was not possible to demonstrate this by comparing sites. However, years can be compared, since soil temperature differed on a particular date from year to year. In 1973 soil temperature at East Mara increased earlier than in 1971 or 1972 (Fig. 1) and growth was initiated earlier (Figs. 3 and 4). Also the estimated soil temperatures (2.9 ± 0.9 and 2.6 ± 0.1° C) at the time of growth initiation were remarkably similar at the two sites. It has been reported that rough fescue begins growth during May in Alberta when the soil temperature at 20 cm is 2° C (Johnston and MacDonald 1967). Bailey and Anderson (1978) in Alberta observed that rough fescue begins growth soon after snow melt. Growth initiation in the spring would not be limited by insufficient soil water, since soil water content is recharged following snow melt (Fig. 2). At East Mara, April air temperatures were lowest in 1972 (Table 1) yet growth initiation was not dramatically delayed in 1972, especially when compared to 1971 (Figs. 3 and 4). Thus growth initiation appears to be more closely related to soil temperature than to soil water content or to air temperature.

Cessation of rough fescue growth in the summer appears to be related to soil water content. The date for summer growth cessation varied greatly from year to year at both sites (Table 2). However, the soil water content at the time of growth cessation was remarkably similar from year to year at the two sites. Soil water content at the two sites could not be compared since East Mara soil has a higher water holding capacity than Hamilton soil. Yield

Table 2. Phenological development of rough fescue at the two interior British Columbia sites during 1971, 1972, and 1973.

	Hamilton			East Mara		
Phenological stage[1]	1971	1972	1973	1971	1972	1973
Boot	May 27	—	May 1	May 12	May 10	Apr 30
Early head	June 3	May 18	May 8	May 19	May 17	May 7
Full head	June 10	May 25	May 30	May 22	May 24	May 14
Early flower	June 17	June 1	May 30	June 2	May 31	May 28
Full flower	June 24	June 15	June 6	June 9	June 7	June 5
End of flower	July 1	June 22	June 13	June 23	June 14	June 12
Seed in milk	—	—	June 29	June 30	—	June 19
Seed in dough	—	July 11	—	July 7	July 5	June 26
Seed ripe	July 22	—	July 5	July 14	—	July 3
Seed shattering	—	July 24	July 5	—	July 17	July 3
Leaf growth ends:						
estimated visually	June 17	July 7	June 13	June 23	June 28	May 28
estimated from measurements	June 10	June 29	May 30	June 2	June 7	May 28
Fall regrowth begins:						
estimated visually	Sept. 3	none	Oct. 16	Sept. 15	none	Oct. 3
estimated from measurement	Sept. 9	none	none	Sept. 22	none	Oct. 17

[1]Early heading was when 10% of the heads in the boot were pushed out of the boot. Late heading was when 90% of the heads were out of the boot. Early flowering was when 10% of the heads were flowering and full flowering was when 90% of the heads were flowering. The end of leaf growth was estimated visually in the field and was calculated from length measurements using Duncan's multiple range test.

Table 3. Number of heads and tillers per plant and basal area per plant at the two interior British Columbia sites during 1972, 1973, and 1974.

Site	Year	Number of heads/plant[1]	Number of tillers/plant[1]	Basal area/plant[1] (cm^2)
Hamilton	1972	26.5*a*	300*a*	84*b*
	1973	3.3*b*	241*b*	83*b*
	1974	0.0*b*	216*b*	80*b*
East Mara	1972	1.4*b*	321*a*	105*a*
	1973	1.5*b*	146*c*	80*b*
	1974	0.0*b*	223*b*	100*a*

[1]Values are $\bar{x}$ for n=30 plants. Different letters indicate significant difference within a column at P=0.05 (Duncan's new multiple range test).

continued to increase at low soil water content after leaf growth ceased. This could be expected if growth is being controlled by water supply, since cell expansion is more sensitive to water stress than photosynthesis (Hsiao 1973). Air temperature may also be a factor in growth cessation, since it was quite low at Hamilton during May and June of 1972 and leaf and culm growth continued for a longer than normal period of time at this site in 1972 (Figs. 4 and 5). A lower air temperature would have the effect of decreasing the demand for water. Soil temperature is not high enough at the time of growth cessation to be a limiting factor. In a growth-chamber experiment rough fescue plants showed maximum growth at a soil temperature of 18° C and showed substantial growth at a soil temperature of 27° C (Smoliak and Johnston 1968). Thus rough fescue growth cessation in the summer appears to be mainly controlled by available water.

Rough fescue seed production in Alberta is erratic (Johnston and MacDonald 1967). Erratic seed production might be related to the fact that environmental factors during a rather long time period can affect seed production. For example, seed head initiation occurs in the fall (Johnston and MacDonald 1967), but final seed head development is not completed until the following summer. Seed head production was greatest in 1972 compared to 1973 or 1974 (Table 3). Fall regrowth in 1971 (Fig. 4) showed that fall environmental conditions, at the time when 1972 seed head initiation would be taking place, were favorable at least for vegetative growth. However, 1973 also had fall regrowth (Fig. 4), but no seed heads were produced in 1974 (Table 3). Perhaps it is important that fall regrowth occurred later in 1973 than in 1971. May and June of 1972 were cooler than other years and so the possibility exists that development of seed heads is favored by low temperatures. Unfortunately, the explanation for erratic seed head production is not apparent from our recorded environmental data, or from Johnston and MacDonald's (1967) environmental data. This points out the need to monitor as many environmental parameters as possible and the need to record the complete yearly profile of each environmental parameter in order to determine environmental causes for particular growth responses.

In conclusion, the pattern of growth and phenological development of rough fescue in the interior of British Columbia has been documented for a 3-year period. Growth and phenology of rough fescue varies from year to year and site to site. A particular phenological stage only varies within about a 3-week period from year to year. In this experiment, year-to-year variability was approximately equal to site differences. Thus if a range manager appreciates the yearly variability that can occur at a site, the patterns of growth documented in this paper should be useful for making utilization decisions in most parts of interior British Columbia. For example, the probability that one year's rest from grazing would improve the range by allowing natural reseeding is very low. Range grasses are susceptible to grazing during the growth period, and immediately following growth cessation (Stoddart and Smith 1955). Thus the approximate growth period for rough fescue in interior British Columbia, established in this experiment, identifies when the grazing manager should exercise caution. A study designed to determine specific periods during this growth period when rough fescue is especially susceptible to grazing will be reported on in the future.

Literature Cited

Bailey, A.W., and M.L. Anderson. 1978. Prescribed burning of a *Festuca-Stipa* grassland. J. Range Manage. 31:446-449.

Hodgkinson, H.S., and A.E. Young. 1973. Rough fescue *(Festuca scabrella* Torr.) in Washington. J. Range Manage. 26:25-26.

Hsiao, T.C. 1973. Plant responses to water stress. Ann. Rev. Plant Physiol. 24:519-570.

Johnston. A., and M.D. MacDonald. 1967. Floral initiation and seed production in *Festuca scabrella* Torr. Can. J. Plant Sci. 47:577-583.

McLean, A., and E.W. Tisdale. 1972. Recovery rate of depleted range sites under protection from grazing. J. Range Manage. 25:178-184.

Smoliak, S., and A. Johnston. 1968. Germination and early growth of grasses at four root-zone temperatures. Can. J. Plant Sci. 48:119-127.

Stoddart, L.A., and A.D. Smith. 1955. Plant physiology in relation to grazing. p. 102-103 *In:* Range Management. McGraw-Hill, N.Y. 433 p.

Tisdale, E.W. 1947. The grasslands of the southern interior of British Columbia. Ecology 28:346-381.

Rootplowing, Front-end Stacking, and Seeding Effects on Herbaceous Plant Species Composition

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Abstract

Effects on herbaceous plant species composition of two mechanical brush manipulation treatments (rootplowing and front-end stacking) with and without grass seeding were investigated in the Rio Grande Plain of Texas. Clearing of brushy rangeland by either rootplowing or front-end stacking increased native grass and forb diversity. During the first year after treatment, forbs accounted for about 70% of plant species composition based on density, but by the third and fifth year, they decreased to 25%. Plots seeded to native or introduced grasses established good stands, and by the second year, desirable forage had increased. Buffelgrass *(Cenchrus ciliaris)*, an introduced seeded species, was the most aggressive species. Five years after mechanical brush manipulation, this species accounted for a major portion of the plant composition in both seeded and nonseeded treatments.

The vegetation of much of the Rio Grande Plain of Texas has changed greatly since domestic livestock were introduced over 100 years ago. Generally, perennial grasses have decreased and shrubs such as mesquite *(Prosopis glandulosa)*, blackbrush acacia *(Acacia rigidula)* and cacti (*Opuntia* Spp.) have increased. Although the quality of management has improved greatly on most range within the last two or three decades, most rangeland is still below its forage production capacity (Texas Conservation Needs Committee 1974).

Although some believe that the brush invasion is recent, reports on the early vegetation of the Rio Grande Plain indicated that brush species always have been present although in limited size and density (Johnston 1963; Inglis 1964; Lehmann 1965). In the Rio Grande Plain of Texas, about 85% (5.5 million ha) of the area supports at least a 20% woody canopy cover (Smith and Rechenthin 1964).

Control of woody species by mechanical treatment is expensive, complex, and difficult, since many species occur on the same range site. Control is complicated because certain species may require different treatments at different times. In addition, some species are desirable wildlife food plants and should not be controlled.

Rootplowing, a mechanical manipulation practice that cuts off woody plants below ground by means of a horizontal blade pulled behind a tractor, generally at a depth of 35 to 40 cm, has been highly effective in combating dense stands of mixed brush. In low rainfall areas, however, the practice could destroy a high percentage of existing desirable perennial grasses and result in the invasion of annual grasses and weeds (Fisher et al. 1959). Mathis et al. (1971) reported that in Throckmorton County, Texas, rootplowing decreased grass production for the next six growing seasons. In west Texas, Hughes (1966) reported more total production after rootplowing, but forbs and annual grasses constituted the major vegetation. In the Coastal Prairie of Texas, Powell and Box (1967) concluded that controlling brush with minimum soil disturbance was the best method for improving vegetative composition. However, they used natural plant succession; no artificial vegetation or seeding was used.

Fisher et al. (1959) reported that in northwest Texas, seeding grasses after rootplowing produced good stands of native and introduced grass species. On the rolling and Southern High Plains, however, Jaynes et al. (1968) reported that seeding native grasses after rootplowing often resulted in unsatisfactory stands.

Front-end stacking, a recently introduced mechanical practice, has not been thoroughly evaluated. A front-end stacker is a modified dozer blade using a toothed, rake-like "stacker" with teeth 14 to 36 cm apart. The teeth pull the plants out of the soil. In the Coastal Prairie of Texas, Powell and Box (1967) found that scalping, a manipulation similar to front-end stacking, decreased herbage production.

We conducted this study to investigate further the effects of rootplowing and front-end stacking with and without seeding on changes in species composition of herbaceous plant communities.

Study Area

The study area is on the southern edge of the Rio Grande Plain about 38 km north of Rio Grande City, Starr County, Texas. Long-term average annual precipitation is 43 cm. Potential evaporation exceeds precipitation by four fold (USDC 1970). Most precipitation occurs as thunderstorms that are unevenly distributed both geographically and seasonally. Occasionally, tropical disturbances produce heavy fall rains. Thus, September has the highest long-term monthly average. Another rainfall peak occurs in late May or early June from squall-line thunderstorms.

Summer temperatures are high, and daily maximum temperatures in July and August are usually 38° C or higher. Fall freezes occur 7 out of 10 years, and spring freezes occur 9 out of 10 years. The average length of the growing season is 305 days (USDC 1970).

The study area is a sandy loam soil range site with level to gently sloping topography (0 to 5%). The associated soil types are McAllen and Brennan sandy loams. These soils have a noncalcareous fine sandy loam surface layer and a sandy clay loam subsoil. The Brennan series is a member of the fine-loamy, mixed, hyperthermic family of Aridic Haplustalfs; the McAllen series belong to the hyperthermic family of Ardic Ustochrepts. The fine sandy loam surface layer ranges from about 25 to 50 cm in depth. Permeability of the subsoil is moderate. The water holding capacity and fertility of these soils are high; thus, this site has a high production potential.

The dominant woody plant species include cenizo*(Leucophyllum frutescens)*, blackbrush acacia, coyotillo *(Karwinskia humboldtiana*, coma *(Bumelia celastrina)*, mesquite, and capul *(Schaefferia cuneifolia.)*

Dominant native grass species include Wright's threeawn *(Aristida wrightii)*, Texas bristlegrass *(Setaria texana)*, hooded windmillgrass *(Chloris cucullata)*, and red grama *(Bouteloua trifida)*.

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Forb cover is sparse; western ragweed *(Ambrosia psilostachya)*, ragweed parthenium *(Parthenium hysterophorus)*, rose palafoxia *(Palafoxia rosea)*, and lazy daisy *(Aphanostephus skirrhobasis)* are most common.

Methods

Mechanical treatments were established during June, 1972, on native undisturbed brushland in poor range condition due to overgrazing. A randomized split block design had three replications of main plots of two mechanical brush-manipulation treatments (rootplowing and front-end stacking) and an undisturbed control. Each replication or block consisted of three 2.4-ha strips, one strip each for rootplowing, front-end stacking, and the control. Each strip was divided equally into three 0.8-ha subplots, which were seeding treatments of (1) a single introduced species, buffelgrass *(Cenchrus ciliaris)*, at 2.2 kg/ha, (2) a mixture of five native grass species (Table 1), and (3) nonseeded. Subplots were handseeded between August 31 and September 6, 1972.

Table 1. Five native grasses seeded as a mixture and corresponding seeding rates.

Species	Rate[1] (kg/ha)
Pink pappusgrass *(Pappophorum bicolor)*	0.4
Arizona cottontop *(Digitaria californica)*	0.7
Plains bristelgrass *(Setaria macrostachya)*	0.4
Two-flower trichloris *(Trichloris crinita)*	0.3
Four-flower trichloris *(Trichloris pluriflora)*	0.3

[1]Rates based on pure live seed.

All plots were deferred from domestic livestock grazing until winter, 1974. They were then grazed from late spring to early summer and again in late fall each year. The number of animal units varied each year, but plots were grazed for 90, 140, 135, and 160 days for 1974, 1975, 1976, and 1977, respectively. Utilization of current growth was about 60% each year.

Woody plant canopy cover was determined using the line intercept method (Canfield 1942). Woody species density and relative frequency were determined before mechanical treatment by the point-centered quarter method (Dix 1961). Seventy-five points were established on each of the three 2.4-ha strips of brush for the point-centered quarter method and nine line transects 30 m long for the line intercept method. Changes in herbaceous composition were evaluated by point quadrat methods (20 quadrats per subplot). Herbaceous species data were collected twice yearly (June and November).

Plant nomenclature follows Vines (1960), Gould (1975), and Correll and Johnston (1970). Data were statistically analyzed by analysis of variance procedures (Cochran and Cox 1956). Duncan's multiple range test was used to test for individual comparisons.

Table 2. Woody plant species frequency and density before mechanical brush manipulation treatments in 1972.

Species	Frequency (%)	Density (plants/ha)
Cenizo *(Leucophyllum frutescens)*	32	520
Black brush *(Acacia rigidula)*	27	500
Coyotillo *(Karwinskia humboldtiana)*	31	400
Coma *(Bumelia celastrina)*	25	480
Capul *(Schaefferia cuneifolia)*	21	350
Cranjeno *(Celtis pallida)*	20	280
Sage *(Salvia ballatafolia)*	19	280
Guayacan *(Porliera angustifolia)*	22	260
Cactus (*Opuntia* Spp.)	16	250
Mesquite *(Prosopis glandulosa)*	15	200
Total major spp.		3520
Miscellaneous spp.		1405
Total spp.		4925

Pretreatment Conditions

Before mechanical brush manipulation, the plant community was dominated by low-growing woody species including some cacti and a few grasses and forbs in the understory. A total of 28 woody species were identified. Total woody plant density was 4,925 plants/ha (Table 2) with 10 species contributing 3,520 plants/ha. This high woody plant density was associated with low herbaceous plant density and production. Woody plant canopy cover averaged 32%. Cenizo and blackbrush acacia were dominant and accounted for 1,020 plants/ha. Cenizo and coyotillo had the highest relative frequency, 32 and 31%, respectively.

The grass flora was composed of 16 species (Table 3). Four species accounted for 63% of the plant composition and 12 miscellaneous species combined accounted for 25%. Texas bristlegrass, red grama, hooded windmill, and Wright's threeawn with frequency of occurrence values exceeding 25% were well distributed throughout the study area. All forbs accounted for 12% of the plant composition.

Table 3. Herbaceous plant species composition and frequency before mechanical brush manipulation in 1972.

Species	Species composition (%)	Frequency (%)
Grasses		
Red grama *(Bouteloua trifida)*	13	31
Hooded windmillgrass *(Chloris cucullata)*	11	37
Wright's threeawn *(Aristida wrightii)*	14	26
Texas bristlegrass *(Setaria texana)*	25	36
Gummy lovegrass *(Eragrostis curtipedicillata)*	6	14
Hall's panicum *(Panicum hallii)*	6	10
Buffelgrass *(Cenchrus ciliaris)*	3	3
Sand dropseed *(Sporobolus cryptandrus)*	2	7
Four-flowered trichloris *(Trichloris pluriflora)*	1	3
Fall witchgrass *(Leptoloma cognatum)*	1	1
Pink pappus *(Pappophorum bicolor)*	1	1
Miscellaneous grasses	5	9
Forbs		
Western ragweed *(Ambrosia psilostachya)*	4	4
Wooly tidestromia *(Tidestromia lanuginosa)*	2	3
Ragweed parthenium *(Parthenium hysterophorus)*	1	1
Rose palafoxia *(Palafoxia rosea)*	1	2
Miscellaneous forbs	4	5

Precipitation

Total annual precipitation amounts recorded were 86, 60, 55, 73, and 40 cm for 1973 to 1977, respectively (Fig. 1). Precipitation during this period was above normal (43 cm) in all years except 1977.

Seasonal distribution of rainfall was irregular during the period from 1973 to 1976, a period when mean annual precipitation was above the record mean. It was below the mean during the winter season of all years, but 1973. In 1977, when mean annual precipitation was below the mean the winter mean was also below normal. The precipitation means in spring of 1973 and 1977 were different from the normal; 1973 was extremely dry, while 1977 was extremely wet. Annual precipitation for summer was above the record mean for all 5 years. All years but 1977 were characterized by extremely wet summers. Fall precipitation for 1973, 1974, and 1976 was above the mean; 1975 and 1977 were below. In 1977, no precipitation was received during the months of November and December.

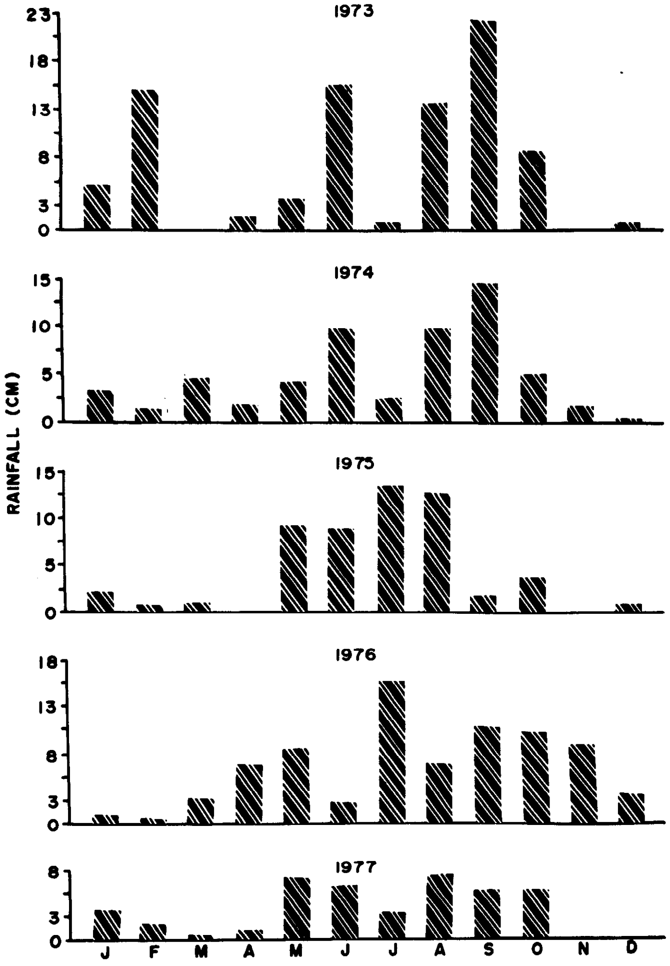

Fig. 1. *Monthly precipitation record in study area from 1973 to 1977.*

Results

Herbaceous Composition

The effect of mechanical treatments on plant species composition (PC) based on density and plant frequency (PF) as compared with an undisturbed control was variable (Tables 4, 5, and 6). Both mechanical manipulation treatments showed more forb density than the control for 3 years following treatment; however, after 5 years forb density was significantly higher only in the rootplowing treatment.

Mechanical Manipulation (main treatments)

In 1973, hooded windmillgrass acounted for the highest PC and plant frequency (PF) of all grass species in both mechanical brush manipulation treatments (Table 4). However, in the control treatment, red grama accounted for the highest PC (20.8%) and hooded windmillgrass accounted for the highest frequency (51%). Two-flowered trichloris, a seeded species, did not germinate or establish in any of the plots. The other five seeded species combined accounted for 8.7, 5.2, and 6.8% PC for rootplowed, front-end stacking, and control, respectively. Forb PC was high, 69.3% for rootplowed and 66.8% for front-end stacking, but accounted for only 26.8% PC for the control treatment.

Total number of plants/ha in 1973 was higher in front-end stacking and the control, as compared to rootplowed (Table 4). However, forbs such as western ragweed, ragweed parthenuim, rose palafoxia, and lazy daisy accounted for most plant numbers in both mechanical manipulation treatments. During periods of high rainfall, other species such as espanta vaqueros *(Tidestromia lanuginosa),* falsemallow *(Malvastrum americanum),* common verbena *(Verbena hipinnatifida),* and other annuals were common.

By 1975, plant density had decreased in all main treatments (Table 5); the greatest reduction occurred in front-end stacking. Forb density only contributed to 18% PC in front-end stacking and was significantly lower than rootplowed treatment. The control treatment decreased by 3% PC from 1973 but had higher PF than both mechanical manipulation treatments; this, however, was not significantly different.

Percent PC contributed by seeded species increased in all treatments in 1975. Percent PC of all five seeded species combined was 28.6, 19.0, and 19.0 for rootplowed, front-end stacking and the control, respectively. Buffelgrass and Arizona cottontop PC in rootplowed were significantly higher than both front-end stack and the control treatment. Three-flowered trichloris had the highest PC of all the seeded species in both mechanical manipulation treatments and was significantly different from the control. In the control treatment, three nonseeded grass species, red grama, hooded windmillgrass, and Wright's threeawn, contributed more than 37% PC and were the most frequent.

Five years following treatment (1977), total plant density averaged 519,590 plants/ha for all main treatments (Table 6). The reduction in plant density can be attributed to a great reduction in forbs, especially in the mechanical manipulation treatments. In 1977, forb PC was 32.1% for rootplowed as compared to 23.6 and 25.3% for front-end stacking and the control, respectively.

Table 4. Herbaceous plant species composition (PC) and plant frequency (PF) of major species for rootplowing (RP), front-ending stacking (S), and control (C) in 1973.

Species	RP (%) PC	RP (%) PF	S (%) PC	S (%) PF	C (%) PC	C (%) PF	X (%) PC	X (%) PF
Red grama *(Bouteloua trifida)*	1.8 b[2]	12 b	3.0 b	24 b	20.8 a	47 a	8.5 b	28 d
Hooded windmillgrass *(Chloris cucullata)*	7.9 b	46 b	9.3 ab	62 a	12.3 a	51 ab	9.8 b	53 c
Wright's threeawn *(Aristida wrightii)*	1.3 b	12 b	2.0 b	18 b	8.9d a	40 a	4.0 c	23 de
Texas bristlegrass *(Setaria texana)*	3.2 ab	27 a	1.3 b	10 b	5.6 a	27 a	3.4 c	21 def
Plains bristlegrass *(Setaria macrostachya)*	2.6 a	18 a	0 b	4 b	0.5 ab	1 b	1.0 c	8 g
Buffelgrass *(Cenchrus ciliaris)*	0.9 b	12 a	1.2 b	11 a	3.9 a	6 b	2.0 c	10 fg
Sand dropseed *(Sporobolus cryptandrus)*	1.3 b	16 a	1.0 b	12 b	3.1 a	16 a	1.8 c	15 efg
Four-flowered trichloris *(Trichloris pluriflora)*	0.6 a	6 b	1.1 a	10 a	0.3 a	1 c	0.7 c	6 g
Arizona cottontop *(Trichachne californica)*	2.5 a	18 a	1.5 b	13 a	1.3 b	3 b	1.8 c	11 efg
Pink pappus *(Pappophorum bicolor)*	0.8 a	9 a	1.4 a	6 a	0.8 a	8 a	1.0 c	8 g
Miscellaneous grasses	7.8 b	58 b	11.4 ab	89 a	15.7 a	82 a	11.7 b	76 b
Forbs	69.3 a	100 a	66.8 a	90 b	26.8 b	78 c	54.3 a	89 a
Total plants/ha	630,785		1,208.107		946,485		928,459	

[1]Data are averages of two samplings (June and November).

[2]Values followed by the sample letter are not significantly different within each main treatment and each species at the 0.5 probability level as determined by Duncan's multiple range test. Comparisons for main treatments for both PC and PF of each species are made horizontally. Comparisons for means of species are made vertically.

Table 5. Herbaceous plant species composition (PC) and plant frequency (PF) of major species for rootplowing (RP), front-ending stacking (S), and control (C) in 1975.

	RP (%)		S (%)				0C (%)	
Species	PC	PF	PC	PF	PC	PF	PC	PF
Red grama *(Bouteloua trifida)*	2.0 b	5 c	4.5 b	14 b	12.0 a	24 a	6.2 cde	14 def
Hooded windmillgrass *(Chloris cucullata)*	8.6 c	26 b	29.6 a	67 a	12.4 b	36 b	16.9 b	43 b
Wright's threeawn *(Aristida wrightii)*	9.1 b	26 b	9.6 b	34 ab	12.8 a	39 a	10.5 c	33 bc
Texas bristlegrass *(Setaria texana)*	6.5 a	27 a	2.1 b	14 b	8.3 a	26 a	5.6 def	22 cd
Plains bristlegrass *(Setaria macrostachya)*	2.0 a	12 a	0.2 b	4 b	0.1 b	0.3 c	0.7 f	5 f
Buffelgrass *(Cenchrus ciliaris)*	5.5 a	19 b	4.5 b	29 a	4.5 b	21 b	4.8 def	23 cd
Sand dropseed *(Sporobolus cryptandrus)*	2.4 b	9 b	5.5 a	27 a	3.2 ab	14 b	3.7 def	17 def
Four-flowered trichloris *(Trichloris pluriflora)*	8.2 a	27 a	6.4 a	25 a	2.4 b	9 b	5.6 def	20 de
Arizona cottontop *(Trichachne californica)*	11.4 a	37 a	2.6 b	15 b	2.4 b	11 b	5.5 def	21 de
Pink pappus *(Pappophorum bicolor)*	1.5 b	9 b	5.3 a	20 a	6.4 a	21 a	4.4 def	17 def
Miscellaneous grasses	9.6 b	26 b	12.1 a	48 a	11.7 a	40 ab	13.1 cd	38 b
Forbs	33.2 a	67 a	18.0 b	67 a	23.8 ab	75 a	25.0 a	70 a
Total plants/ha	604,989		770,952		669,791		681,911	

[1]Data are averages of two samplings (June and November).
[2]Values followed by the same sample letter are not significantly different within each main treatment and each species at the 0.5 probability level as determined by Duncan's multiple range test. Comparisons for main treatments for both PC and PF of each species are made horizontally. Comparisons for means of species are made vertically.

Total PC contributed by four remaining seeded species was 30.2, 18.9, and 18.5% for rootplowed, front-end stacking, and the control, respectively. Buffelgrass contributed the highest single species PC for both mechanical manipulation treatments, rootplowed being significantly higher than the control. Arizona cottontop and four-flowered trichloris contributed 7.0 and 9.2% PC each in rootplowing treatment and were both significantly higher than front-end stacking and the control. Pink pappus contributed the highest PC of the seeded species in the control and was significantly higher than both mechanical manipulation treatments.

Seeding Treatment (sub-treatments)

The PC% contributed by seeded and nonseeded grass species and forbs under different seeding treatments following mechanical manipulation treatments and the undisturbed control are shown in Figure 2. Forb PC was high the first year following mechanical treatment regardless of seeding treatment, but decreased with time.

Establishment of seeded buffelgrass was faster than any other seeded species on all treatments. In 1973, buffelgrass made slightly more than 2% of the PC following both manipulation treatments but had increased to about 17% by 1977. Seeded buffelgrass was slower in establishing on the control plots. In 1973, 1 year after seeding, buffelgrass accounted for only 1% of the PC. By 1975 and 1977 buffelgrass increased to 5 and 7%, respectively. It invaded most of the other treatments and in 1977 it was just as common in the nonseeded as in the seeded treatments.

Plains bristlegrass and Arizona cottontop, native seeded species, establish faster than any other species when planted in rootplowed plots. However, by 1977, plains bristlegrass had completely disappeared and Arizona cottontop decreased in PC from 12% in 1975 to 6.2% in 1977. However, Arizona cottontop invaded other plots and in 1977 it contributed 9.9% PC in the buffelseeded plots and 6.6% in the nonseeded plots that had been rootplowed.

Plain bristlegrass never established itself in any of the seeding treatments following front-end stacking or the control. Pink pappusgrass established itself better in all seeding treatments of the control than either of the mechanical manipulation treatments. It invaded the plots where it was not seeded and in 1977 contributed 7.8 and 6.5% of the PC in buffelgrass seeded and nonseeded treatment, respectively.

Four-flower trichloris was slow in establishment, but by 1975 it contributed at least 11% of the PC in both mechanical manipulation treatments where it had been seeded. By 1977, four-flower trichloris contributed 13.8% of the PC in the rootplowed treatment where it was seeded, 4.5% in the buffelseeded plots, and 9.3% in the nonseeded plots.

Plant species composition contributed by nonseeded grass species in the nonseeded treatment of rootplowed plots was 27, 43, and 36% in 1973, 1975, and 1977, respectively. Red grama and Wright's threeawn were reduced the most in rootplowed plots, while hooded windmill increased and Texas bristlegrass was unaffected. Some important annual and perennial grasses also appeared: southwest-

Table 6. Herbaceous plant species composition (PC) and plant frequency (PF) of major species for rootplowing (RP), front-ending stacking (S), and control (C) in 1977.

	RP (%)		S (%)				0C (%)	
Species	PC	PF	PC	PF	PC	PF	PC	PF
Red grama *(Bouteloua trifida)*	0.8 b	3 c	3.0 b	12 b	15.7 a	28 a	6.5 cd	14 ef
Hooded windmillgrass *(Chloris cucullata)*	11.6 b	33 b	28.6 a	70 a	11.2 b	44 b	17.1 b	49 b
Wright's threeawn *(Aristida wrightii)*	6.2 b	31 b	8.6 b	39 a	12.6 a	43 a	9.1 c	38 c
Texas bristlegrass *(Setaria texana)*	7.4 a	33 a	0.8 b	7 b	6.5 a	26 a	4.9 de	22 def
Plains bristlegrass *(Setaria macrostachya)*	—	—	—	—	—	—	—	—
Buffelgrass *(Cenchrus ciliaris)*	11.8 a	37 ab	8.9 ab	44 a	7.3 b	34 b	9.3 c	38 c
Sand dropseed *(Sporobolus cryptandrus)*	2.5 b	18 b	7.6 a	37 a	3.1 b	16 b	4.4 de	24 de
Four-flowered trichloris *(Trichloris pluriflora)*	9.2 a	40 a	5.3 b	27 b	2.1 c	9 c	5.5 de	25 de
Arizona cottontop *(Trichachne californica)*	7.0 a	33 a	1.3 b	10 b	1.6 b	10 b	3.3 de	18 ef
Pink pappus *(Pappophorum bicolor)*	2.0 b	13 b	3.4 a	19 ab	7.5 a	27 a	4.3 de	20 def
Miscellaneous grasses	9.4 a	25 b	8.9 a	34 a	7.1 a	31 ab	8.6 c	30 cd
Forbs	32.1 a	78 b	23.6 b	86 a	25.3 b	87 a	27.0 a	84 a
Total plants/ha	429,540		613,390		515,840		519,590	

[1]Data are averages of two samplings (June and November).
[2]Values followed by the sample letter are not significantly different within each main treatment and each species at the 0.5 probability level as determined by Duncan's multiple range test. Comparisons for main treatments for both PC and PF of each species are made horizontally. Comparisons for means of species are made vertically.

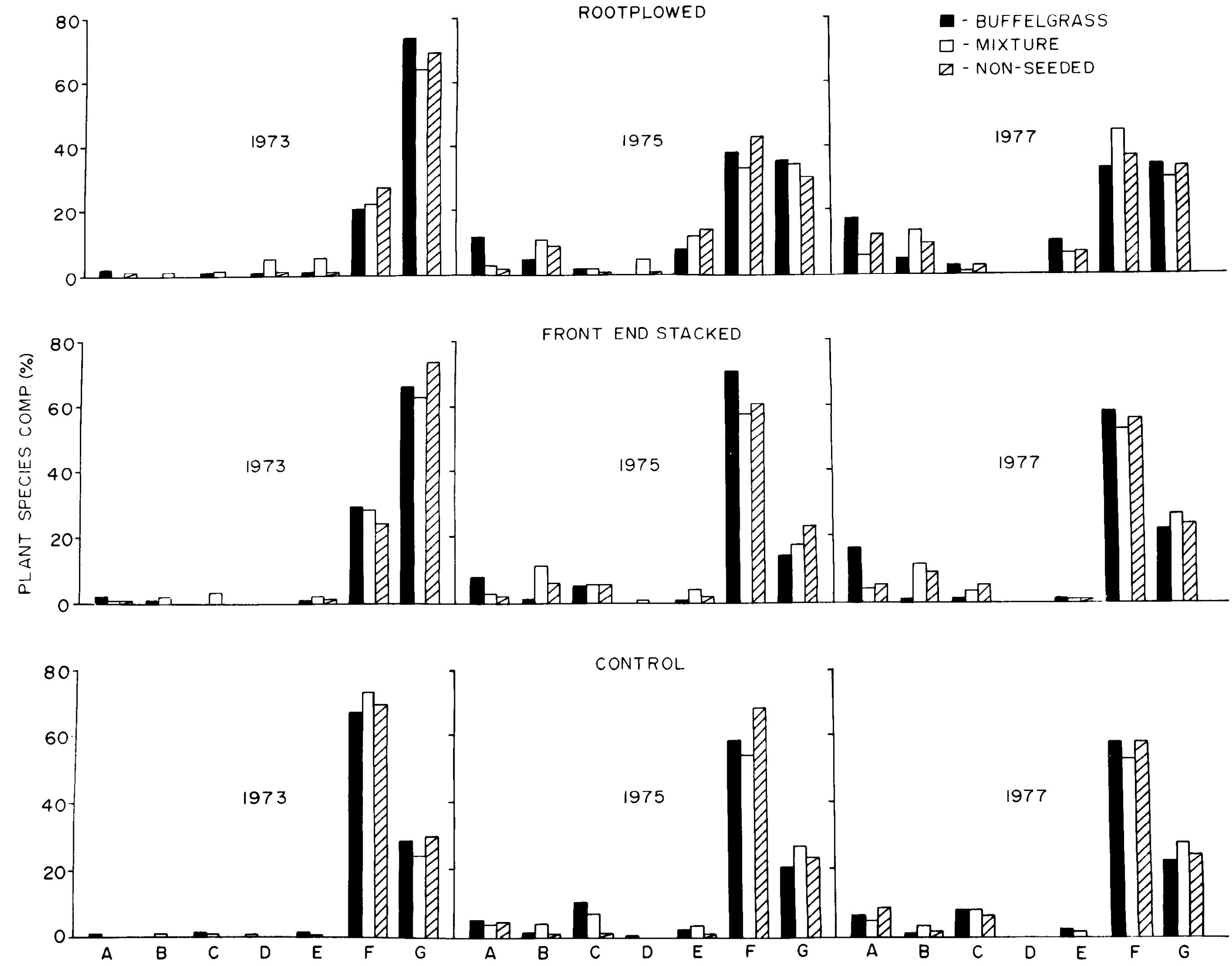

Fig. 2. *Species composition in 1973, 1975, and 1977 after rootplowing, front-end stacking, and no mechanical treatment. Species listed are: A = buffelgrass; B = four-flower trichloris; C = pink pappusgrass; D = plains bristlegrass; E = Arizona cottontop; F = nonseeded species; and G = forbs. Each bar represents plant composition of each seeded species on each of the three seeding treatments. For nonseeded species and forbs, the bar represents totals of all species.*

ern bristlegrass *(Setaria scheelei),* knotgrass *(Setaria firmula),* natalgrass *(Rhychelytrum repens),* slim tridens *(Tridens muticus),* gummy lovegrass *(Eragrostis curtipedicillata),* and coast sandbur *(Cenchrus incertus).* The same nonseeded species occurred in the buffelgrass and native mixture seeded treatments, however, contributed less PC than in the nonseeded treatments in 1973 and 1975. By 1977, nonseeded species contributed about the same PC % in all seeding treatments subjected to rootplowing.

The PC of most nonseeded species of all seeding treatments subjected to front-end stacking was reduced in 1973. However, by 1975, PC contributed by nonseeded species was equal or higher than that of the undisturbed control in all seeded treatments. By 1977, PC of nonseeded species was reduced in all front-end stacking seeding plots; however, it was still almost equal to the PC of the undisturbed control. Most major nonseeded species except Texas bristle and red grama were higher in PC in 1977 than before treatment. Hooded windmillgrass and sand dropseed increased the most in all seeding plots subjected to front-end stacking.

In all seeding treatments of the undisturbed control, eleven nonseeded grass species accounted for the major portion of the PC. Wright's threeawn, red grama, Texas bristlegrass, and hooded windmillgrass were the most common species throughout the study period. By 1977 PC of all nonseeded species was reduced, indicating that seeded species established or invaded the nonseeded control treatments.

Discussion

Before mechanical treatment, very little herbaceous vegetation was growing under the woody plant overstory. Texas bristlegrass was the only grass species consistently occurring directly under the woody plants.

Clearing brushy rangeland by either rootplowing or front-end stacking increased the diversity of native grasses and forbs. During the first year, however, forb species accounted for a high percentage (68%) of the PC on both mechanical treatments. By the third and fifth year, forbs accounted for only about 25% of the PC, indicating an increase in the percentage of grasses. The higher forb density on areas disturbed by mechanical manipulation treatments as compared with relatively undisturbed areas (control) was associated with natural secondary succession due to disturbances and higher soil moisture. After disturbances, the soils accumulated more moisture in the profile than did the undisturbed soils (Gonzalez and Dodd 1979). Thus, more moisture was available for plant growth. Similar results were reported by Powell et al. (1967). Herbaceous plant composition (grasses and forbs) for the undisturbed area (control) was relatively stable throughout the study period.

Mechanical treatments destroyed and uprooted some grass species and increased less desirable species (like some forbs and weedy annual grasses) during the first year after treatment. Similar results have been reported in other areas (Mathis et al. 1971; Powell and

Box 1967). In areas cleared and seeded to climax or introduced grass species, however, good stands were established, and by the second year, desirable forage had increased.

Buffelgrass, an introduced seeded species, was the most aggressive species. This species accounted for a major portion of forage in the plots where it was seeded. By 1977, it had invaded all treatments and accounted for a high portion of the forage in all treatments. Buffelgrass invasion on all treatments indicated a rapid response to available soil moisture. Indications were that its competitive capability was equal to or greater than that of other perennial grasses in the study. Even though buffelgrass PC was low in all treatments, this species by itself contributed more than 50% of the total forage production by weight in all treatments (Gonzalez and Dodd 1979). This plant is robust, large, and produces much biomass.

The contribution to PC by three seeded native grass species (pink pappus, plains bristlegrass, and Arizona cottontop) was generally high the first three years after treatment and then decreased with time. Plains bristlegrass was completely absent by the fourth year. This probably reflected selective grazing. Four-flower trichloris, like buffelgrass, increased in PC with time on plots subjected to both mechanical treatments. Grazing animals, however, did not utilize this species as much as other species. The order of cattle consumption for the seeded species was observed to be buffelgrass > plains bristlegrass > Arizona cottontop and pink-pappus > four-flower trichloris.

Species composition of volunteer nonseeded grasses was reduced the first year after mechanical manipulation as compared with the control (23% vs 70%). By the third year, however, 63% of the composition in the front-end stacked treatment and 38% in the rootplowed treatment was made up of nonseeded speices. Little change occurred in PC by nonseeded species from 1975 to 1977, indicating a trend toward a stable plant community.

Conclusions

Clearing and seeding of southern Texas rangeland increases grass species composition. With time and proper management, there should be a shift from annual forbs and annual grasses to desirable perennial grasses. Management considerations are necessary, however, in deciding which woody species should be preserved. More information is needed in southern Texas to determine livestock and wildlife preferences with regard to utilization of woody plants.

Change in grass composition from native species to buffelgrass will probably occur any time buffelgrass is introduced into the native stand. Observations from this study indicated that cattle prefer buffelgrass and utilized it more than native grasses. Moreover, its rapid growth and recovery after rainfall promotes its capacity to dominate and invade native grass stands. Buffelgrass should not be seeded, however, if diverse rangeland including many native perennial grasses is desired.

Literature Cited

Canfield R.H. 1942. Application of the line intercept method in sampling range vegetation. J. Forestry. 39:338-394.

Cockran, W.G., and G.M. Cox. 1956. Experimental Designs. John Wiley and Sons, Inc., New York. 454 p.

Correll, D.S., and M.C. Johnston. 1970. Manual of the Vascular Plants of Texas. Texas Research Foundation, Renner, Texas. 1881 p.

Dix, R.L. 1961. An application of the point-centered quarter method to the sampling of grassland vegetation. J. Range Manage. 18:190-194.

Fisher, C.E., C.H. Meadors, R. Behrens, E.D. Robinson, P.T. Marion, and H.L. Morton. 1959. Control of mesquite on grazing lands. TAMU. Texas Agr. Exp. Sta., College Station, Texas. Bull. 935.

Gonzalez, C.L., and J.D. Dodd. 1979. Production response of native and introduced grasses to mechanical brush manipulation, seeding, and fertilization. J. Range Manage. 32:305-309.

Gould, F.W. 1975. Texas plants: A checklist and ecological summary. TAMU. Texas Agr. Exp. Sta., College Station, Texas. 121 p.

Hughes, E.E. 1966. Effects of rootplowing and aerial spraying on microclimate, soil conditions, and vegetation of a mesquite area. Texas Agr. Exp. Sta. Misc. Pub. 812.

Inglis, J.M. 1964. A history of vegetation on the Rio Grande Plains. Texas Parks and Wildlife Dept. Bull. 45. 122 p.

Jaynes, C.C., E.D. Robinson, and W.G. McCully. 1968. Rootplowing and revegetation on the Rolling and Southern High Plains. TAMU. Texas Agr. Exp. Sta., College Station, Texas. Prog. Rep. 2584.

Johnston, M.C. 1963. Past and present grasslands of southern Texas and northestern Mexico. Ecology. 44:456-466.

Lehmann, V.W. 1965. Fire in the range of Attwater's prairie chicken. Proc. Fourth Annual Tall Timbers Fire Ecology Conf. 127-143.

Mathis, G.W., M.M. Kothmann, and W.J. Waldrip. 1971. Influence of rootplowing and seeding on composition and forage production of native grasses. J. Range Manage. 24:43-47.

Powell, J., and T.W. Box. 1967. Mechanical control and fertilization as brush management practices affect forage production in south Texas. J. Range Manage. 20:227-235.

Smith, H.N., and C.A. Rechenthin. 1964. Grassland restoration: the Texas brush problem. Unnumbered Bull. USDA, Soil Conserv. Serv., Temple, Texas. p. 139.

Texas Conservation Needs Committee. 1974. Conservation needs inventory, Texas. U.S. Dep. Agr. Soil Conserv. Serv., Temple, Texas.

U.S. Dep. Commerce. 1970. Climatological Summary. Brownsville, Texas. 46 p.

Vines, R.H. 1960. Trees, shrubs, and woody vines of the Southwest. U. Texas Press, Austin. 1104 p.

Rooting of Mesquite (*Prosopis*) Cuttings

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Abstract

Natural mesquite stands and other seed-propagated mesquite are extremely variable because of mesquite's obligately outcrossed breeding mechanism. Clonal propagation methods are required to reduce genetic variation in controlled experiments and for propagation of ornamentals. Cuttings of six species of *Prosopis* (mesquite) representing Hawaiian, North American, and South American germplasm were successfully rooted using a translucent high humidity chamber, greenhouse-grown cutting stock, a foliar dithane (fungicide) spray, and a 3 sec. 100% dimethylsulfoxide dip containing (mg/L):indolebutyric acid (6,000), napthaleneacetic acid (9,000), boric acid (100), calcium chloride (200), thiamine (100), and Banrot (100).

Self-incompatibility in mesquite (*Prosopis* spp.) (Simpson 1977) causes outcrossing so that trees propagated from seed are extremely variable. We have observed coefficients of variation as high as 70% for mesquite biomass production in deliberately planted even-aged mesquite stands (Felker et al. 1981). Vegetative propagation techniques are necessary to reduce genetic variability in controlled greenhouse and field experiments. Several reports of vegetative propagation of rangeland and desert shrubs have appeared (Chase and Strain 1966; Everett et al. 1979; Nord and Goodin 1970; and Wieland et al. 1971); however, the only report of mesquite vegetative propagation is a negative one (Chase and Strain 1966). We report the first successful rooting of mesquite cuttings.

Methods

The origins of these plants, with two exceptions, are described in a previous publication (Felker et al. 1981). Accession 0351 originated from a cutting of a 25-year old, 17.5 m tall ornamental tree of South American origin growing near Indio, California, and accession 0352 originated from a cutting of a 4 m tall, 1.75-year old *P. alba* growing in a plot on the University of California, Riverside Agricultural Experiment Station.

Plants used for cuttings in Table 1 were grown in pots in the greenhouse and were approximately a year old with a maximum height of about 2 m. Each cutting contained two nodes with the leaves removed from the lower node. All cuttings for each species came from the same plant and were taken from the tip back until brown wood was encountered. Cuttings were given a 3-second dip to a depth of 1 to 2 mm in the hormone solution before they were stuck in vermiculite filled pots. Plastic pots approximately 13 $\times$ 13 $\times$ 13 cm were used. Each pot (160 cm^2 surface area) received 80 ml of a 500 mg/L Banrot ™ suspension. The average diameter and length of cutting were 3 and 60 mm respectively. The *P. alba* cuttings were longer (10 cm) and thicker and did not callus to the extent of the other cuttings. Use of larger cuttings for *P. alba* was unavoidable because the distance between nodes was longer than for other species. The cuttings were evaluated after 3 weeks.

The plastic pots were placed in a translucent high humidity tent chamber with a thermostatically controlled evaporative cooler. The tent chamber was located in the greenhouse. A 10 g/L Dithane suspension was sprayed on all cuttings in Tables 2 and 3 and markedly reduced problems with the fungus alternaria. For mature trees terminal branches were cut to 50-cm lengths, misted with a Dithane suspension, the ends placed in water, and transported in a portable, ice-filled cooler. Within 2 hr after collection, two node cuttings were made and the hormone treatment applied. The indole amino acid conjugates were graciously provided by R. Hangarter, Dept. Botany and Plant Pathology, Michigan State University, East Lansing, Michigan 48824.

Results and Discussion

The results of initial screening trials using 2 N H_2SO_4 predips (Lee et al. 1976), osmocote (Gouin 1974), ethrel (Swanson 1974) wounding (Howard 1973) and various auxins led to a hormonal dip consisting of in(mg/L): indolebutyric acid–6,000; naphthaleneacetic acid–9,000; boric acid–100, $CaCl_2 \cdot 2H_20$–200, thiamine–100; Banrot™–100. The solvent was 70% ethanol since lower ethanol concentrations would not dissolve the naphthalene acetic acid. The cutting solution was stored in the freezer and discarded if it became yellow.

Daytime relative humidities of only 60% were achieved in this chamber, and thus two pots were covered with a polyethylene bag and two pots were left uncovered. As shown in Table 1, six species of widely divergent origins gave at least 70% successful rooting when using a polyethylene cover and the hormone mix described above. The polyethylene cover over individual pots did not seem to be very helpful except for the clone of the ornamental *Prosopis* (0351). When all the species were considered together, the number of roots/cutting and the length of the longest root/cutting were significantly greater (5% level) in the covered treatment. Successful use of this technique is not restricted to a few special species or accessions since on the average eight roots of maximum length of 8 cm were obtained in 3 weeks from widely divergent plant species.

Dimethylsulfoxide (DMSO) was substituted for 70% ethanol because DMSO is less volatile and because DMSO can tolerate more water from wet plant stems without causing precipitation of NAA and IBA.

A comparison of the root-inducing properties of three strengths of a commercially available rooting formulation (cutstart xx, xxx, and xxxx) that is very effective in rooting jojoba *(Simmondsia chinensis)* cuttings (Yermanos, pers. comm) with the formulation described here is presented in Table 2. The length of the longest root did not appear to be significantly different among treatments but the formulation we developed gave a greater percentage rooting and a greater number of roots per cutting.

The technique reported here has its shortcomings since even in the greenhouse it works better in the spring than in the summer or fall. In the spring 100% of cuttings from clone 0351 rooted as reported in Table 1 but only 15% rooted in November. Some environmental-plant hormone interaction appears to be regulating cutting success for greenhouse-grown seedlings since, at a particu-

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Table 1. Rooting ability among widely divergent *Prosopis* species.

Species (accession number) (Origin)		Percent rooted	Number roots per number attempted	Length longest root per number attempted/(cm)
P. alba (0352)	covered	80	4.4 a[1]	3.4 a
(Argentina)	uncovered	30	1.6 a	1.1 a
P. articulata (0016)	covered	100	6.5 a	12.6 a
(Mexico)	uncovered	90	7.0 a	10.6 a
P. chilensis (0009)	covered	90	9.0 a	6.4 a
(Argentina)	uncovered	100	12.2 a	12.2 b
P. glandulosa var *torreyana*	covered	90	14.1 a	10.4 a
(0001)	uncovered	70	11.4 a	7.2 a
(California)				
P. pallida (0041)	covered	90	10.0 a	7.9 a
(Hawaii)	uncovered	80	6.0 a	6.6 a
P. velutina (0020)	covered	70	6.8 a	7.4 a
(Arizona)	uncovered	50	3.2 a	3.5 a
P. spp (0351)	covered	100	6.6 A	8.2 A
	uncovered	30	0.9 B	0.7 B
All varieties	covered	88	8.20 a	8.04 a
	uncovered	64	6.04 b	5.98 b

[1]Mean separation by Duncans multiple range test was only performed within a species for covered and uncovered. Means followed by same small (or capital) letter are not different at 5% (or 1%) level.

Table 2. Comparison of rooting formulation described here with a commercially available rooting formulation.[1]

Hormone treatment	Replicate	% rooted	Length longest root (cm)	Number of roots
Formulation described here	1	60	12.6 ± 7.9	8 ± 4.9
	2	80	9.6 ± 6.0	6.6 ± 4.6
	3	73	10.5 ± 3.2	11 ± 9.9
Cutstart xx	1	20	7.5 ± 3.5	1 ± 0
	2	30	9.1 ± 6.9	2.7 ± 2.0
	3	30	17 ± 3.0	2.3 ± 1.1
Cutstart xxx	1	30	5.7 ± 8.9	1.3 ± 0.6
	2	61	14 ± 3.9	2.1 ± 1.1
	3	33	15 ± 5.2	2.5 ± 1.7
Cutstart xxxx	1	31	12.1 ± 5.6	1.0 ± 0
	2	64	10.7 ± 3.3	2.4 ± 1.3
	3	50	10.7 ± 6.3	1.8 ± 1.3

[1]Cuttings were taken from greenhouse grown ornamental mesquite of accession 0351. Ten cuttings per replicate were used.

Table 3. Effect on indoleamino acid conjugates on rooting of mesquite cuttings.

Hormone Used[2]	% rooted	Average number of roots per cutting[1]	Length longest root per cutting
A. Using stock material from 7 ft. tall clonal plants (accession 0351) in greenhouse.			
indolebutyric acid	40.6	7.1 ± 3.0	15.9 ± 3.6
indolebutyryl-phenylalanine	53.1	5.4 ± 4.0	10.7 ± 6.1
indolebutyryl-alanine	53.1	7.3 ± 3.9	15.3 ± 5.3
indoleacetyl-alanine	50.0	2.2 ± 1.6	14.4 ± 4.9
indoleacetyl-leucine	37.5	2.0 ± 1.3	12.7 ± 4.4
B. Using stock material from 3-year-old tree (*P. velutina*) out-of-doors. Zero percent rooting for all treatments (no rooted cuttings from 160 cuttings).			

[1]For each treatment 4 pots with 8 cuttings were used (4 replicates). Computation of average number of roots and length longest root is for those cuttings which rooted (not divided by 32).
[2]Mixture was composed of naphthalene acetic acid 9,000 mg/L; boric acid, 200 mg/L; thiamine, 200 mg/L; Banrot, 200 mg/L; $CaCl_2 \cdot 2H_2O$, 200 mg/L, and the hormone indicated. IBA was used at 6,000 mg/L and other hormones were used at equivalent molarities. Mixture was dissolved in 100% DMSO and used as a 3 sec. dip.

lar time, all species root well or not at all.

Indoleacetic acid (IAA) predominantly exists in legume seeds in the form of amide linked IAA-amino acid conjugates, which unlike free IAA are immune to attack by peroxidases (Cohen and Bandurski 1978). Several of these IAA and IBA conjugates were examined for their capability to overcome the recalcitrant nature of out-of-doors grown trees to initiate roots from cuttings (Table 3). When using a greenhouse-grown stock material, little differences in the rooting of cuttings made with indolebutyric compounds were noted although a lower number of roots per cutting were observed with the indoleacetic compounds. The IBA-alanine treated cuttings had greener looking leaves and appeared to have a more fibrous root system than other treatments. None of these compounds were effective in rooting cuttings of an out-of-doors grown 3-year-old *P. velutina* that was similar to the *P. velutina* successfully rooted in Table 1. Repeated attempts throughout the growing season to obtain cutting from a specific mature out-of-doors grown *Prosopis* generally will be successful in obtaining one or two rooted cutting if liberal use of dithane spray and thorough disinfection of cutting tools with ethanol is practiced. The rooted cuttings obtained can be grown under optimal greenhouse conditions where rooting percentages of 50% or more can often be obtained.

The first report of rooting of mesquite cuttings can be very successful if carried out in the spring of the year using young trees with actively growing foliage. More research will be required to allow successful propagation of mesquite all year round from young and old trees.

Literature Cited

Chase, V.C., and B.R. Strain. 1966. Propagation of some woody desert perennials by stem cuttings. Madrono 18:240-243.

Cohen, J.D., and R.S. Bandurski. 1978. The bound auxins: Protection of indole-3-acetic acid from peroxidase-catalyzed oxidation. Planta 139, 203-208.

Everett, R.L., R.O. Meeuwig, and J.O. Robertson. 1978. Propagation of Nevada shrubs by stem cuttings. J. Range Manage. 31:426-429.

Felker, P., G.H. Cannell, and P.R. Clark. 1981. Variation in growth among 13 *Prosopis* (mesquite) species. Expl. Agr. 17:209-218.

Gouin, F.R. 1974. Osmocote in the propagation house. Proc. Internat. Plant Prop. Soc. 24:337-341.

Howard, B.H. 1973. A measure of the consistency of the response of cuttings to propagation treatments as a guide to the value of experiments on nurseries. Proc. Internat. Plant Prop. Soc. 23:203-209.

Lee, C.I., J.L. Paul, and W.P. Hackett. 1976. Root promotion on stem cuttings of several ornamental plant species by acid or base treatment. Proc. Internat. Plant Prop. Soc. 26:95-99.

Nord, E.C., and J.R. Goodin. 1970. Rooting cuttings of shrub species for plantings in California wildlands. U.S. Dep. Agr. Forest Serv. Res. Note. PSW-213.

Simpson, B.B. 1977. Breeding systems of dominant perennial plants of two disjunct warm desert ecosystems. Oecologia (Berl.) 27:203-226.

Swanson, B.T. 1974. Ethrel as an aid in rooting. Proc. Internat. Plant Prop. Soc. 24:351-361.

Wieland, P.A.T., E.F. Frolich, and A. Wallace. 1971. Vegetative propagation of woody shrub species from the Northern Mojave and Southern Great Basin deserts. Madrono 21:149-152.

Chemical Control of *Crupina vulgaris*, a New Range Weed in Idaho and the United States

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Abstract

***Crupina vulgaris*, crupina, a member of the *Compositae* family, is a recently introduced threat to the rangelands of Idaho. It is a competitive winter annual which, when established, develops nearly solid stands to the exclusion of desirable forage species. It was demonstrated by field trials that fall and spring application of picloram, glyphosate, dicamba, and 2,4-D (amine) were effective in greatly reducing or eliminating crupina for 2 years. Once crupina was removed by this effective management tool, desirable forage species replaced the unpalatable crupina.**

Crupina, *(Crupina vulgaris)*, is a newly introduced weed species invading range and pasture lands in northern Idaho. This is the only known occurrence in the United States (U.S. Dept. Agr. 1973). Crupina, a winter composite, is a native of the Mediterranean region and has spread northward to Russia. Generally, crupina is adapted to disturbed soil sites where its competition from associated species is minimal; however, it is considered to be a serious problem in Russia (U.S. Dept. Agr. 1973). In Idaho cattle will not graze sites of crupina infested rangelands. The plant is competitive and produces solid stands which reduce forage production and carrying capacity.

Since crupina is a newly introduced rangeland weed species, no control measures are available for reducing or eliminating infestations. This study was conducted to determine the effectiveness of selected herbicides for the control of crupina under field conditions.

Distribution

Crupina now covers approximately 8,000 acres in Idaho, namely Clearwater and Lewis counties of Idaho. The infestation occurs primarily on rangelands in relatively deep canyons with steep slopes. Native vegetation of the infested sites consists of annual and perennial grasses and forbs with deciduous brush as the major species and conifers, principally ponderosa pine *(Pinus ponderosa)*, scattered sparsely throughout. The soils in these areas are well drained, slightly acid and rocky to silty loam formed from basalt and wind deposited silt. Rainfall varies from 38 to 76 cm, the mean annual temperature from 8 to 12° C and the elevation ranges from 365 to 1,070 m. Lands which are annually cropped with wheat or barley lie adjacent to the infected areas.

Plant Description

Crupina achenes germinate after adequate moisture is received from fall rains. The large cotyledon leaves (Fig. 1) are followed by a

Fig. 1. *Seedling crupina plant exhibiting the large cotyledon leaves and first true-leaves.*

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basal rosette in late fall or early spring. The dense fibrous root system develops quickly after seedling establishment. The basal leaves are generally entire, oblanceolate to rotund, 1–3 cm long; stem leaves (Fig. 2), up to 7 cm long, are alternate and pinnatifid or bipinatifid (Hitchcock and Cronquist 1976, U.S. Dept. Agr. 1973).

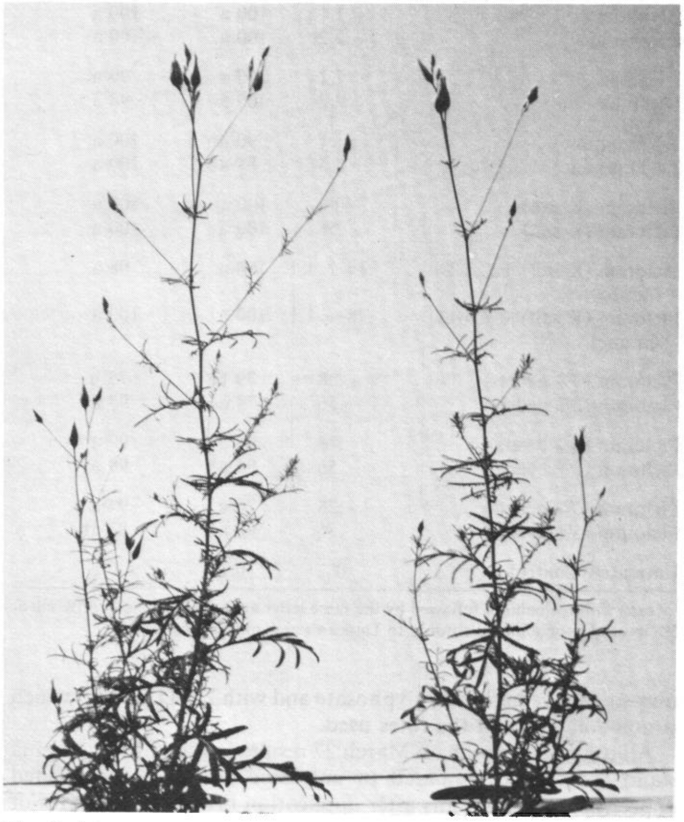

Fig. 2. *Mature crupina plant with pinnatified stem leaves.*

Flora stem initiation generally begins in April under Idaho climatic conditions. The first flower (Fig. 3) appears 4 to 6 weeks later. The 12-mm long flowers are lavender to purple. Plants are from 3 to 12 dm in height with shorter plants producing 5 to 10 heads and taller plants at least 130 heads (Hitchcock and Cronquist

Fig. 3. *Flowers of* Crupina vulgaris. *Flowers are lavender to purple.*

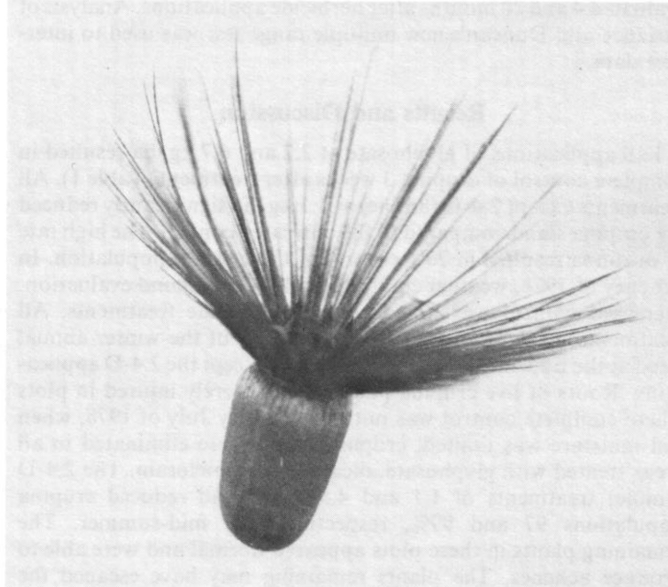

Fig. 4. *Large, cylindrical and truncate achene of crupina. Pappus hairs are up to 10 mm long.*

1976, U.S. Dep. Agr. 1973). Achene production averages 150 per plant but can be over 400 per plant.

The achenes are large, cylindrical, and truncate, about 4 mm long and 3 mm wide (Fig. 4). The pappus consists of several rows of barbed hairs up to 10 mm long. The entire achene is covered with dense hairs, shading from black at the base to silvery fawn at the apex. The achenes are relatively heavy; those collected from two areas in 1979 average 2.55 g/100 achenes. Thus, wind dispersal of achenes is minimal, but dispersal by water is possible as the achenes float readily. Mature achenes fall to the ground base end first and are buried to the pappus in the light dry soils of the area. The achenes germinate readily when fall rains commence. Germination tests conducted by the Idaho State Seed Laboratory in 1977 showed a germination of 85% with 7% dormant and 8% dead achenes.

Materials and Methods

Field trials to determine herbicide effectiveness on crupina were established on sites in Idaho County on October 4, 1977, and March 27, 1978, on an ungrazed rocky silt loam soil. Each site was infested with an average of approximately 500 plants per m². Other species which occurred on the site were Idaho fescue *(Festuca idahoensis),* downy brome *(Bromus tectorum), Erodium* sp., *Allium* sp. and arrowleaf balsamroot *(Balsamorhiza sagittata).* Stands of these species were sparse because of dense crupina infestations. Crupina rosettes were from 5 to 15 cm in diameter at both dates of application; little spring growth had occurred by late March in 1978. Soil temperatures were 15 to 13° C at 10 cm, air temperatures 8 and 14° C, relative humidity 55 and 50%, and wind velocity 0 to 1.5 and 2.0 to 3.0 kph, respectively, for the October and March treatment dates. Two rates each of glyphosate, dicamba, 2,4-D (amine) and picloram (K salt) were applied in the fall and in the spring. The spring trial included two picloram (K salt) plus 2,4-D (amine) combinations, and two rates each of picloram (2% pellets), picloram (2% beads), and picloram (5% pellets). Liquid herbicide formulations were applied by knapsack sprayer with 374 l/ha water as the carrier. Granular materials were broadcast by hand. Treatments were applied to plots 2.74 m by 9.14 m. Each treatment was replicated three times in a randomized complete block design. Percent control of crupina was determined by comparing plant populations in treated areas to those in non-treated plots. Control evaluations were made on the fall treatments 1, 4, 9, and 24 months after treatment. The spring treatments were evaluated 4 and 20 months after herbicide applications. Analysis of variance and Duncan's new multiple range test was used to interpret data.

Results and Discussion

Fall applications of glyphosate at 2.2 and 6.7 kg/ha resulted in complete control of crupina 3 weeks after treatment (Table 1). All treatments except 2,4-D (amine) at 1.1 kg/ha significantly reduced the crupina stand compared to the untreated control. The high rate of dicamba resulted in 70% control of the original population. In January of 1978, weather conditions allowed a second evaluation. Increased control was noted with all herbicide treatments. All treatments produced 90% or better control of the winter annual weed at the time of the second evaluation except the 2,4-D applications. Roots of live crupina plants were severely injured in plots where complete control was not achieved. By July of 1978, when soil moisture was limited, crupina stands were eliminated in all areas treated with glyphosate, dicamba, and picloram. The 2,4-D (amine) treatments of 1.1 and 4.5 kg/ha had reduced crupina populations 97 and 99%, respectively, by mid-summer. The remaining plants in these plots appeared normal and were able to produce achenes. The plants remaining may have escaped the herbicide treatments or are plants from later germination of dormant achenes. The former is more likely as no plants survived the non-soil-active glyphosate treatments.

Table 1. Percent of control of *Crupina vulgaris* by selected herbicides applied October 4, 1977.

Herbicide	Rate (kg/ha)	Evaluation date 10/24/77	1/6/78	7/10/78	10/10/79
Glyphosate	2.2	100 a[1]	100 a	100 a	94 a
Glyphosate	6.7	100 a	100 a	100 a	98 a
Dicamba	1.1	37 c	92 b	100 a	97 a
Dicamba	4.5	70 b	100 a	100 a	100 a
2,4-D (amine)	1.1	10 cd	18 d	97 b	80 a
2,4-D (amine)	4.5	30 c	32 c	99 a	99 a
Picloram (K salt)	0.3	33 c	95 ab	100 a	98 a
Picloram (K salt)	1.1	40 c	100 a	100 a	99 a
Untreated Control	0	0	0 e	0 c	0 b

[1]Means within a column followed by the same letter are not significantly different at the 5% level of probability according to Duncan's new multiple range test.

Evaluations on October 10, 1979, 2 years after treatment, showed continued control of mature plants. Rainfall in September and early October was insufficient to germinate the achenes produced in 1979 and no fall rosettes were present. Crupina control of 94% or better was obtained with all treatments except 2,4-D (amine) at 1.1 kg/ha which resulted in 80% control. Crupina plants in the control plots achieved nearly 100% ground cover with densities of from 50 to 20 mature plants per m². Only a few plants of prickly lettuce *(Lactuca serriola)* and moth mullein *(Verbascum blattaria)* were associated with the crupina plants in the control plots; virtually no grass was present. In treated plots solid stands of primarily downy brome had become established.

The low incidence of wind achene dispersal and the lack of achene dormancy are possible reasons for the failure of crupina to become reestablished on plots treated 2 years previously with the non-soil active herbicide glyphosate and with 2,4-D (amine) which is non-soil active at the rates used.

Table 2. Percent of control of *Crupina vulgaris* by eight herbicide formulations applied March 27, 1978.

Herbicide	Rate (kg/ha)	Evaluation Date 7/10/78	10/10/79
Glyphosate	1.1	100 a[1]	100 a
Glyphosate	2.2	100 a	100 a
Dicamba	1.1	100 a	99 a
Dicamba	2.2	100 a	98 a
2,4-D (amine)	1.1	90 ab	100 a
2,4-D (amine)	4.5	88 ab	100 a
Picloram (K salt)	.28	100 a	100 a
Picloram (K salt)	.56	100 a	100 a
Picloram (K salt) + 2,4-D (amine)	.14 + 1.1	100 a	98 a
Picloram (K salt) + 2,4-D (amine)	.28 + 1.1	100 a	100 a
Picloram (2% pellets)	.28	79 bc	75 b
Picloram (2% pellets)	.56	73 c	93 a
Picloram (2% beads)	.28	98 a	97 a
Picloram (2% beads)	.56	94 ab	99 a
Picloram (5% pellets)	.28	70 c	94 a
Picloram (5% pellets)	.56	90 ab	83 ab
Untreated Control	0	0 d	0 c

[1]Means within a column followed by the same letter are not significantly different at 5% level of probability according to Duncan's new multiple range test.

All treatments made on March 27 resulted in significant crupina stand reductions compared to untreated areas when evaluated approximately 4 months after application (Table 2). All rates of glyphosate, dicamba, picloram (K salt) and picloram (K salt) + 2,4-D (amine) gave complete control of the target species. Picloram (5% pellets) at .28 kg/ha and picloram (2% pellets) at .28 and .56 kg/ha resulted in significantly less control than the previously mentioned treatments. Uneven distribution of a relatively small number of picloram pellets may have contributed to the reduced control with the 2% and 5% formulations compared to the smaller picloram beads or the liquid picloram (K salt) treatments. Rainfall from application to evaluation was approximately 35 cm, which should have been adequate for leaching of picloram from the granular materials into the root zones.

The October 1979 evaluations indicated that herbicide performances was comparable to the July 1978 evaluations (Table 1). As with the fall applications, crupina plants did not become reestablished once their population was reduced or eliminated. Grass stands replaced the unpalatable crupina in herbicide treated areas, demonstrating the dramatic change to a desirable forage with the removal of crupina.

Literature Cited

Hitchcock, D. Leo, and Arthur Cronquist. 1976. Flora of the Pacific Northwest. University of Washington Press, Seattle and London. p. 509.

U.S. Dep. Agr. 1973. Economically important foreign weeds. Potential problems in the U.S. U.S. Dep. Agr. Handbook No. 498. Washington, D.C.

Yield and Quality of Creeping Bluestem as Affected by Time of Cutting

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Abstract

Creeping bluestem *(Schizachyrium stoloniferum* Nash.) is a rhizomatous native grass that is the dominant species on many Florida rangelands. To evaluate its grazing potential, dry matter yield, in vitro organic matter digestibility (IVOMD), crude protein, neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL), were measured in plants cut at 10 and 20 cm stubble heights during 70-day intervals from June to October (summer), August to December (summer-fall), and October to February (winter). Winter yields were significantly greater (2,090 kg/ha) than summer yields (1,600 kg/ha) with summer-fall yields intermediate (1,860 kg/ha). After 3 years there was a significant decline in dry matter in plants cut at 10 cm, but yield was sustained in plants cut at 20 cm. Herbage regrowth in July to August was high in IVOMD (37.8%). Crude protein and IVOMD percentages were also greater in November to December regrowth (7.5 and 36%, respectively) and January to February regrowth (6.8 and 37%, respectively). However, since forage yield was lowest at the time, yield of protein and digestible organic matter were lowest. Percent NDF, ADF, and ADL were not greatly affected by initial growth or regrowth periods and averaged 80.0, 42.3 and 5.8%, respectively. Creeping bluestem may be one of Florida's greater yielding native grasses, but will require protein and energy supplements to provide good livestock performance.

Creeping bluestem (*Schizachyrium stoloniferum* Nash.) is a warm-season, rhizomatous perennial grass (Yarlett 1970), and its dominance on Florida (Yarlett 1963), Georgia, and Alabama (Halls et al. 1964) flatwoods range makes the species among the most widespread and desirable of Southern native grasses. It responds favorably to range improvement and increases pasture yield above that of wiregrass (*Aristida stricta* Michx.) dominated range. Yarlett (1965) estimated that green weight yields of creeping bluestem increased from 1,800 kg/ha at 3 months after mechanical brush control to 6,700 kg/ha at 11 months after treatment.

Creeping bluestem was found to out-yield four other native grasses in an investigation by Roush and Yarlett (1973). Time, frequency, and height of cut were found to affect yield and vigor. Lowest yield (12 metric tons/ha of green forage) resulted from cutting at 10 cm above the soil whenever the plant reached 20 cm in height. Greatest yield (21.5 metric tons/ha) resulted from harvesting 50% of the plant in April, June, and September. These yields reported by Roush and Yarlett were high because all grasses received fertilization.

The major contribution that creeping bluestem can make in a grazing program results from its forage production potential. Cattle can have a 5 to 6-month grazing period as compared with 1 to 2-month period with other native forage resources.

Crude protein and in vitro dry matter digestibility (IVDMD) of a composite of several bluestems, including creeping bluestem, were reported by Lewis (1975). In April forage averaged 10.2% protein and 54.0% IVDMD, but declined to 3.2% protein and 34.0% IVDMD by October.

In order to evaluate the potential of creeping bluestem, additional information is needed about its seasonal yield and quality. This investigation was designed to determine the dry matter yield, in vitro organic matter digestibility (IVOMD), crude protein, neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) in plants cut at 10 and 20 cm above the soil during 70-day intervals from June to October, August to December, and October to February.

Materials and Methods

Experimental work was conducted at the University of Florida's Ona Agricultural Research Center which is 27° 55′ N and 81° 55′ W. The soil was unlimed, unfertilized Immokalee fine sand, which is an Arenic Haplaquod. From samples taken in the upper 15 cm, soil pH was 4.0, and inherent soil P was 6.0; K, 75.0; Ca, 550.0; and Mg, 165.0 kg/ha.

A thick stand of creeping bluestem, which had not been burned during the 3-years prior to its selection in 1975, was cut to 10 cm and all forage removed in early January, 1976. The experiment was designed as a split-plot with whole plots arranged in four randomized, complete blocks. There were three whole plots which were time of clipping or sampling: June to October; August to December; and October to February. Each whole plot was cut three times per year: at the beginning of each period (June, August, October) and twice thereafter on approximately 70-day intervals. The initial growth refers to forage accumulated between the third or last cutting (ie. October) and the first cutting (ie. June), and regrowth refers to the forage produced in the two, 70-day intervals after the initial harvest. Sub-plots were height of cutting above the soil, and plots, which were 1.5 × 5.0 m, were cut at 10 and 20 cm with a rotary-type harvester.

Yield and dry matter were calculated from fresh sub-samples of approximately 0.25 kg, dried at 60° C. Methods desribed by Gallaher et al. (1977) and Isaac and Johnson (1976) were used for nitrogen analysis and that of Moore et al. (1972) for IVOMD. Yield of digestible organic matter (DOM) was calculated by multiplying dry matter yield by both IVOMD and organic matter percent. NDF, ADF, and ADL were determined according to the procedure described by Van Soest (1963) and Van Soest and Wine (1967).

Results and Discussion

Dry matter yield

Forage yield from June to October of 1978-79 was significantly lower ($P<0.05$) than the yield of the previous 2 years (Table 1). There was no significant drop in yield in the third year when creeping bluestem was clipped in August to December or October to February. When time of clipping was examined within 1976-77 and 1977-78, it was found that production resulting from cutting

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Table 1. Annual dry matter yield (kg/ha) of creeping bluestem as affected by year and time of clipping. Ona, Florida, 1976-79.

Year	Clipping period: June to Oct.	Aug. to Dec.	Oct. to Feb.	
1976-77	1670[a] [1]	1900[a]	1930[a]	b,ab,a[2]
1977-78	1790[a]	1950[a]	2150[a]	b,ab,a
1978-79	1350[b]	1740[a]	2180[a]	c,b,a
Average	1600	1860	2090	

[1]For vertical (year) comparison. Means within columns followed by the same letter are not significantly different. (Duncan's multiple range test, $P<0.05$).
[2]For horizontal (time of clipping) comparison. The letters correspond to the three means within a year. Means having the same letter are not significantly different. (Duncan's multiple range test, $P<0.05$).

Table 2. Annual dry matter yield (kg/ha) of creeping bluestem as affected by year and height of cut. Ona, Florida, 1976-79.

Year	Height of cut (cm): 10	20	
1976-77	2330[a]	1340[b]	a,b[2]
1977-78	2100[a]	1800[a]	a,b
1978-79	1700[b]	1800[a]	a,a

[1]For vertical (year) comparison. Means within columns followed by the same letter are not significantly different (Duncan's multiple range test, $P<0.05$).
[2]For horizontal (height of cut) comparison. The letters correspond to the two means within a year. Means with the same letter are not significantly different. (Duncan's multiple range test, $P<0.05$).

plants from June to October was significantly lower than that of October to February, while production resulting from cutting in August to December was not different from either. In 1978-79 mean yields from each of the three time periods were different.

Creeping bluestem makes most of its growth in the spring and summer (Yarlett and Roush 1970), and periodic clipping from June to October interrupted this growth. Forage yields were greater in the August to December and October to February periods because of the heavier yields accumulated by the initial harvest, which represented 60 and 77% of the total yield values for these respective periods shown in Table 1. The initial growth of the June to October cutting period represented 37% of the total average 1,600 kg/ha.

Cutting creeping bluestem at 10 cm above the soil significantly reduced dry matter yields after 1977-78 (Table 2), but there was no significant drop in yield when plants were cut at 20 cm. In 1976-77 and 1977-78 cutting plants at 10 cm resulted in higher yields, and this would be expected as more herbage was harvested when cut closer to the soil. In 1978-79 there was no difference in yield between height of cut treatments. The plant stands were thinning out at the 10-cm height of cut, and tiller density (not in tables) was significantly less in the plots cut in June to October at the 10-cm level (117 tillers/m^2) as compared with the tiller density average from all other plots (171 tillers/m^2). The reduction in yield after 3 years of cutting at 10 cm in June, August, and October was probably due more to lower yield per tiller, rather than a significant loss of tillers.

Forage Quality

Crude protein was not significantly different ($P<0.05$) in forage accumulated prior to the beginning of each of the three sampling periods (initial growth) (Table 3). Regrowth from July to August or September to October was significantly lower in crude protein content, than that harvested November to December or January to February. There were small changes in protein percentages found in the forage sampled within the June to October (5.0 to 5.7%) or the October to February (4.5 to 6.8%) clipping periods, although protein differences between these two periods were great. The August to December clipping period, which overlapped in former two periods, had the most dramatic changes in crude protein, which ranged from 4.8 to 7.7%.

Since protein yield was influenced most by dry matter yield, protein yields were greatest for the forage accumulated from March to October (70 kg/ha) (Table 4). Although ranchers using creeping bluestem during the winter would have more protein per hectare at the beginning of the season, little protein production could be expected from regrowth in November through February.

Percent IVOMD in forage was significantly lower in the March to October initial growth (27.4%) as compared with forage accumulated in January to August (31.5%), and the latter was lower than the initial November to June forage (34.3%) (Table 5). These

Table 3. Crude protein (CP) on a dry matter basis in creeping bluestem as affected by time of initial growth and regrowth period. Ona, Florida, 1976-77 1977-78.

	Months when forage was produced						
	Initial growth		Regrowth				
Clipping period	Months	% CP	Months	% CP	Months	% CP	
June-Oct.	Nov.-June	5.0[a] [1]	July-Aug.	5.8[b]	Sept.-Oct.	5.7[c]	b,a,a[2]
Aug.-Dec.	Jan.-Aug.	4.8[a]	Sept.-Oct.	5.8[b]	Nov.-Dec.	7.7[a]	c,b,a
Oct.-Feb.	Mar.-Oct.	4.5[a]	Nov.-Dec.	7.4[a]	Jan.-Feb.	6.8[a]	c,a,b

[1]For vertical comparison. Means within columns followed by the same letter are not significantly different (Duncan's multiple range test, $P<0.05$).
[2]For horizontal comparison. Letters correspond to the three means on the same line. Means having the same letter are not significantly different (Duncan's multiple range test, $P<0.05$).

Table 4. Yield (kg/ha) of crude protein (CP) from creeping bluestem as affected by time of initial growth and regrowth period. Ona, Florida, 1976-77 and 1977-78.

	Months when forage was produced						
	Initial growth		Regrowth				
Clipping period	Months	CP	Months	CP	Months	CP	
June-Oct.	Nov.-June	30[c] [1]	July-Aug.	30[a]	Sept.-Oct	30[a]	a,a,a[2]
Aug.-Dec.	Jan.-Aug.	50[b]	Sept.-Oct.	30[a]	Nov.-Dec.	20[b]	a,b,c
Oct.-Feb.	Mar.-Oct.	70[a]	Nov.-Dec.	20[b]	Jan.-Feb.	10[c]	a,b,c

[1]For vertical comparison. Means within columns followed by the same letter are not significantly different (Duncan's multiple range test, $P<0.05$).
[2]For horizontal comparison. Letters correspond to the three means on the same line. Means having the same letter are not significantly different (Duncan's multiple range test, $P<0.05$).

Table 5. In vitro organic matter digestibility (IVOMD) in creeping bluestem as affected by time of initial growth and regrowth period. Ona, Florida. 1976-77 and 1977-78.

	Months when forage was produced						
	Initial growth		Regrowth				
Clipping period	Months	% IVOMD	Months	% IVOMD	Months	% IVOMD	
June-Oct.	Nov.-June	34.3[a1]	July-Aug.	37.7[a]	Sept.-Oct.	33.6[b]	b,a,b[2]
Aug.-Dec.	Jan.-Aug.	31.5[b]	Sept.-Oct.	33.8[b]	Nov.-Dec.	35.7[a]	c,b,a
Oct.-Feb.	Mar.-Oct.	27.4[c]	Nov.-Dec.	36.9[a]	Jan.-Feb.	37.2[a]	b,a,a

[1]For vertical comparison. Means within columns followed by the same letter are not significantly different (Duncan's multiple range test, $P<0.05$).
[2]For horizontal comparison. Letters correspond to the three means on the same line. Means having the same letter are not significantly different (Duncan's multiple range test, $P<0.05$).

Table 6. Yield (kg/ha) of digestible organic matter (DOM) in creeping bluestem as affected by time of initial growth and regrowth period. Ona, Florida, 1976-77 and 1977-78.

	Months when forage was produced						
	Initial growth		Regrowth				
Clipping period	Month	DOM	Months	DOM	Months	DOM	
June-Oct.	Nov.-June	210[c1]	July-Aug.	200[a]	Sept.-Oct.	170[a]	a,a,b[2]
Aug.-Dec.	Jan.-Aug.	350[b]	Sept.-Oct.	170[a]	Nov-Dec	80[b]	a,b,c
Oct.-Feb.	Mar.-Oct.	430[a]	Nov.-Dec.	100[b]	Jan-Feb	30[c]	a,b,c

[1]For vertical comparison. Means within columns followed by the same letter are not significantly different (Duncan's multiple range test, $P<0.05$).
[2]For horizontal comparison. Letters correspond to the three means on the same line. Means having the same letter are not significantly different ($P<0.05$).

differences in IVOMD were due to age of forage sampled. November to June initial forage was younger, spring growth as contrasted with senescent forage produced in the spring and summer and sampled in August or October. The IVOMD values were greater in regrowth than in their respective initial growths, and this was especially obvious in regrowth after the March to October initial, which increased from 27.4% initially to 36.9 and 37.2% in regrowth. Even the regrowth highest in IVOMD (July to August regrowth was 37.7%) was apparently about 10% lower than the IVDMD values reported by Lewis et al. (1975) for bluestems grown during this period in southern Georgia.

Yield of digestible organic matter like protein yield was more of a function of dry matter yield than IVOMD% and was greatest at the end of March to October initial growth period (Table 6). Regrowth from July to August resulted in greater DOM yields than November to December or January to February regrowth.

Percent NDF ranged from 79.1 to 82.0% and was not significantly different when comparisons were made among the initial growth cuttings (Table 7). NDF in regrowth from the June to October or August to December clipping period was not significantly different from the NDF of their respective initial periods. However, regrowth after the March to October initial period did drop significantly in NDF during each of the successive harvests. IVOMD% was fairly closely associated with NDF% with $r=0.70$. Leland et al (1976) reported cell wall constituents of unburned *Andropogon gerardi* (Vitman) and *S. scoparium* (Michx. Nash.) to be about 76% to 79%, respectively, which is similar to those values in Table 7.

Percent ADF and ADL were affected by time of use (Table 8). Both ADF and ADL percentages were significantly higher in the October to February period than in the June to October period. The low IVOMD% reflects the high percentage of seemingly undigestible cellulose found in the ADF fraction. Leland et al (1976) reported lower cellulose values for *A. gerardi* and *S. scoparium,* which were 33% and 34%, respectively. Lignin was 6% to 7%, respectively, in these species. The ADL% reported for creeping bluestem was not usually high so if lignin had a negative affect on

Table 8. Percent acid detergent fiber (ADF) and percent acid detergent lignin (ADL) in creeping bluestem as affected by time of use. Ona, Florida 1977-78.

	Clipping period		
	June to October	August to December	October to February
ADF	42.8[a1]	43.2[a]	43.0[a]
ADL	5.3[b]	5.5[b]	5.9[a]

[1]Means on the same line followed by the same letter are not significantly different. (Duncan's LSD, K = 100).

Table 7. Percent neutral detergent fiber (NDF) in creeping bluestem as affected by time of initial growth and regrowth period. Ona, Florida, 1977-78.

	Months when forage was produced						
	Initial growth		Regrowth				
Clipping period	Months	NDF	Months	NDF	Months	NDF	
June-Oct.	Nov.-June	80.9[a1]	July-Aug.	80.9[a]	Sept.-Oct.	81.5[a]	a,a,a[2]
Aug.-Dec.	Jan.-Aug.	81.6[a]	Sept.-Oct.	81.5[a]	Nov.-Dec.	81.3[a]	a,a,a
Oct.-Feb.	Mar.-Oct.	82.0[a]	Nov.-Dec.	80.7[a]	Sept.-Oct.	81.5[a]	a,a,a[2]
Aug.-Dec.	Jan.-Aug.	81.6[a]	Sept.-Oct.	81.5[a]	Nov.-Dec.	81.3[a]	a,a,a
Oct.-Feb.	Mar.-Oct.	82.0[a]	Nov.-Dec.	80.7[a]	Jan.-Feb.	79.1[a]	a,b,c

[1]For vertical comparison. Means within columns followed by the same letter are not significantly different (Duncan's multiple range test, $P<0.05$).
[2]For horizontal comparison. Letters correspond to the three means on the same line. Means having the same letter are not significantly different. (Duncan's multiple range test $P<0.05$).

Table 9. Percent acid detergent fiber (ADF) and percent acid detergent lignin (ADL) in creeping bluestem forage as affected by initial harvest and regrowth. Ona, Florida. 1977-78.

	Cell Fraction	
Harvest	ADF	ADL
Initial	44.1[a1]	6.2[a]
1st regrowth	42.9[b]	5.2[b]
2nd regrowth	42.0[c]	5.3[b]

[1]Means within columns followed by the same letter are not significantly different (Duncan's LSD, K = 100).

digestibility, it was probably due to where the lignin was located in the cell rather than the quantity.

Both ADF and ADL percentages were higher in the initial harvest than in the two following 70-day regrowth periods (Table 9). This response was a reflection of older forage accumulated for the initial harvest. Regrowth ADF and ADL were lower than the initial harvest and were indicative of a better forage.

Although Yarlett and Roush (1970) had reported five vegetative tillers to one productive tiller on ungrazed, unburned creeping bluestem, the herbage in this study remained completely vegetative. The low protein and digestibility values were apparently due to low soil fertility and anatomical characteristics at the cellular level in leaf and sheath tissue.

These data indicate that intake, protein and digestible energy would be limiting factors for mature dry cows grazing creeping bluestem. Protein and digestibiliy of creeping bluestem does not appear to be greatly different from that reported for wiregrass (Kirk et al. 1974; Lewis et al. 1975). However, yield of creeping bluestem is greater than yield from wiregrass and this alone is justification for management to foster its dominance on Florida range. Continued research should deal with management that will improve grass quality.

Conclusions

Annual yields of creeping bluestem were highest when used from October to February as compared to use from June to October. Cutting creeping bluestem during June to October was detrimental to sustained yield, whereas cutting in August to December or October to February did not reduce yields after 3 years. Cutting at 10 cm resulted in a significant reduction in dry matter yield after 3 years as compared with cutting at 20 cm above the soil surface, which resulted in sustained yields.

Crude protein and IVOMD percentages were significantly greater in regrowth as compared to initial growth. Yield of protein and digestible organic matter was greatest in forage which had been accumulated from March to October. Although there were statistical differences in NDF, ADF or ADL percentages from creeping bluestem during the year, they were slight, and it is not anticipated that they would result in differences in livestock performance.

Literature Cited

Gallaher, R.N., C.O. Weldon, and F.C. Boswell. 1977. A semi-automated procedure for total nitrogen in plant soil samples. Soil Sci. Soc. Amer. Proc. 40:887-889.

Halls, L.D., R.H. Hughes, R.S. Rummell, and B.L. Southwell. 1964. Forage and cattle management in longleaf-slash pine forests. U.S.D.A. Farmers Bull. 2199.

Issac, R.A., and W.C. Johnson. 1976. Determination of total nitrogen in plant tissue using block digester. J. Ass. of Anal. Chem. 69:98-101.

Kirk, W.G., G.K. Davis, F.G. Martin, E.M. Hodges, and J.F. Easley. 1974. Effect of burning and mowing on the composition of pineland threeawn. J. Range Manage. 27:420-423.

Leland, J.A., L.H. Harbers, R.R. Scalles, C.E. Owensby, and E.F. Smith. 1976. Range burning and fertilizing related to nutritive value of bluestem grass. J. Range Manage. 29:306-308.

Lewis, C.E., R.S. Lowrey, W.G. Manson, and F.E. Knox. 1975. Seasonal trends in nutrients and cattle digestibility of forage on pine-wiregrass range. J. Anim. Sci. 41:208-212.

Moore, J.E., G.O. Mott, D.G. Dunham, R.W. Omer. 1961. Forage capacity in vitro OM digestion procedure. J. Anim. Sci. 31 (1) 231. Abstract No. 261.

Roush, R.D., and L.L. Yarlett. 1973. Creeping bluestem compared with four other native range grasses. J. Range Manage. 26:19-21.

Van Soest, P.J. 1963. Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fiber and lignin. J. Ass. Offic. Anal. Chem 56:829-835.

Van Soest, P.J., and R.H. Wine. 1967. Use of detergents in the analysis of fibrous feeds. IV. Methods for determination of plant cell walls. J. Ass. Offic. Anal. Chem. 50:50-55.

Yarlett, L.L. 1963. Some important and associated native grasses on central and south Florida ranges. J. Range Manage. 16:25-27.

Yarlett, L.L. 1965. Control of saw palmetto and recovery of native grasses. J. Range Manage. 18:344-345.

Yarlett, L.L., and R.D. Roush. 1970. Creeping bluestem (*Andropogon stolonifer* (Nash.)Hitchc.) J. Range Manage. 23:117-122.

Guiding a Range Curriculum with an Educational Needs Assessment

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Abstract

This study, undertaken as a cooperative effort between the Utah State University Range Science Department and the Instructional Development office, surveyed 138 alumni of the department to assist in the identification of needs for curriculum improvement. Strong support for the following educational concerns was evident: (1) a practical and pragmatic emphasis in the curriculum, including focus upon political and economic aspects of range management; (2) an emphasis upon communication skills, particularly oral communication, and dealing with "people problems"; (3) a field component to complement the classroom wherever possible. Findings from the study have led to the revision of two courses, the beginning of two others, and have endorsed a core course on land management policy recently introduced into the College of Natural Resources. The results of the survey have assisted curriculum development in the Range Science Department at Utah State University and may prove helpful for other educators in the field.

Periodic review and appraisal should be a normal part of higher education. In the case of a professional degree such as a Range Science BS, the faculty have a responsibility to the profession to make sure that the curriculum being offered and the standards of instruction provide adequate training for a range management career.

As philosophies of rangeland management have changed over the last half century (Harris 1977) there have been changes in the job requirements of the range manager and also in the attitude of both students and faculty toward a range education. Some components of a range curriculum seem relatively permanent, such as basic ecology and taxonomy, but others ought to respond to the needs of the times, especially in relation to land use policy and the economic environment. In a characterization by a Forest Service administrator (Arnold 1970), the 1970's was the "environmental decade," placing new and diverse demands on the land management agencies and additional pressures on livestock operators. It is reasonable to assume that in the 1980's these pressures will intensify, compounded with world energy demands.

In 1969 the Utah State University Department of Range Science undertook a self-analysis to determine what updating of the curriculum was necessary to better prepare students to find challenging employment upon graduation. As a guide to the evaluation, the opinions of graduates of the Department were surveyed by a questionnaire. The responses indicated a need to broaden the curriculum, with more emphasis on administrative and communicative skills (McKell 1970).

For the academic, the challenge in teaching such a multidisciplinary subject as range science is to strike a balance between basic and applied information, between principles and technical skills, between education in sciences and human relations. The responsibility for a satisfactory education is shared by academics and laymen alike, so that students who intend to call themselves range men receive a training acceptable to the profession as a whole (Box 1964).

The assignment of priorities and designation of importance in range education is a long-standing debate. Courses in basic and applied sciences have traditionally formed the backbone of range science curricula (Heady 1961). There has been a tendency to emphasize basic sciences over technology and to stress ecological principles with which graduates can solve range management problems by a combination of a priori reasoning and experience (Tisdale 1956, Keith 1957, Washburn 1957, Morris 1961, Hooper 1969, and Arnold 1970).

In 1957 Johnson referred to range management as a "salesman's job." Communications and public relations have often been identified as an integral part of the range management profession that should receive more preparation in college (Dyksterhuis 1953, Sampson 1954, Costello 1957, and Hervey 1964). In a survey of range professionals conducted by Kienast and Scifres (1973), most respondents stressed the need for more coursework in the social sciences and for development of communicative skills, but a more extensive survey of federal agency personnel (Cook and Bonham 1974) showed that communication training is not considered to be as important as other components of the curriculum. Others have suggested that range science graduates should be more qualified in the fields of business and administration (Heady 1961, Hervey 1964, and McKell 1970). Several commentators on range education have viewed the college experience as training to equip graduates to think, solve problems, and integrate information (Sampson 1951, Costello 1957, Lehman 1966, and especially Dregne and Pettit 1972).

In 1976 the USU Range Science Department decided to reexamine its curriculum and to gauge the quality of education through a survey of its alumni. In addition to evaluation of course material and the extent to which the classes prepared students for a career, the Department was also interested in the impact of the college education on attitudes and motivation, and the value of student advising and continuing education. The assistance of the Division of Instruction Development in the USU Learning Resources program was enlisted to determine questionnaire content and design and to conduct statistical analyses of responses.

Procedure

The weakest link in the systematic development of a curriculum is often the identification and definition of the problem. As educators, we often assume that we have our fingers upon the pulse of the discipline, and that the structure of the knowledge required by graduates of our program is self-evident. Unfortunately, the result often reflects our past academic training far more than the training needed by graduates in a changing world. Kaufman (1972) and Witkin (1977) have suggested a technique for studying needs and systematically documenting the most critical ones for program emphasis. Focusing upon the difference between desired and perceived actual conditions, this "needs assessment" study becomes a

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means of setting program priorities. The present study, similar to one done previously in the USU Wildlife Science Department (Eastmond and Kadlec 1977), used questionnaires sent to all graduates of the department over a 15-year period for whom we had addresses.

In conducting such a study, certain assumptions are necessary. One of these is that a departmental curriculum is open to revision and that faculty will be willing to make decisions based upon alumni opinion data. Another is that the graduate population sampled is knowledgeable about student needs and that their sentiments can be gauged accurately with a questionnaire. A final assumption is that student needs in the field will not change drastically in the course of conducting the study and implementing the results. All of these assumptions seemed reasonable for this situation, but the decision was examined openly.

Working with a committee of five Range faculty members, the consultant from Instructional Development constructed an initial questionnaire and pilot-tested it with 15 graduates located in Utah and surrounding states. On the basis of this trial run, the original long questionnaire was split into two shorter survey instruments. Several modifications were made to simplify and facilitate the task of responding. Following revision, one questionnaire was distributed to half the alumni selected at random, and the other questionnaire sent to the remainder. Altogether 304 questionnaires were mailed to graduates of the Department since 1960 and a follow-up letter sent 3 weeks later.

The first questionnaire was designed to assess the graduates' impressions of various aspects of the undergraduate experience, dealing with such matters as advising, fieldwork, course repetition, the value of a few specific courses, and some general topics. By the format of the questionnaire, alumni were given statements to which they could indicate varying degrees of agreement or disagreement.

For the second questionnaire, respondents were asked to rate the performance of the Department of Range Science in a number of areas on a five-point scale from successful to unsuccessful. These areas were technical knowledge and skills, thinking skills, communication skills, attitude and motivation, background and breadth. In addition, at the conclusion of the questionnaire, they were asked to look again at the 43 questions and circle the ten most critical items for curriculum improvement. The determination of critical items for the curriculum revision was based upon these ratings.

An important feature of the study was the quality assurance role played by the faculty committee. Besides reviewing the work of the consultant, the plan for sampling, and data analysis, the committee became involved with the study and familiar with the results. Thus, when the results became available for discussion by the whole Department, a cadre of faculty was available to certify the adequacy of the procedures and lend support to act upon the results. Thus, the usability of the study was enhanced.

It is worth noting that nearly two decades (1960–1976) of graduates were being asked to respond to questions about their academic program. Certainly considerable time had elapsed, especially for earliest graduates, allowing for the influence of extensive experience on the job. A number of fairly significant curriculum and faculty changes were made over that time period as well, so that all graduates were not evaluating an identical curriculum nor assessing the educational talents of the same teachers. As could be expected, a higher response rate was found for more recent graduates.

Results and Discussion

Of the 295 deliverable questionnaires, 138 or 47% were returned, 66 of the first questionnaire and 72 of the second. The response rate for alumni graduated since 1973 was considerably higher (67%), and was similar to the response pattern for the previous Wildlife study at USU (Eastmond and Kadlec 1977). It was found that the vast majority (80%) had not completed graduate degrees beyond the B.S. Graduates tended to work in Utah (33%) or the surrounding states of Idaho, Nevada, Arizona, Colorado and Wyoming (38%).

Major employers were mainly the Bureau of Land Management (26%) and the U.S. Forest Service (28%), which corresponds quite closely with an employment survey of 628 range science graduates from various universities who obtained permanent positions of which 55% were in federal agencies (Powell 1975). A number of additional employers were represented, but for comparison purposes, the remaining groups were simply categorized into "Other, Range Related" (33%), and "Other, Non-Range Related" (13%). In contrast to Powell's survey, relatively few USU graduates are employed by the Soil Conservation Service. Statistical comparisons were made for responses by year of graduation and by type of employer. For the most part, the statistical analyses did not reveal significant differences; exceptions are noted below.

Responses to the statements in questionnaire #1 were scored to a maximum of 5, representing strong agreement with the statement offered, down to a minimum of 1, denoting strong disagreement. The highlights among the 24 items are presented in Table 1. Academic advising for undergraduates by departmental faculty received a strong endorsement, likewise the importance of a solid foundation in basic ecological concepts and principles. Some felt that more advanced training in plant ecology would be desirable, which matches the deficiency in ecology noted for range majors by Forest Service respondents in the survey by Kienast and Scifres (1973).

The notion that professors actively engaged in research are more competent and stimulating teachers (Tisdale 1956) did not score far beyond the positive side of neutral, but on the other hand, faculty who combined research and teaching careers were not criticized. Granted that there is an inherent tendency toward overall positive responses to survey questionnaires of this type due to both

Table 1. Highlights from questionnarie #1, giving mean scores and deviations from neutral for 66 respondents. A score of 3.0 represents a neutral position (range 1.0 to 5.0), with lower values expressing disagreement and higher scores denoting agreement with the statements offered.

	Score	Deviation from neutral
Advisement		
Advisement is helpful	3.75	+.75
Advisement is unnecessary	1.62	-1.38
Ecology studies		
The General Ecology course is useful and satisfactory	3.99	+.99
Range majors need an advanced plant ecology course	3.67	+.67
Combining teaching with research		
The best teachers do research as well	3.30	+.30
Researchers tend to neglect teaching	3.00	0
Practical and applied aspects		
Undergrads should be exposed to real-life problems of ranchers and range managers	4.47	+1.47
Field labs are necessary to complement classroom	4.46	+1.46
Students with urban backgrounds are handicapped	3.48	+.48
Most field labs are not applicable to everyday work	2.40	-.60
There is too much curriculum emphasis on economic and practical aspects vs. wildlife and aesthetics	[1]*2.07	-.93
Information in workshops and shortcourses designed for govt. agency staff should be available to undergraduates	[1]*3.49	+.49

[1]*Significant difference ($p<.05$) among groups based on year of graduation (1960–64, 1965–72, 1973–76).

respondent generosity and the "halo effect" (Cronbach 1970, p. 572), we may conclude that graduates did not perceive any difference in the teaching abilities of professors involved with research compared to those who are not.

The highest endorsement in this first questionnaire was for a practical and pragmatic emphasis in the undergraduate curriculum, as reflected in the six entries under the relevant heading in Table 1. Though a statistical test showed a significant difference ($p<.05$) between age groups for only the last two items in Table 1, there was a consistent tendency for recent graduates to rate practical training at a higher level than graduates of at least 10 years standing. There could be several reasons for this: (1) the older graduates are more conservative in expressing their opinions, with less inclination to mark the extreme scores on the available range; (2) older graduates have been promoted from "field" positions to desk jobs where the problems are largely administrative; (3) new graduates have a heightened sensitivity to on-the-job deficiencies when fresh from campus; (4) the recent graduates are expressing a backlash against the popular emphasis of the 1960's on aesthetic and somewhat intangible value judgments of range utility.

Students generally possess a practical perception of the goals of a university education (e.g., Collins 1956), but the influx of students from a broader spectrum of society particularly evident in recent years led Cross (1971) to observe that

> . . .New Students are positively attracted to careers and prefer to learn things that are tangible and useful. They tend not to value the academic model of higher education that is prized by faculty, preferring instead a vocational model that will teach them what they need to know to make a good living. (p. 159)

It is clear that a satisfactory range science curriculum must provide training in useful marketable skills; as Sampson (1954) and Hervey (1964) have pointed out, a curriculum should be shaped by employment opportunities.

Recipients of the second questionnaire were asked to rate the success of the Department in providing students with certain skills, attitudes, or perspectives. Answers were scored from 1 to 5, representing performance ratings of very unsuccessful to very successful. A "don't know" column was provided and given a score of 0. The ratings of the most important questions (summarily paraphrased) are given in Table 2 arranged in order of score, and designated by group.

Skills associated with writing, use of English, reading, and understanding professional materials appear in the top half of the list. Skills associated with communication, especially at the verbal level, appear with low ratings in the bottom half, an echo of the earlier survey (McKell 1970) and an indication that oral language skills are getting less attention than they deserve. This particular outcome was confirmed by the answers to Free Response questions in both questionnaires in which communication techniques and handling "people problems" were identified as areas with insufficient preparation at the undergraduate level. The future success of a range student depends fully as much upon being able to intelligibly express and convince others of range facts learned as upon knowing the facts (Dyksterhuis 1953, among others).

Graduates indicated satisfactory introduction at college to utilizing professional publications. This may, of course, be a commentary on textbook study and library work associated with most university curricula and not a reflection of education in the Department of Range Science, per se. It may also reveal a low level of involvement in reading and sophisticated writing on the part of alumni. Whatever the case, it would seem that graduates believe that reading and writing skills do not need special attention in curriculum revision, which is borne out by the data in Table 3. In the survey of range professionals conducted by Cook and Bonham (1974), English was identified by only 2.1% of respondents as a shortcourse needed for improving the ability of Range Conservationists to carry out their assignments.

Items in the Knowledge category were rated from excellent through to very poor. Some of those in the lower part of the scale represent special aspects of range management that have assumed importance in only the last 5 or 10 years, such as attention to

Table 2. Highlights from questionnaire #2, describing the performance of Range Science Department by mean scores and deviations from neutral for 72 respondents. A score of 3.0 represents a neutral position (range 1.0 to 5.0) with deviations expressing the relative success or failure of the faculty in teaching performance.

				Talent cluster of educational categories		
Adequacy of instruction	Skill or knowledge	Mean score	Deviation from neutral	Reading and writing	Oral Communication (Public relations)	Knowledge (*Strong field component)
Excellent	Range plant identification	4.64	+1.64			X*
Good	Multiple use management	3.78	+ .78			X
	Knowledge of information sources	3.74	+ .74	X		
	Assimilating ideas from publications	3.69	+ .69	X		
	Record-keeping and documentation	3.56	+ .56	X		
	Assessing range condition and trend	3.54	+ .54			X*
Fair	Writing reports	3.48	+ .48	X		
	Solving real-life management problems	3.46	+ .46			X*
	Applying math and stats	3.41	+ .41			X
	Use of English	3.39	+ .39	X		
	Determining optimum range utilization	3.38	+ .38			X
Marginal	Communicating research and technical information	3.28	+ .28		X	
	Justifying management decisions to public	3.26	+ .26		X	
	Teaching range managment practices	3.26	+ .26		X	
	Economic aspects	3.22	+ .22			X
	Range livestock production	3.12	+ .12			X
Poor	Persuasion techniques	2.97	− .03		X	
	Energy development and impacts	2.42	− .58			X
	Endangered species	2.39	− .61			X
	Overcoming political obstacles	2.17	− .83		X	
	Use of computers	1.83	−1.17			X

endangered species and impacts of energy development. The introduction of computer technology to range science education is too recent to justify evaluation; its appearance on the bottom of the list is likely more of a check on the validity of the responses than a commentary on the value of training in the use of computers.

An advanced course in range livestock production was being developed at the time the questionnaires were distributed and has since been established in the curriculum, rectifying, hopefully, the low rating for this field of knowledge.

Economic aspects of range management did not receive a high performance score overall, but analysis by year of graduation revealed that recent graduates rated this area of instruction with a significantly higher score (4-16) than the classes of 1960 through 1972. This trend may be understood in the context of a change during the 1970's toward more emphasis on management and less attention to economic theory. Courses in this area now include real-life problem-solving, determining optimum range utilization and weighing alternative use strategies. Although additional training in the fields of economics and politics was at the top of the list of targets for future curriculum emphasis (Table 3), the economics side of the proposition received only mild support from recent alumni.

Table 3. Analysis of questionnaire items identified by 59 respondents as targets for future emphasis to improve the educational program in the Department.

Subject area	Number of specific questions in subject area	Mean number of checks	Mean as % of respondents	% of respondents who checked in subject area (intensity rating)
Ability to deal with economic considerations and political obstacles	2	28	47	75
Practical application of range science to field problems	3	23	39	76
Ability to argue persuasively and convince both lay and professional people	3	19	33	73
Multiple use concepts, policies and measures	2	18	31	51
Range plant identification and condition assessment	2	18.5	31	51
Understanding ecosystem properties and utilization for optimum production	3	17	29	61
Range livestock production	1	16	27	27
Energy development and range impacts	1	15	25	25
Ability to write well	2	12	20	36
Use of stats and field smapling skills	2	10	17	29
Use of computer to solve problems	1	8	14	14
Keeping up with professional literature and using the information	4	5	8	27
Problems of endangered species	1	4	7	7

Education in knowledge with a strong field component received general approbation from the alumni. When the scores of individual items are checked on the scale of one to five, however, the approval is clearly qualified, and there is obviously room for improvement in those areas where the Department should be most competent and most highly recognized, such as assessing range condition and trend.

The responses to the second questionnaire summarized in Table 2 are useful in evaluating teaching performance but provide little by way of direction for curriculum revision. For example, the low score for performance in teaching computer skills does not automatically mean that this subject should therefore be dropped from the curriculum. Guidelines for possible changes in the curriculum were obtained by asking alumni to identify ten of the total 43 questions (in the second questionnaire) as items deserving emphasis for future education development in the Department. A summary analysis of critical items is given in Table 3.

Even though plant identification and condition assessment scored well on the performance part of the questionnaire, they also ranked high in emphasis for future improvement, which underlines their centrality to a college range training.

It is interesting to note that the impact of energy development is recommended for future curriculum emphasis by a quarter of the respondents, while problems of endangered species, another popular issue of the current decade, was scarcely marked.

The use of statistics and field sampling techniques did not rank very high on the list in Table 3, which could mean that instructional coverage is already quite adequate, even though performance in this area is not outstanding (Table 2).

Three quarters of the alumni marked for future educational emphasis questions dealing with economic considerations and political problems in range management, the pragmatics of range science, and persuasive communication. A need was identified for more education in multiple use policies and practices, and for an ecosystem approach to optimum utilization.

Rangelands that once were the almost exclusive province of ranchers, prospectors, and provident hunters are now the playground of American suburbia and often the watershed resource for distant urban sprawls. This trend in variable use adds capricious expectations to the traditional demands of management practice, and resource management becomes a complicated political exercise (Harris 1977). The range manager of today may be confronted with unforeseen management situations in the decades ahead, such as the evolution of ranching into a form of conspicuous consumption like owning one's own aircraft for the life style it provides rather than for an income base (Clawson 1972), a terminal case of change in rangeland values. The range graduate must be flexible and adaptable to the new politics of public land management. Several years ago McGuire (1973) concluded that "no longer can we rest our case solely on professional judgement or technical facts," we also need diplomacy, courtesy and persuasive arguments to address the claims of those who do not comprehend technical facts and may not respect professional judgment.

Aftermath

It has been 2 years since the data from this study were first reported at the annual departmental retreat. The findings provoked considerable interest among faculty at that time and the study has since become part of the department's data arsenal for such items as an accreditation self-study report written in 1979, or course revision for individual professors.

As a department, the decision to add several new courses is the most tangible evidence that this study made a difference. The first curriculum change to be implemented as a result of the questionnaire was the introduction of a course specifically designed to teach communication techniques in natural resource management. A plant taxonomy course followed, and there has been discussion of more instruction in range ecology. The advanced course in range livestock production has already been mentioned. The highly important need areas of economic and political considerations are being dealt with through a three-course, core curriculum for the entire Natural Resources college, since these issues certainly transcend departmental lines (Eastmond and Kadlec 1977). In any case, the direct outcomes and subsequent spinoffs from this study have been considerable.

It is noteworthy that no courses have been *dropped* specifically because of this study, which, although logical, reflects a very real situation in curriculum change, namely that it is easier to enthusiastically support the new rather than eliminate the old. More likely is the prospect of weeding out courses based upon low enrollments in a future departmental housekeeping move.

It should also be noted that the Range Science Department has in no way felt limited by the findings of the study. For example, there was little indication from the questionnaire that a course in international aspects of range management was deserving of attention, with only five respondents citing this item as critical. And yet a senior level course dealing with these international issues has been recently introduced and appears relatively popular. In other curriculum areas as well, this survey has been taken as indicative but not definitive, as pointing out possible directions but certainly not representing the final word. The opinions of alumni as reflected in this survey are taken as one important perspective, a perspective which is often lacking in departmental decision making, but a perspective which is not without its own limitations.

Literature Cited

Arnold, R.K. 1970. Changing educational needs for research, teaching, and extension. J. Range Manage. 23:330-333.

Box, T.W. 1974. Trends in range management education. J. Range Manage. 17:237-241.

Clawson, M. 1972. Range management in the United States for the next one to three generations. J. Range Manage. 25:328-332.

Collins, R.A. 1956. A student looks at range education. J. Range Manage. 9:207-208.

Cook, C.W., and C.D. Bonham 1974. An analysis of range conservation academic training. J. Range Manage. 27:480-483.

Costello, D.F. 1957. Range management education. V. College training for range management students: an employer's view. J. Range Manage. 10:121-122.

Cronbach, L.J. 1949. Essentials of Psychological Testing. Harper and Row, New York.

Cross, K.P. 1971. Beyond the Open Door: New Students to Higher Education. Jossey-Bass, San Francisco.

Dregne, H.E., and R.D. Pettit 1972. Environment, ecology, and range management curricula. J. Agron. Educ. 1:72-75.

Dyksterhuis, E.J. 1953. Some notes and quotes on range education. J. Range Manage. 6:295-298.

Eastmond, J.N., and J.A. Kadlec 1977. Undergraduate educational needs in wildlife science. Wildlife Soc. Bull. 5:61-66.

Harris, G.A. 1977. Changing philosophies of rangeland management in the United States. J. Range Manage. 30:75-78.

Heady, H.F. 1961. Range curricula. J. Range Manage. 14:301-314.

Hervey, D.F. 1964. The challenge of the future as viewed by educators in range schools. J. Range Manage. 17:119-121.

Hooper, J.F. 1969. The uniqueness of range management. J. Range Manage. 22:67-68.

Johnson, R. 1951. Range education. J. Range Manage. 4:315-318.

Kaufman, R.A. 1972. Educational System Planning. Prentice-Hall, Englewood Cliffs, N.J.

Keith, T.B. 1957. Range management education. III. Animal husbandry training for the range livestock producer. J. Range Manage. 10:23-25.

Kienast, C.R., and C.J. Scifres 1973. Survey of professional attitudes toward range science education and training. J. Range Manage. 26:161-164.

Lehman, A. 1966. A technical education isn't enough. J. Range Manage. 19:171-172.

McGuire, J.R. 1973. Status and outlook for range in the new politics. J. Range Manage. 26:312-315.

McKell, C.M. 1970. Range management at the crossroads. J. Range Manage. 23:222-223.

Morris, M.W. 1961. Range management as a profession. J. Range Manage. 14:3-5.

Powell, J. 1975. Who hires them? A survey of range graduate employment. Rangeman's J. 2:47-49.

Sampson, A.W. 1951. Range management education. J. Forest 49:507-510.

Sampson, A.W. 1954. The education of range managers. J. Range Manage. 7:207-212.

Tisdale, E.W. 1956. Range management education. II. College training in range management. J. Range Manage. 9:218-219.

Washburn, L.E. 1957. Range management education. IV. The educational problem common to range management and animal husbandry. J. Range Manage. 10:79-82.

Witkin, B.R. 1977. Needs assessment Kits, Models and Tools. Educational Technology 17:11, p. 5-18.

Comparative Biomass and Water Status of Four Range Grasses Grown under Two Soil Water Conditions

HEMA PANDE AND J.S. SINGH

Abstract

The influence of water stress on growth of four grasses was investigated. *Panicum coloratum* and *Chloris gayana,* the two C_4 species, were more adversely affected, while the two C_3 species *(Poa pratensis* and *Lolium perenne)* were found to tolerate the water stress conditions better as reflected by a comparatively smaller decline in their biomass.

Water stress develops in a plant when the rate of transpiration exceeds the rate of water uptake in transport through the plant (Kozlowski 1968). The effect of water stress has been studied in numerous plants with the indication that under such conditions the growth is usually retarded (Mott and McComb 1975, Gerakis et al. 1975, Etherington 1967, etc.). According to De Puit and Caldwell (1975), water stress reduces plant growth by decreasing net assimilation. It has also been noted that C_3 and C_4 plants respond differentially to water stress. Many C_4 plants (e.g., *Zea Mays*) (Boyer 1970) are found to be more severely affected by drought than C_3 plants although they have many characteristics which enable them to adapt effectively under stress. On the other hand, many C_3 species such as *Poa pratensis* (Carrol 1943), can withstand water stress rather effectively.

The purpose of this study was to obtain information on the influence of water stress on growth of four range grasses. Out of these four grasses, *Poa pratensis* L. (Kentucky bluegrass) and *Lolium perenne* L. (Perennial rye grass) have C_3 pathway of photosynthesis and the other two, *Chloris gayana* (Kunth (Rhodesgrass) and *Panicum coloratum* L. (Makarakeri grass), possess the C_4 photosynthetic pathway. While the first two species grow naturally in the temperate Himalaya, the latter two are being tested for introduction in this area to augment the forage supply.

Material and Methods

Plant Material

Tillers of *Poa pratensis* and *Lolium perenne* were collected in the beginning of July, 1977, from a native sward at Naini Tal (29° 24′ N.lat. and 79° 28′ E. long., 2,050 m altitude), while those of *Chloris gayana* and *Panicum coloratum* were obtained from the farm of Indo-German Agricultural Development Association (IGADA) at Almora (67 km north of Naini Tal). Within each species the tillers were of uniform size. The tillers were transplanted into polyethylene pots filled with a weighed amount of a mixture of soil and farmyard manure (3:1) and grown under glasshouse conditions at Naini Tal from July to November, 1977. Temperature in the glasshouse ranged between 11° C (minimum) and 32° C (maximum) during the experimental period.

Soil Water Conditions

The water-holding capacity of the pot mixture was determined (Piper 1966) before the start of the experiment and after tiller transplantation. For the first 2 weeks, the pots were watered regularly to bring the soil water to the level of maximum waterholding capacity. After this period soil water content in one set of pots for each species was maintained at full water holding capacity (1 WHC) while in the other set the soil was allowed to dry to a level as close as possible to half water-holding capacity (½WHC). Under both conditions pots were weighed every 3rd or 4th day and soil water was brought to the desired level (i.e., 1 WHC and ½ WHC). Also, soil water content was monitored gravimetrically at frequent intervals. For each species 72 pots were maintained under 1 WHC and 72 pots under ½ WHC. There was small variation in water content within each set as exemplified by data in Table 1.

Table 1. Percent soil water content on November 9, 1977.

Species	Treatment 1 WHC	Treatment ½ WHC
Poa pratensis	45 ± 1.60	25 ± 1.10
Lolium perenne	42 ± 1.60	25 ± 1.60
Panicum coloratum	46 ± 1.60	21 ± 1.70
Chloris gayana	43 ± 1.10	23 ± 0.80

Plant Water Status

The relationship between the initial and turgid water content has been expressed in various forms, such as water saturation deficit (WSD) (Oppenheimer and Mendel 1939) and relative turgidity (Weatherly 1950) or relative water content (RWC) (Ehlig and Gardner 1964; Slatyer and Barrs 1965). The term relative turgidity has been frequently used but it is an unsuitable term, as the measured value by no means expresses turgor (Slavik 1974). However, since both WSD and RWC are related with each other (WSD = 100 - RWC), determination of one of them is sufficient to express the plant water status. For the determination of WSD, the last fully emerged leaf in each case was sampled, weighed, immersed in distilled water for 2½-3 hours, again weighed, oven dried, and reweighed. The following expression was used:

$$\text{Water saturation deficit (\%)} = \frac{\text{Saturated weight-original fresh weight}}{\text{Saturated weight-oven dry weight}} \times 100$$

The absolute water content before saturation (WCBS) and after saturation (WCAS) was calculated on per gram dry weight basis.

Before excising the leaves the apparent width and thickness at the midpoint of each leaf was measured to determine leaf rolling index (LRI)[1]. The expression used for the calculation of LRI was:

$$\text{LRI} = \frac{\text{Apparent thickness of leaf (mm)}}{\text{Apparent width of leaf (mm)}}$$

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[1]Redmann, R.E. 1973. Plant water relationships. Tech. Rep. No. 29. Canadian Commission for IBP. Matador Proj., Univ. Saskatchewan. 84 p.

The total number of leaf samples for all the above determinations were 9,9 (1 WHC, ½ WHC) for *Poa pratensis;* 10,14 (1 WHC, ½ WHC) for *Lolium perenne;* 11,12 (1 WHC, ½ WHC) for *Panicum coloratum* and 6,6 (WHC, ½ WHC) for *Chloris gayana.*

Pigment Concentration

On the same date when leaf water status was determined, leaf samples from three plants under each treatment were collected from each plot for chlorophyll estimation. The outline of these leaf samples were drawn on a paper to determine leaf area, using a planimeter. Each leaf sample was then divided in two halves, one of which was used to determine dry weight, while the other was used for chlorophyll determination. Chlorophyll was extracted in 80% acetone and the optical density (OD) was read at 630, 645, 652, and 665 nm in a spectrophotometer. The expressions given by Arnon (1949) were used for the calculation of pigment concentration:

$$\text{Total Chl (a+b), (mg/l)} = \frac{OD_{652} \times 1000}{34.5}$$

$$\text{Chl a (mg/l)} = 15.6\ OD_{665} - 2.0\ OD_{645} - 0.8\ OD_{630}$$

$$\text{Chl b (mg/l)} = \text{Total Chl} - \text{Chl a}$$

Plant Biomass

The rest of the plant material, from which leaves were sampled for chlorophyll, was then carefully removed, washed, separated into component parts (leaves, stem, and roots), oven dried at 80° C, and weighed. The weight of the material used for chlorophyll determination was added to the leaf weight.

Total Leaf Area and Specific Leaf Area

The specific leaf area was calculated by dividing the leaf area by leaf dry weight (as determined above, see pigment concentration). The specific leaf area was multiplied by the total leaf dry weight to obtain total leaf area per plant.

The degree of succulence was calculated using the following expression:

$$\text{Degree of succulence} = \frac{\text{Water content at saturation (g)}}{\text{Surface area (cm}^2\text{)}}$$

The data reported in this paper were collected in November, 1977, when the experiment was terminated.

Results and Discussion

Both shoot and root dry weights were lower in plants under ½ WHC compared to the 1 WHC condition (Table 2). The decline in the plant biomass was greatest for *Panicum* followed by *Chloris* and *Poa. Lolium* showed the least reduction in total biomass. Several authors have reported a reduction in the dry matter yield of grasses caused by water stress (Mott and McComb 1975, Gerakis et al. 1975). This decrease is evidently due to a decline in net assimilation brought about by decreased water potentials in the leaves (De Puit and Caldwell 1975). Kozlowski (1964, 1968), Slatyer (1967), Crafts (1968), and Kramer (1969) have also reported that a decrease in turgor due to water stress influences cell expansion, which in turn causes reduction in photosynthesis. The effect of water stress on the yield may be accentuated since the rate of decline of photosynthesis may be more rapid than that of respiration under water stress (Kramer 1969, Levitt 1972). In certain situations water stress coupled with high temperature may even cause an increase in respiration rate thus depressing the net assimilation further (Hellmuth 1968, Troughton and Cowan 1968, and Dunn 1970). Etherington (1967) found that even very slight water deficits reduced photosynthesis in *Alopecurus pratensis* considerably. That the adverse effect of water stress on growth is variable for different species and depends on their relative drought tolerance has been shown by various authors (Mott and McComb 1975, Gerakis et al. 1975).

Table 2. Effect of water stress on dry matter yield of four grasses.

Species	Total shoot dry weight (g/plant)	Total root dry weight (g/plant)	Total plant dry weight (g/plant)	Root/shoot ratio
Poa pratensis				
1 WHC	2.1 ± 0.03	1.4 ± 0	3.5 ± 0.03	0.6 ± 0.01
½ WHC	1.5 ± 0.03	0.6 ± 0.06	2.1 ± 0.03	0.04 ± 0.06
Lolium perenne				
1 WHC	2.3 ± 0.03	1.9 ± 0.50	4.2 ± 0.50	0.8 ± 0.20
½ WHC	2.2 ± 0.10	1.6 ± 0.30	3.8 ± 0.40	0.7 ± 0.01
Panicum coloratum				
1 WHC	7.4 ± 0.80	2.4 ± 0.70	9.8 ± 1.40	0.3 ± 0.10
½ WHC	4.0 ± 0.30	1.1 ± 0.90	5.1 ± 0.40	0.3 ± 0.03
Chloris gayana				
1 WHC	6.1 ± 0.30	0.9 ± 0.30	7.0 ± 0.10	0.14 ± 0.10
½ WHC	3.3 ± 0.20	0.9 ± 0.3	4.2 ± 0.30	0.30 ± 0.10

The relative decrease in shoot and root dry weights was different in different species. The water stress caused a severe reduction in the shoot dry weight of the two C_4 species (about 50%), while in *Poa* and *Lolium* the reduction was negligible. This would indicate that the two C_3 species are more resistant to water stress; Carrol (1943) also found *Poa pratensis* to be one of the most drought-tolerant species out of several pasture grasses test. Boyer (1970) found that photosynthesis in *Glycine hispida* was not reduced until leaf water potential dropped below −11 bars, while photosynthesis of corn was affected anywhere below −3.5 bars. Therefore, *Z. mays,* which has a C_4 pathway, is more sensitive to desiccation.

Reduction in the root dry weight was greatest for *Poa* (58%) followed by *Panicum* (53%) and *Lolium* (18%). In fact, in *Lolium* the root dry weight under ½ WHC was considerably higher on all sampling dates before the final harvest for which data are reported in this paper. On the other hand, the water stress had no influence on the root weight of *Chloris.* Only a slight, or no, decrease in root weight may be due to some stimulation of root growth by slight moisture stress. This has also been reported for certain other species (Eaton 1942, Jarvis 1963).

There was a decline in the root/shoot ratio due to water stress in *Poa* and *Lolium,* while in the case of C_4 plants either the root/shoot ratio increased *(Chloris)* or remained unchanged *(Panicum).* Several authors have reported an increase in root/shoot ratios of plants growing under water stress (Peters and Runkles 1967, Black 1968). According to Loomis et al. (1971) the water stress slows shoot growth more and sooner than it does root growth. The root/shoot behaviour of *Poa* and *Lolium* did not conform to the above findings (e.g., Fig. 1 a,b). Gerakis et al. (1975) in *Bromus,* and Williams and Shapter (1955) in many graminaceous species also showed a decrease in root/shoot ratio with increasing water stress. Evidently, within limits, an increase in

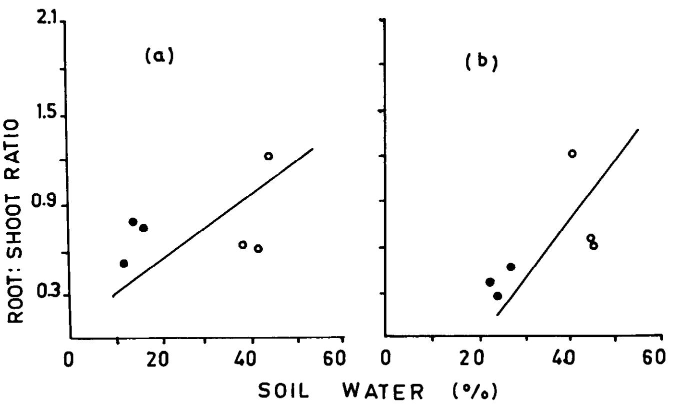

Fig. 1. *Root: shoot ratio of* Lolium perenne *(a), and* Poa pratensis *(b) at different soil water conditions. Solid circles represent plants grown near ½ WHC and open circles represent plants grown near 1 WHC. In this and other figures, curves are fitted by eye.*

Table 3. Leaf area and pigment concentration (mean ± 1 SE) in four grasses grown under two soil watering conditions.

Species	Specific leaf area (cm^2)	Total leaf area (cm^2)	Chlorophyll (mg/g dry weight) Chl a	Chl b	Total Chl
Poa pratensis					
1 WHC	439.90 ± 68.00	697.60 ± 138.50	1.03 ± 0.04	0.68 ± 0.09	1.70 ± 0.11
½ WHC	513.30 ± 66.10	611.30 ± 111.80	1.31 ± 0.11	1.54 ± 0.15	2.86 ± 0.26
Lolium perenne					
1 WHC	628.10 ± 142.30	975.0 ± 163.50	1.17 ± 0.17	0.66 ± 0.17	1.83 ± 0.34
½ WHC	493.20 ± 71.70	895.80 ± 180.20	0.91 ± 0.04	0.34 ± 0.06	1.24 ± 0.01
Panicum coloratum					
1 WHC	579.80 ± 51.00	2406.50 ± 384.40	1.23 ± 0.08	1.67 ± 0.20	2.90 ± 0.28
½ WHC	358.80 ± 23.40	936.60 ± 151.80	0.73 ± 0.04	0.42 ± 0.07	1.15 ± 0.12
Chloris gayana					
1 WHC	202.20 ± 30.50	679.60 ± 124.40	0.41 ± 0.07	0.47 ± 0.14	0.88 ± 0.21
½ WHC	323.90 ± 39.80	527.20 ± 24.7	0.30 ± 0.01	0.51 ± 0.05	0.81 ± 0.05

Table 4. Certain plant water status parameters for four grasses grown under two soil water conditions.

Species	(Mean ± SE) Water content before saturation (g H_2O/g dry weight)	Water content after saturation (g H_2O/g dry weight)	Water saturation deficit (%)	Water saturation deficit deficit on the basis of 1 WHC plants	Leaf rolling index
Poa pratensis					
1 WHC	1.7 ± 0.15	4.1 ± 0.17	42 ± 2.2	—	0.005 ± 00
½ WHC	1.2 ± 0.05	4.7 ± 0.24	61 ± 1.7	70	0.017 ± 0.004
Lolium perenne					
1 WHC	2.6 ± 0.29	3.7 ± 0.37	29 ± 3.2	—	0.013 ± 0.002
½ WHC	0.64 ± 0.05	2.2 ± 0.20	72 ± 4.2	81	0.017 ± 0.001
Panicum coloratum					
1 WHC	2.1 ± 0.10	3.0 ± 0.15	29 ± 1.6	—	0.005 ± 0.001
½ WHC	1.5 ± 0.15	2.7 ± 0.27	54 ± 3.7	58	0.009 ± 0.002
Chloris gayana					
1 WHC	1.8 ± 0.27	5.2 ± 0.47	65 ± 4.4	—	0.005 ± 0.001
½ WHC	1.7 ± 0.10	5.0 ± 0.47	65 ± 3.2	66	0.013 ± 0.002

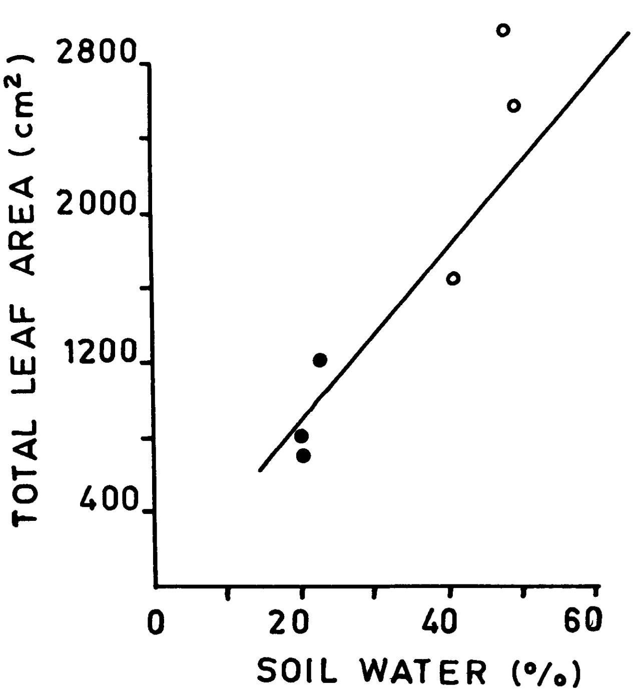

Fig. 2. *Relationship between total leaf area and soil water in* Panicum coloratum. *Solid circles represent plants grown near ½ WHC and open circles represent plants grown near 1 WHC.*

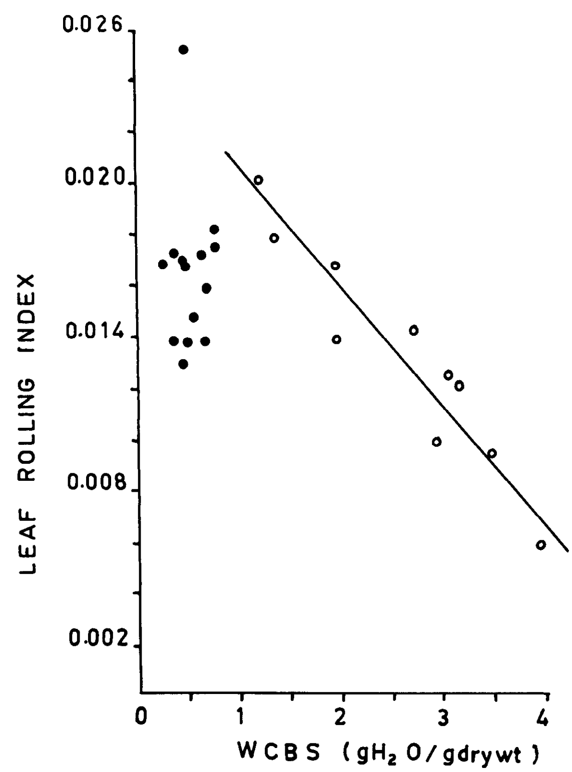

Fig. 3. *Relationship between leaf rolling index and absolute water content before saturation (WCBS) in* Lolium perenne. *Solid circles represent plants grown near ½ WHC and open circles represent plants grown near 1 WHC.*

the supply of water to the roots may increase both root and shoot growth, the latter to a greater extent (Troughton 1960, 1962, Wardlaw 1968; Davidson 1969, Luxmoore and Millington 1971). Both *Poa* and *Lolium* had the greatest root/shoot ratios. This characteristic is thought to be conducive to drought tolerance (Maximov 1929; Parker 1968).

The values for total leaf area per plant were somewhat lower in ½ WHC plants as compared to the plants under 1 WHC; however, the effect was not significant in *Poa* and *Lolium* (Table 3). In *Poa* and *Chloris* the specific leaf area in plants under ½ WHC was greater than that in 1 WHC plants, while the reverse was true for the other two species (Table 3). The chlorophyll concentration, with the exception of *Poa*, was lower in plants growing under ½ WHC. In three out of four species there appeared to be a positive relationship between total leaf area and soil water (e.g., Fig. 2). Water stress may often slow the leaf expansion even before affecting photosynthesis (Brouwer and de Wit 1969). Further, Etherington (1967) has reported that in *Alopecurus pratensis* the reduction of net assimilation rate conforms with the lowered photosynthesis, and the reduced leaf area ratio suggests that water stress limits full tissue expansion.

The water content before saturation (WCBS), as expected, was higher in plants of all species grown under 1 WHC (Table 4). The difference in this attribute between 1 WHC and ½ WHC conditions was maximum in *Lolium* and almost negligible in *Chloris*. After saturation, the water content of the leaf tissue increased in all the cases but the magnitude of increase was variable. For instance, in *Poa* and *Chloris* the water content subsequent to saturation increased about four times, while in *Panicum* and *Lolium* the increase was only 1.5 to 2 times (Table 4). Consequently, the water content needed for saturation was much more in the cases of *Chloris* and *Poa* as compared to the other two species.

Although the leaf tissue from the plants grown under 1 WHC also showed a considerable amount of WSD, the latter was conspicuously magnified in the plants under ½ WHC, with the exception of *Chloris*, in which the difference in WSD between the two water treatments was negligible. When the WSD in leaves under ½ WHC was calculated relative to that of 1 WHC plants the values came out relatively higher for *Poa* and *Lolium* as compared to the two C_4 species (Table 4).

Invariably the leaf rolling index (LRI) was higher for plants grown under ½ WHC (Table 4). Leaves of a number of grasses show a tendency to roll in response to higher temperatures and low water availability. This reduces the radiation load on the leaves as well as increases the transfer of sensible heat (Maxwell and Redmann 1974)[2]. Leaf rolling is taken as an important adaptational feature for withstanding water stress and perhaps as a good index of water status of plant. Maxwell and Redmann (1974)[2], while working on the water relations of *Agropyron dasystachyum*, have reported that the degree to which the leaves roll appears to be directly related to the water potential of the tissue within the range of 0 to -35 bars. Further there existed a very significant correlation between absolute water content (=WCBS) and water potential of leaf tissue. In the present study there existed an inverse relation between leaf rolling index (LRI) and water content before saturation (WCBS). The relation was particularly marked in plants under 1 WHC of *Lolium* (e.g. Fig. 3); in other cases, particularly in plants under ½ WHC, this relation was not so marked indicating a good deal of variability in these two attributes from species to species.

According to Larcher (1929), the relationship between transpiring surface and water stored in the tissue is expressed by the specific leaf area and degree of succulence. Since the rate of water evaporation usually increases with increasing transpiring area, a high degree of succulence is congenial to water conservation in a leaf. In the present study maximum degree of succulence was recorded for *Chloris* (average 0.026) and minimum for *Panicum* (average 0.005). The water stress did not materially affect the degree of succulence. However, WSD was positively related with the degree of succulence (Fig. 4 a,b) indicating an increasing trend at water conservation with increasing water deficit. Further, there was relatively a much wider range both in degree of succulence as well as in saturation deficit for the two C_4 species (Fig. 5). The water stressed plants (½ WHC) did not show any clear-cut relation between LRI and degree of succulence. The plants are known to become relatively insensitive as far as their water relations are concerned under prolonged drought conditions (Slatyer 1967).

In conclusion it may be stated that in all the four plants,

[2]Maxwell, J. and Redmann, R.E. 1974. Water relations and growth of *Agropyron dasystachyum*: recovery from soil moisture stress. Matador project. Tech. Rep. No. 64. Canadian Committee for the Internat. Biol. Programme.

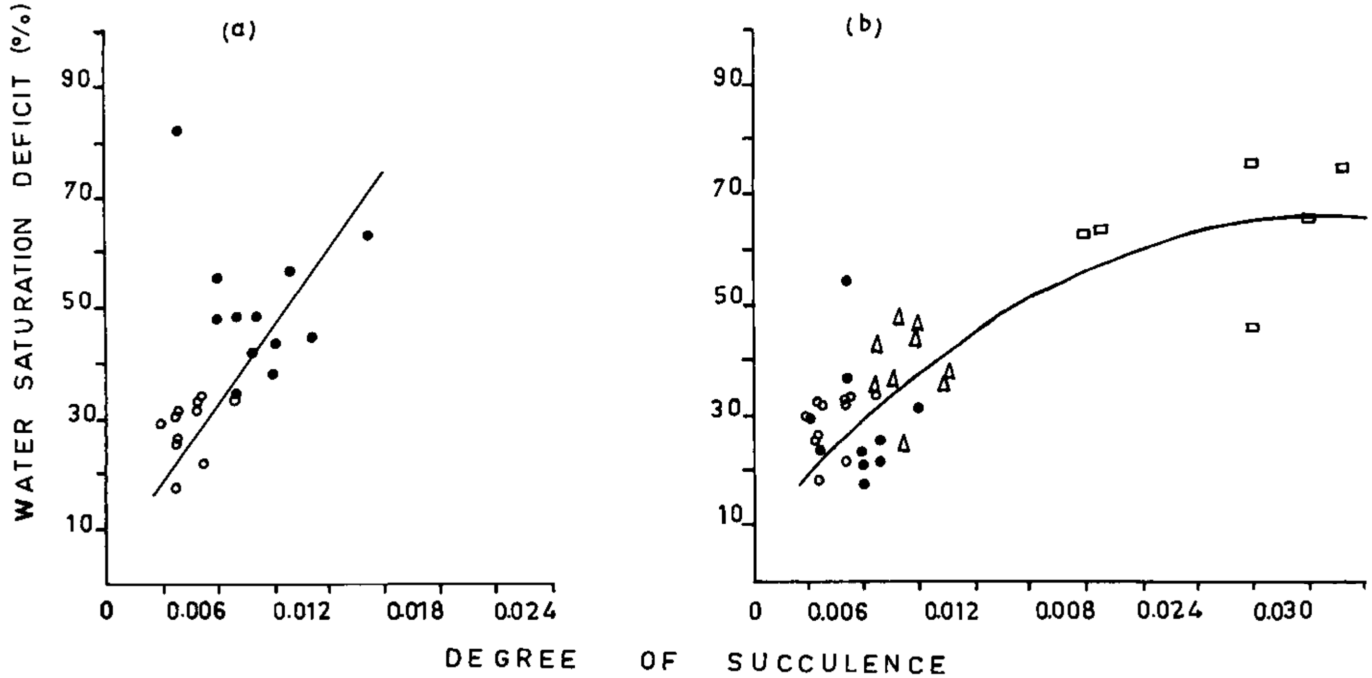

Fig. 4. *Relationship between saturation deficit and degree of succulence. (a)* Panicum coloratum, *solid circles represent plants grown near ½ WHC and open circles represent plants grown near 1 WHC.* *(b) Plants grown near 1 WHC. Solid cirlces =* Lolium perenne, *open circles =* Panicum coloratum, *triangles =* Poa pratensis, *and squares =* Chloris gayana.

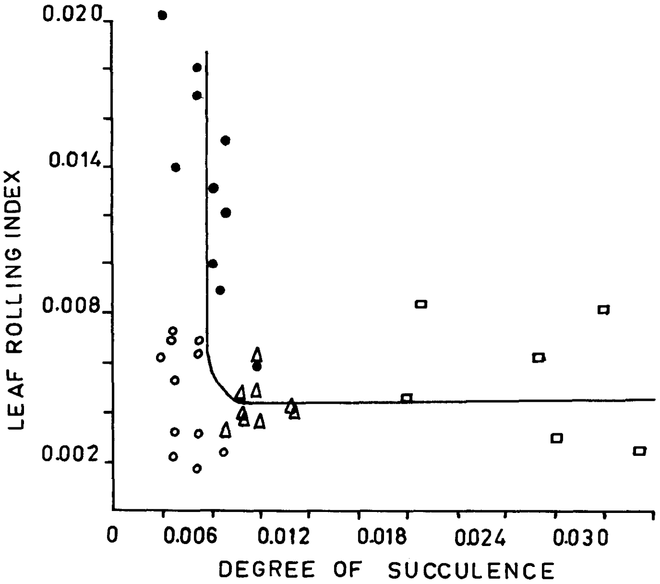

Fig. 5. *Relationship between leaf rolling index and degree of succulence in plants grown near 1 WHC. Solid circles* = Lolium perenne, *open circles* = Panicum coloratum, *triangles* = Poa pratensis, *and squares* = Chloris gayana.

notwithstanding the type of photosynthetic pathway involved, water stress results in a decline in growth. Relatively there was a greater decline in the plant biomass of C_4 plants (39% *Chloris*, 48% *Panicum*) as compared to the C_3 plants (9% *Lolium*, 31% *Poa*). The C_3 plants developed a greater amount of WSD under conditions of water stress as compared to the C_4 plants, reflected comparatively a greater amount of leaf rolling and a higher root/shoot ratio. Thus the two native C_3 species were found to be better at resisting water stress compared to the two introduced C_4 species. This is in contrast to the general belief that the C_4 species have a greater drought resistance than C_3 species (Singh et al. 1980). Perhaps the C_4 plants possess a competitive advantage over C_3 plants only under conditions of high temperature and intermittent water stress (Doliner and Jolliffe 1979), while in a low temperature region such as as Naini Tal, the C_3 plants are better at resisting drought.

Literature Cited

Arnon, D.I. 1949. Copper enzymes in isolated chloroplasts (1) Polyphenol oxidase in *Beta vulgaris.* Plant Physiol. 24:1-15.

Black, C.A. 1968. Soil Plant Relationships, 2nd ed. Wiley, New York.

Boyer, J.S. 1970. Differing sensitivity of photosynthesis to low leaf water potential in corn and soybean. Plant Physiol. 46:236-239.

Bouwer, R., and C.T. de Wit. 1969. A simulation model of plant growth with special attention to root growth and its consequences. *In:* W.J. Whittington, (ed.). Root Growth, p. 224-44. Butterworth London.

Carrol, J.C. 1943. Effects of drought, temperature, and nitrogen on turf grasses. Pl. Physiol., Lancaster, 18:19-36.

Crafts, A.S. 1968. Water deficits and physiological processes. *In:* Water Deficits and Plant Growth (T.T. Kozlowski, ed.), Vol. II, Chapter 3, p. 85. Academic Press, New York.

Davidson, R.L. 1969. Effects of edaphic factors on the soluble carbohydrate contents or roots of *Lolium perenne* L. and *Trifolium repens* L. Ann. Bot. (N.S.) 33:579-589.

DePuit, J.E., and M.M. Caldwell. 1975. Gas exchange of three cool semi-desert species in relation to temperature and water stress. J. Ecol. 63:835-856.

Dolliner, L.H., and P.A. Jolliffe. 1979. Ecological evidence concerning the adaptive significance of the C-4 discarboxylic acid pathway of photosynthesis. Oecologia (Berl.) 38:23-34.

Dunn, E.L. 1970. Seasonal patterns of carbondioxide metabolism in evergreen sclerophylls in California and Chile. Ph.D. Thesis, Univ. of California. Los Angeles.

Eaton, F.M. 1942. Toxicity and accumulation of chloride and sulfate salts in plants. J. Agr. Res. 64:357-99.

Ehlig, C.F., and Gardner, W.R. 1964. Relationship between the transpiration and internal water balance of plants. Agron. J. 56:127-30.

Etherington, J.R. 1967. Soil water and growth of grasses. II. Effects of soil water potential on growth and photosynthesis of *Alopecurus pratensis.* J. Ecol. 55:373-80.

Gerakis, P.A., Guerrero, E.P., and Williams W.A. 1975. Growth, water-relations and nutrition of three grassland annuals as affected by drought. J. App. Ecol. 12:125-135.

Hellmuth, E.O. 1968. Ecophysiological studies on plants in arid and semi-arid regions in Western Australia. I. Autecology of *Rhagodia baccata.* J. Ecol. 56:319-444.

Jarvis, M.S. 1963. A comparison between the water relations of species with contrasting types of geographical distribution in the British Isles. The water relations of plants *In:* A.J. Rutter and F.H. Whitehead (eds.) p. 289-312. Blackwell Scientific Publications, Oxford.

Kramer, P.J. 1969. Plant and Soil Water Relationship-A modern Synthesis. McGraw Hill, New York.

Kozlowski, T.T. 1964. Water Metabolism in Plants. Harper, New York.

Kozlowski, T.T. 1968. Introduction. *In:* T.T. Kozlowski, (ed.). Water Deficits and Plant Growth, Vol. 1, p. 1. Academic Press, New York.

Larcher, W. 1929. Physiological plant ecology (Translated by M.A. Biederman-Thornson). Springer-Verlag, Berlin (1975).

Levitt, J. 1972. Responses of Plant to Environmental Stress. Academic Press New York.

Loomis, R.S., W.A. Williams, and A.D. Hall. 1971. Agricultural productivity. Annu. Rev. Plant Physiol. 22:431-68.

Luxmoore, R.J., and R.J. Millington, 1971. Growth of perennial rye-grass in relation to water, nitrogen and light intensity I. Effects on leaf growth and dry weight. Plant Soil 34:269-281.

Maximov, N.A. 1929. The Plant in Relation to Water. Allen and Unwin, London.

Mott, J.J., and A.J. McComb. 1975. Effects of moisture stress on the growth and reproduction of three annual species from an arid region of Western Australia. J. Ecol. 63:825-834.

Oppenheimer, H.R., and K. Mendel. 1939. Orange leaf transpiration under orchard conditions. I. Soil moisture. high. Palestine J. Bot. 2:171-250.

Parker, J. 1968. Drought resistance mechanisms. *In:* T.T. Kozlowski (ed.). Water Deficits and Plant Growth. p. 195-234. Academic Press, New York.

Peters, D.B., and J.R. Runkles. 1967. Shoot and root growth as affected by water availability. *In:* R.M. Hagan, H.R. Haise, and T.W. Edminster (eds.). Irrigation of Agricultural Lands. p. 373-89. Amer. Soc. of Agron., Madison, Wisconsin.

Piper, C.S. 1966. Soil and Plant Analysis. Hans Publishers, Bombay.

Singh, J.S., M.J. Trlica, P.G. Risser, R.E. Redmann, and J.K. Marshall. 1980. Autotrophic subsystem. *In:* A.I. Breymeyer and G.M. van Dyne (ed.) Grasslands, Systems Analysis, and Man. Cambridge University Press, London, p. 59-200.

Slatyer, R.O., and H.D. Barrs. 1965. Modifications to the relative turgidity techniques with notes on its significance as an index of the internal water status of leaves. *In:* Methodology of Plant Ecophysiology, p. 331-41. UNESCO, Paris.

Slatyer, R.O. 1967. Plant Water Relationships. Academic Press, New York.

Slavik, B. 1974. Methods of Studying Plant Water Relations. Academia Publishing House of the Czechoslovak Academy of Sciences, Prague; Springer-Verlag, New York.

Troughton, A. 1960. Further studies on the relationship between shoot and root systems of grasses. J. Br. Grassl. Soc. 15:41-47.

Troughton, A. 1962. The roots of temperate cereals. Common W. Bur. Pastures Field Crops. Mimeo. Publ. No. 2/1962. p. 1-91.

Troughton, J.H., and I.R. Cowan. 1968. Carbondioxide exchange in cotton: Some anomalous fluctuations. Science, N.Y. 161, 281-83.

Wardlaw, I.F. 1968. The control and pattern of movement of carbohydrates in plants. Bot. Rev. 34:79-105.

Weatherly, P.E. 1950. Studies in the water relations of cotton plant. I. The field measurement of water deficits in leaves. New Phytol. 49:81-97.

Williams, R.F., and R.E. Shapter. 1955. A comparative study of growth and nutrition in barley and rye as affected by low water treatment. Aust. J. Biol. Sci. 8:435-66.

Increased Soil Water Storage and Herbage Production from Snow Catch in North Dakota

R.E. RIES AND J.F. POWER

Abstract

This study documents the effect of three grass stubble heights (15, 30, and 60 cm) on overwinter storage of soil water and the subsequent effect on forage production the following growing season. Soil water was increased over the winter by 0.24 cm for each centimeter of grass stubble left between 15 and 60 cm in height. Each centimeter increase in soil water stored over the winter increased forage production by 115 and 62 kg/ha for introduced and native species, respectively. Results indicate the importance of stubble height in increasing forage production from grasslands of the Northern Great Plains by trapping snow and storing soil water for use by the plant community the following growing season.

Snow catch and the resulting meltwater can be an important source of soil water for dryland agriculture. Matthews (1940) discussed the importance of using snow meltwater in Canadian prairie agriculture in Saskatchewan and described some of the methods used for trapping snow. Willis and Haas (1969) discussed the importance of snow as a source of water in the Northern Plains.

Various techniques have been used over the years to increase snow catch and subsequent storage of meltwater for use in agricultural production. Haas and Willis (1968, 1971) reported that conservation bench terraces and level bench terraces increased the snow catch and reduced snow melt runoff when compared with nonterraced areas. The additional soil water stored on the benched areas significantly increased crop and forage production. Rauzi (1973) reported similar findings from the use of level bench terraces in northeastern Wyoming.

Perennial grass barriers of tall wheatgrass (*Agropyron elongatum* Host.) provided effective snow catch and erosion control in northeastern Montana (Black and Siddoway 1971). Greb and Black (1971) evaluated vegetation barriers and artificial fences for managing snow in the Central and Northern Plains. Both techniques enhanced snow catch, resulting in more soil water available for use by desired vegetation. Pitting and interseeded crested wheatgrass (*Agropyron* spp.) increased trapped snow resulting in increased soil water storage, forage and annual carrying capacity of native shortgrass rangeland in southeastern Wyoming (Rauzi 1968). Wight et al. (1975), discussing snow management in relation to eastern Montana rangeland, pointed out that snow management on the semiarid rangelands of the Northern Great Plains could provide a hedge against drought. They believe new ideas and research can lead to more effective use of snow as a resource for rangeland. Nicholaichuk and Norum (1975) addressed snow management on the Canadian prairies. They described snow distribution, the history of snow management, the influence of shelterbelts on snow accumulation, and the effect on snow trapping by swathing grain at alternate stubble heights. Data collected for 1973-75 showed that wheat stubble (*Triticum aestivum* L.) swathed at alternate stubble heights of 12 to 5 inches (30 to 13 cm) consistently trapped more snow and retained more potentially available water than uniformly swathed stubble.

The objectives of this study were: (1) to document any change in soil water storage from trapped snow as affected by three grass stubble heights, (2) to document the response of forage production the following growing season to the increased stored soil water.

Study Area and Methods

This study was conducted at the Northern Great Plains Research Center, Mandan, North Dakota, during the winter of 1976–77 and the summer of 1977. The soil was a Parshall fine sandy loam (a member of the fine-loamy, mixed family of *Pachic Haploborolls*). This soil holds about 4.72 cm of water at field capacity and 1.83 cm of water at the wilting point per 30 cm of soil depth.

Data of precipitation, snowfall, temperature and windspeed during the study period (August, 1976–August, 1977) are given in Table 1. Weather data were collected approximately 0.4 km from the study area using U.S. Weather Bureau procedures. Precipitation during the period (26 cm) was substantially below average (44 cm). Snowfall during the winter of 1976–77 was 79 cm, 7 cm less than average. Average wind speed during the study period was 5

Table 1. Weather data during study period (Aug. 1976–Aug. 1977) and long-term average (1915-1977) from the weather station at Northern Great Plains Research Center, Mandan, N.D.

	Precipitation (cm)		Snowfall (cm)		Average windspeed (km/hr.)		Average temperature (°C)	
Month	Actual	Avg.[1]	Actual	Avg.	Actual	Avg.	Actual	Avg.
Aug. '76	1.24	4.14	—	—	5.0	6.6	22	20
Sept. '76	1.22	3.76	—	0.4	4.2	7.1	14	14
Oct. '76	0.20	2.26	7.6	3.0	5.1	7.4	4	7
Nov. '76	0.43	1.30	10.2	10.7	4.7	7.7	− 4	− 2
Dec. '76	0.94	0.99	22.9	15.0	6.0	7.2	−10	− 9
Jan. '77	1.35	0.96	25.4	15.0	5.3	7.7	−17	−13
Feb. '77	0.64	0.96	10.2	14.0	5.3	8.0	− 5	−10
Mar. '77	1.14	1.75	2.5	17.0	7.7	9.2	2	− 3
Apr. '77	0.28	4.04	—	9.1	5.5	10.3	10	6
May '77	3.66	5.43	—	1.3	5.8	9.5	18	13
June '77	5.74	8.74	—	T	5.1	7.7	19	18
July '77	4.22	5.84	—	—	6.1	6.4	22	22
Aug. '77	4.67	4.14	—	—	5.5	6.6	17	20
Total	25.73	44.31	78.8	85.5				

[1]Long-term average

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km/hr, slightly less than long-term average. The air temperature averaged 7° C with 6° C the long-term average.

A mixture of introduced forage species and native forage species, both established in 1975, were used for this study. This experimental area was plowed to a depth of 75 cm before seeding in the spring of 1975. The introduced mixture was seeded on level 6×6-m plots at a rate of 18.5 kg/ha pure live seed composed of 27% smooth bromegrass (*Bromus inermis* Leyss.), 37% Russian wildrye (*Elymus junceus* Fisch.), 27% pubescent wheatgrass (*Agropyron trichophorum* (Link) Richt.), and 9% alfalfa (*Medicago sativa* L.). The native mixture was seeded on level 6 × 6-m plots at a rate of 18.0 kg/ha pure live seed composed of 20% slender wheatgrass (*Agropyron trachycaulum* Link Malte), 20% western wheatgrass (*Agropyron smithii* Rydb.), 30% sideoats grama (*Bouteloua curtipendula* Michx. Torr.), and 30% blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.). The established stand of introduced forage species was better than the stand of native forage species. Plot areas were fertilized with 100 kg N/ha and 45 kg P/ha in the spring of 1975. In the spring of 1976 and 1977, 55 and 80 kg N/ha, respectively, were applied.

Three stubble height treatments were randomly assigned at harvest in 1976 (Fig. 1). One area was clipped to a grass stubble height of 30 cm, a second area was clipped to 15 cm height, and a third area was unclipped (60 cm height). Clipped plant material was removed. Since the prevailing winter winds are from the northwest, a 10-m buffer strip was left on the west and a 14-m buffer strip on the north of each area. Buffer strips were composed of the same introduced and native forage species and were in the same stubble height as the associated plot areas. Of the plots available outside the buffer zones, five for each species mixture were randomly selected in each of the three stubble height areas.

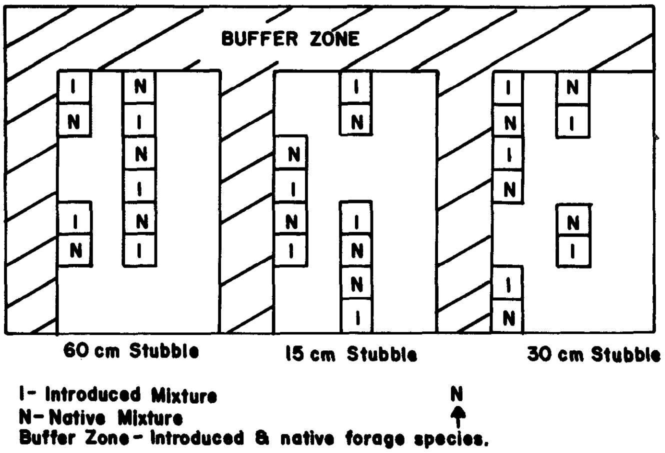

Fig. 1. *Diagram of experimental area.*

Each plot contained a neutron access tube in the center, and soil water content was determined in 30-cm increments to a depth of 1.8 m in mid-October 1976. Soil water content was measured again in mid-April 1977. The difference between the fall and spring was designated as amount of soil water stored over the winter of 1976–77 under the three stubble height treatments.

In late April 1977, all plots were clipped to a 5-cm height and all clipped material was removed to enhance subsequent herbage production measurements.

Production from the two mixtures was measured at near peak biomass accumulation during the 1977 growing season. Vegetation was clipped by species on ten 30× 30-cm plots within each 6×6-m plot. The clipped plant material was oven dried (70° C for 24 hr) and weighed. Production data for each mixture were grouped into forage species, weedy species, and total for further analysis.

Data were analyzed using a split plot analysis of variance, with stubble height as whole plots and species mixtures (introduced or native) as sub-plots.

Analysis showed no significant effect of type of species mixture (introduced or native) on overwinter storage of soil water. Consequently, soil water data for the two species mixtures were combined for further analysis. The relationship between increased soil water content and stubble height was established with linear correlation-regression analysis.

Analysis of forage species, weedy species, and total dry matter production showed that the response to stubble height was significantly different for the two species mixtures. Therefore, further production analyses treated the two types of mixtures independently. The yield response of each mixture was analyzed by linear correlation and regression analysis techniques to establish relationships between production, overwinter stubble height, and increased stored soil water.

Results

Soil Water Storage

The depth to which stored water was increased from meltwater of snow catch over the winter of 1976-77 increased with stubble height. Stored soil water accumulated to a depth of 61, 94, and 162 cm for stubble heights of 15, 30 and, 60 cm, respectively. Soil water below these depths did not change. Overwinter increases in stored water content to a depth of 1.8 m ranged from 1.83 cm under the 15-cm stubble to 12.67 cm under the unclipped 60-cm stubble (Table 2).

Table 2. Change in soil water content from October 1976—April 1977 to a depth of 1.8 m under three heights of grass stubble left over the winter.

Overwinter stubble height stubble height cm	Stored soil water soil water cm
60	12.67 a[1]
30	5.54 b
15	1.83 b

[1]Average values followed by a different letter differ significantly at the 5% level of probability according to Duncan's multiple range test.

Correlation and regression analysis showed that stored water was highly correlated with height of the grass stubble that remained over the winter (see Fig. 2). Based on the equation shown in Figure 2, which was derived from data collected during the winter of 1976–77, an increase of 0.24 cm of stored soil water can be expected for each centimeter increase in stubble height (between 15

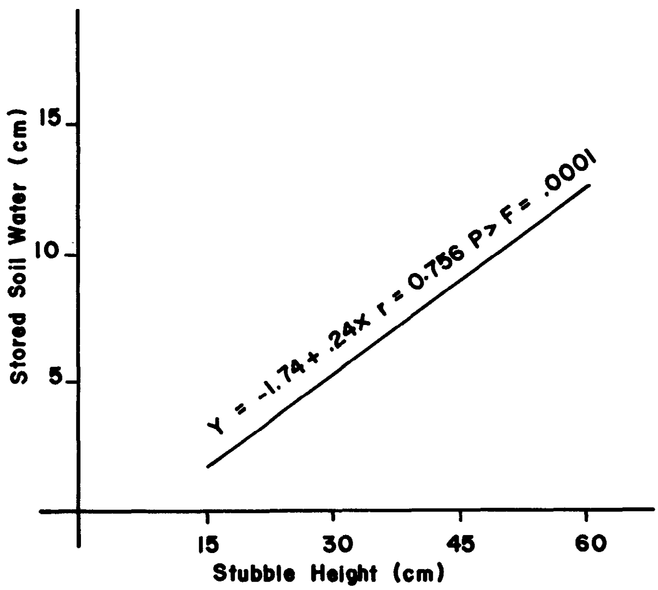

Fig. 2. *Correlation coefficient and regression equation for the relationship of stored soil water to height of overwinter grass stubble.*

to 60 cm of height) that remains over winter. Therefore, each 15 cm of stubble that could be left over winter would increase stored soil water by 3.6 cm.

Herbage Production 1977

Analyses conducted for the forage species, weedy species, and total dry matter components of the vegetation show that forage species production increased with increased stubble height ($P = .001$) and that the native mixture produced less forage than the introduced species mixture ($P = .003$). The production of weedy species was not affected by stubble height, but weed dry matter production was greater in the native ($P = .018$) than in the introduced mixture. Total dry matter was greater in the 60-cm plots than in the other stubble plots ($P = .003$), but there was no measurable difference between the native and introduced species mixtures. Table 3 presents species composition of the vegetation harvested in 1977 from the introduced and native mixtures. These data show that more weeds were present in the native mixture than in the introduced mixture. We believe that the difference was related to the difficulty to establishing native species.

Table 3. Total species composition (percentage on weight basis) of dry matter harvested from introduced and native mixtures in 1977.

Introduced mix		Native mix	
Smooth bromegrass	11%	Western wheatgrass	33%
Russian wildrye	15	Slender wheatgrass	36
Alfalfa	11	Sideoats grama	T
Pubescent wheatgrass	55	Blue grama	1
	92		70
Weeds	8	Weeds	30
	100		100

Herbage production of the introduced mixture ranged from 1,702 kg/ha where 15-cm stubble remained over winter to 3,706 kg/ha where stubble had been unclipped (60 cm) (Table 4). Weedy species production was greatest where the 15-cm stubble remained over the winter (Table 4).

Table 4. Production of introduced and native mixtures as related to height of the stubble left over the previous winter (1976-77).

	Herbage production (kg/ha)			
Overwinter	Introduced mix		Native mix	
stubble height cm	Seeded species	Weedy species	Seeded species	Weedy species
60	3706 a[1]	79 b	2208 a	806 a
30	1835 b	61 b	1654 ab	537 a
15	1702 b	338 a	1189 b	1237 a

[1]Average values in columns followed by a different letter differ significantly at the 5% level of probability according to Duncan's multiple range test.

Forage species yield in the native mixture peaked at 2,208 kg/ha where 60-cm of stubble remained over winter (Table 4). Weedy species in the native stand were not significantly affected by stubble height over the winter (Table 4).

Results of correlation and regression analyses show significant relationships between forage production, overwinter stubble height, and stored soil water for both the introduced and the native mixtures (Fig. 3 and 4). Weedy species production was not related to overwinter stubble height or to increased stored water for either mixture.

Based on the relationship developed from the data collected in this study, a 1-cm increase in stubble height (between 15-60 cm of stubble) left over the winter would increase forage production by the introduced species 47 kg/ha and native species 22 kg/ha. Forage production would be increased 115 and 62 kg/ha, respectively, for each 1-cm increase in overwinter stored soil water.

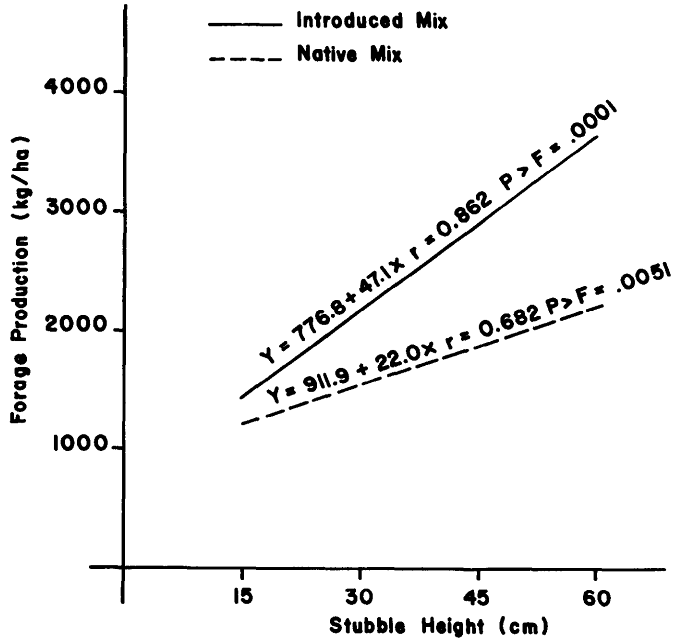

Fig. 3. *Correlation coefficients and regression equations for the relationship of forage production to height of grass stubble left over the previous winter for introduced and native mixtures.*

Discussion

Many environmental factors affect the conversion of snowpack into soil water available for use by vegetation. Snowfall variability between winters and the water content of snow are of prime importance. If snowfall or snow water are below normal, little change in stored soil water content can be expected. Also important are the size and location of the contributing area from which snow can be transported. Other important factors such as winter temperatures, humidity, and wind affect the amount of water lost from the snowpack. Soil permeability, soil water storage capacity, antecedent soil water content, topography of the land area, and the rate at which the snowpack melts also affect soil water storage.

The results from this study show the net gains in soil water storage over the winter of 1976-77 on a Parshall fine sandy loam

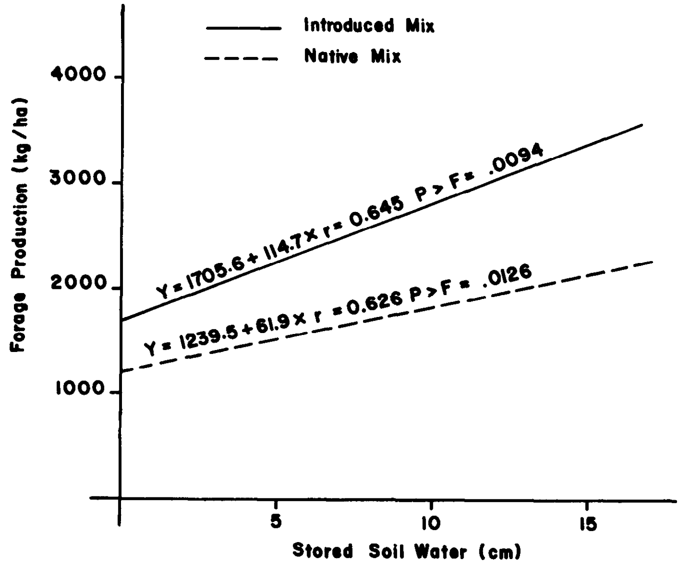

Fig. 4. *Correlation coefficients and regression equations for the relationship of forage production to stored soil water for introduced and native mixtures.*

soil. All factors mentioned above and possibly others affected the net change in soil water observed. These can be expected to vary from year to year and with soil type, and this must be considered in use and interpretations of the data presented.

An evaluation of the conditions during the winter of 1976–77 and of site characteristics where this study was conducted showed a situation favorable for maximum conversion of snow catch to stored soil water. The snowfall was near normal; the soil was dry at the start of the snowfall season; the soil had been deeply tilled to increase infiltration; the area was level to minimize runoff; and the windspeed was somewhat less than normal.

The response of the vegetation to increased stored soil water was also accentuated by low precipitation received during the 1977 growing season, thus increasing the dependence of plant growth on stored soil water. Our study illustrated the protection against drought that can be obtained in the Northern Great Plains by increasing soil water stored from snowmelt, suggested by Wight et al. (1975).

Although these results are not directly applicable to rangeland, they were a quantitative estimate of the effect of stubble height on snow catch and subsequent soil water recharge and herbage production. Grass stubble heights can be controlled by grazing management.

Herbage production response of introduced forage species in this study (115 kg/ha per cm of soil water) was comparable to that of *Elymus junceus* Fisch. (93 kg/ha per cm of soil water) reported by Greb and Black (1971). Smika et al. (1965) measured increases in yields of native mixed prairie forage of about 50 to 100 kg/ha per cm additional water after applying 20 to 40 kg N/ha as compared to 62 kg/ha per cm of soil water for native forage species in this study.

The lower response of the native forage species in this study does not necessarily indicate a lower productivity because there were fewer native forage species established in the native stands. Since weedy species did not respond favorably to increased overwinter stubble height or soil water, stands fully stocked with desirable forage species benefit more from conversion of snow catch to stored soil water than would weedy stands. The significant increase in production of weedy species in the introduced mixture under the 15-cm stubble height (less stored water) seemed to indicate that weeds are strong competitors when soil water becomes limiting.

The significant increase in stored soil water and forage production in response to relatively small increases in the height of grass stubble left over the winter is encouraging. Research on techniques that can put this principle into practice on Northern Great Plains rangeland merits further attention.

Literature Cited

Black, A.L., and F.H. Siddoway. 1971. Tall wheatgrass barriers for soil erosion control and water conservation. J. Soil Water Conserv. 26:107-111.

Greb, B.W., and A.L. Black. 1971. Vegetative barriers and artificial fences for managing snow in the Central and Northern Plains. p. 96-111. *In:* Proc. Snow and Ice in Relation to Wildlife and Recreation Symposium. Arnold O. Haugen (ed.). Ames, Ia.

Haas, H.J., and W.O. Willis. 1968. Conservation bench terraces in North Dakota. Trans. ASAE 11:396-398, 402.

Haas, H.J., and W.O. Willis. 1971. Water storage and alfalfa production on level benches in the Northern Plains. J. Soil Water Conserv. 26:151-154.

Matthews, G.D. 1940. Snow utilization in prairie agriculture. Pub. No. 696. Canada Dept. of Agr.

Nicholaichuk, W., and D.I. Norum. 1975. Snow management on the Canadian prairies. p. 118-127. *In:* Proc. Snow Management on the Great Plains Symposium. Research Committee. Great Plains Agr. Coun. Pub. No. 73. Lincoln, Nebr.

Rauzi, Frank. 1968. Pitting and interseeding native shortgrass rangeland. Res. J. 17. Wyo. Agr. Exp. Sta., Univ. of Wyoming, Laramie. 14 p.

Rauzi, Frank, Leland Landers, and Richard Gray. 1973. Level benches for Northern Plains rangelands. Montana Farmer-Stockman 60:22-23.

Smika, D.E., H.J. Haas, and J.F. Power. 1965. Effects of moisture and nitrogen fertilizer on growth and water use by native grass. Agron. J. 57:483-486.

Wight, J. Ross, E.L. Neff, and F.H. Siddoway. 1975. Snow management on eastern Montana rangelands. p. 138-143. *In:* Proc. Snow Management on the Great Plains Symposium. Research Committee. Great Plains Agr. Coun. Pub. No. 73, Lincoln, Nebr.

Willis, W.O., and H.J. Haas. 1969. Water conservation over winter in the Northern Great Plains. J. Soil Water Conserv. 24:184-186.

Diet of Pronghorn in Western Kansas

MARK L. SEXSON, JERRY R. CHOATE, AND ROBERT A. NICHOLSON

Abstract

Pronghorn were common throughout most of Kansas before settlement of the region by European man. They had begun to decline in numbers, even in sparsely populated western Kansas, by 1877, and were nearly extirpated in the state by 1915. However, small herds of pronghorn persisted along the Kansas-Colorado state line, and these were augmented by herds introduced into several regions of Kansas during the years 1964–1979. The diet of the most successful population of pronghorn in western Kansas was found to consist largely of forbs in late spring, summer, and early autumn, of forbs supplemented with wheat and other dicots in late autumn and early spring, and of wheat in winter. Pronghorn are able to live and reproduce where 30% of the land is used for cultivated crops at least in part because they are able to use those crops as food during months when native foods are in short supply.

The pronghorn *(Antilocapra americana)* was a characteristic inhabitant of the High Plains of Kansas before settlement of that region by European man (Brennan 1932). Early biologists (Allen 1874, Knox 1875) and professional trappers (Mead 1899) commented on their distribution, abundance, and seasonal movements on the plains of Kansas. However, records kept at the Fort Hays Military Reservation (Choate and Fleharty 1975) suggested that pronghorn had begun to decline in number by 1877. This decline continued until, in 1905, Lantz noted that the species was "Fast disappearing" in spite of a law to protect it. By 1912 the only report of pronghorn in Kansas was of three individuals seen in the southwestern corner of the state (Kellogg 1915).

For the next 50 years, pronghorn were considered extirpated or extremely rare in Kansas (e.g. Cockrum 1952) although small herds periodically were seen in western counties (Nelson 1925). In 1962 the Kansas Fish and Game Commission conducted a census and located 37 pronghorn in Wallace and Sherman counties near the Colorado state line. This discovery led to formulation of plans to reestablish breeding populations of pronghorn in the state.

Subsequently, the Kansas Fish and Game Commission introduced herds from Colorado, Nebraska, Wyoming, and Montana. However, much of the prairie in Kansas had been either fenced for livestock grazing or plowed for crop production, and it thus was questionable whether the dietary and habitat requirements of pronghorn could be met in a patchwork of rangeland and cultivated crops. Although the introductions have proven successful (Choate and Sexson 1980), at least in westernmost Kansas, it still is not known how the available habitat has satisfied the dietary requirements of pronghorn.

The objectives of the study, therefore, were to determine the diet of the most successful population of pronghorn in Kansas, and to speculate regarding the prospect for pronghorn in the state.

Authors, when the research was conducted, were graduate student in the Department of Biological Sciences, Director and Curator of Mammals for the Museum of the High Plains, and associate professor of botany, Fort Hays State University, Hays, Kansas 67601. Sexson is presently wildlife biologist for the Kansas Fish and Game Commission, Garden City, Kansas 67846.

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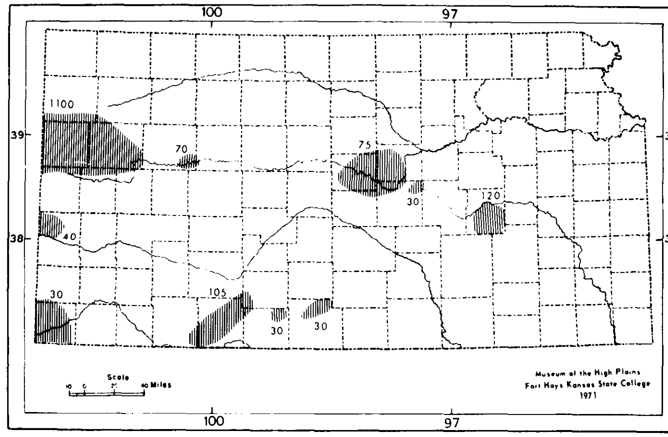

Fig. 1. *Geographic distribution and abundance of pronghorn in Kansas as of December 1979.*

Research Area

The research area was on the High Plains of western Kansas (Fig. 1). It comprised the western part of Wallace County, with its western boundary on the Colorado-Kansas state line. The southern boundary extended eastward from a point where the state line bisects the southern border of section 12, Township 13S, Range 41W, to the southeastern corner of section 8, T. 13S, R. 41 W. From this point, the eastern boundary extended northward to the northeastern corner of section 5, T. 12S, R. 41W. The northern boundary was formed by a line extending westward from this point to the state line.

The area encompassed 17,887 ha (44,220 A) of native shortgrass prairie and cultivated cropland. Shortgrass rangeland occurred on 12,664 ha (31,244 A), hard red winter wheat *(Triticum aestivum)* on 4,808 ha (11,880 A), feed grain and forages on 310 ha (766 A), and alfalfa *(Medicago sativa)* on 126 ha (310 A). Cultivated acreage occurred on level land throughout the research area. The study area was inhabited by approximately 100 pronghorn. During winter they generally were observed in large herds of about 50 to 75 animals.

Vegetation on the rangeland was predominantly warm-season perennial grasses and forbs. Most of the rangeland is grazed by cattle (cow-calf) in all except the winter months. Topography varies from flat to gently rolling, with numerous gullies draining toward the main drainage of the region, the Smoky Hill River. The highest elevation in the study area (and in Kansas) is 1,227 m (4,025 ft), reached in an area of native rangeland on a rise known as Mt. Sunflower. Two drainages (Goose Creek in the northeastern corner and Willow Creek across the southern edge) cross the study area and drain into the Smoky Hill River. Small ponds and stock tanks provide other watering facilities for cattle and pronghorn.

More than 90% of the cultivated land is planted to winter wheat every 2 years; therefore, in any year, half the fields are fallow and contain residue and half are planted. Wheat sometimes is used

Table 1. Mean relative percent frequency of plant species comprising 3% or more of the diet of pronghorn for at least one sample date between November 1977 and October 1978.

Months	Jan.		Feb.		Mar.		Apr.		May	
Collection dates	10	21	4	25	13	25	8	27	7	23
GRASSES:										
Agropyron smithii							0.6	2.1	7.0	3.9
(Western wheatgrass)										
Bouteloua gracilis							0.6	0.4	1.3	3.9
(Blue grama)										
Buchloe dactyloides			0.8				3.1	0.4	0.3	
(Buffalograss)										
Triticum aestivum	73.8	97.6	81.0	100.0	94.4	79.9	72.3	1.7	2.0	1.9
(Winter wheat)										
Other grasses								0.4	1.3	
BROWSE										
Artemisia filifolia								14.6	29.3	14.3
(Sand sagebrush)										
FORBS AND LEGUMES:										
Ambrosia psilostachya								5.2	3.3	15.5
(Western ragweed)										
Artemisia kansana									0.3	
(Kansas sage)										
Aster tanacetifolius							0.6			
(Tansyleaf aster)										
Astragalus pectinatus								2.6	0.7	2.7
(Narrowleaf milkvetch)										
Callirhoe involucrata									0.3	
(Purple poppymallow)										
Chrysopsis villosa								0.4	4.0	4.7
(Leafy goldaster)										
Dyssodia papposa										
(Prairie dogweed)										
Erysimum asperum	3.5		0.8			3.6	1.3	1.3	2.0	4.7
(Plains erysimum)										
Gaura coccinea							1.2	9.4	13.0	15.1
(Scarlet gaura)										
Kochia scoparia						0.7				0.8
(Kochia)										
Lesquerella ovalifolia	12.8									2.7
(Ovalleaf bladderpod)										
Medicago sativa						11.5	0.6	41.6	5.0	3.9
(Alfalfa)										
Oenothera serrulata								6.9		0.4
(Serrateleaf eveningprimrose)										
Psoralea tenuiflora								2.6	5.7	5.0
(Slimflower scurfpea)										
Ratibida columnifera							0.6	0.4	1.0	2.3
(Upright prairieconeflower)										
Sphaeralcea coccinea							3.8	3.4	20.3	4.7
(Scarlet globemallow)										
Verbena stricta							6.3	1.3		3.1
(Woolly verbena)										
Other forbs	5.7	2.4	2.3				3.3	3.6	2.6	9.2
CACTUS:										
Opuntia sp.	3.5		15.1		5.6	4.3	5.7	1.7	0.6	1.2
(Pricklypear)										

during winter for grazing cattle. The remainder of the cultivated land is planted to Sudangrass *(Sorghum bicolor)*, corn *(Zea mays)*, or alfalfa. Sudangrass and alfalfa are baled for feeding of cattle in winter, whereas corn is harvested in autumn as a grain crop. Roadside ditches and wheat fields that have been harvested commonly contain weedy plants, such as kochia *(Kochia scoparia)*, rough pigweed *(Amaranthus retroflexus)*, Russian thistle *(Salsola kali)*, and western ragweed *(Ambrosia psilostachya)*, and often contain winter wheat.

The study area received approximately 36 cm (14 in) of precipitation, or slightly less than average, during the research period (November 1977 through October 1978). Most snow fell in January, February, and March, with the heaviest snowfall (about 38 cm, or 15 in) in February. Rainfall was sparse until late April, when a 5-cm (2-in) rain was received. The remainder of the rainfall was spread evenly through the spring and summer months except in May, when only 1.25 cm (0.5 in) of precipitation was received.

Methods and Materials

The duration of the study was November, 1977, through October, 1978. Vegetation of the prairie was analyzed by the modified step-point technique (Owensby 1973). Because additional data were needed on species composition of forbs, this technique was modified further by recording the nearest forb for each point taken even when there was a direct hit. Samples were

June		July		Aug.		Sept.		Oct.		Nov.		Dec.	
2	24	18	28	12	26	9	30	8	23	5	24	10	28
5.2	1.0	0.4	0.8	0.4			1.5						
	1.9			0.4			1.0			0.5			
0.4	2.6	0.4		1.0	1.0	1.0				0.5	0.8		0.7
3.2							2.7	59.2	74.1	41.2	82.1	98.4	85.0
			0.4	1.7	1.1	0.5	0.7	0.6	2.2				
5.2							2.0		1.5				
21.4	24.9	23.8	8.7	16.6	10.5	10.4	0.3	0.6				0.7	
2.8	2.6	7.9	26.9	20.0	11.1	8.3	2.0			22.2			
							18.0	0.6					
2.4	6.1	0.4				0.5							
0.4	8.9	3.8					11.0						
2.4	4.5	17.2	7.2	0.4			0.3	1.8					
0.4				13.6	2.8								
7.1	2.9			10.2	1.6	8.8	0.3						
10.3	9.6	5.0	14.0	5.5	3.3	1.0							
14.3	6.1	5.0	12.0	6.0		0.5	0.7						
	0.3			0.4	0.6		8.0						0.8
3.2	0.3	1.3	2.1	0.4	5.0	13.0				10.3	15.4		
	0.3		1.2				3.0	1.2	0.7				
3.6	11.2	10.5	3.7	1.3	3.3	2.6	2.0	0.6	0.7				
4.0							3.3	7.1	0.7				
2.8	4.2	3.3	7.0	4.3	2.8	7.8	14.0	20.7		2.1			
0.4	1.0	2.9	0.8			0.5		0.6				0.8	
10.1	10.6	11.8	7.8	15.4	26.8	23.3	25.6	4.0	16.4	2.6	0.1		3.6
0.4	1.0	5.9	7.0	3.4	31.1	21.8	3.6	3.0	3.7	20.6	1.6	0.8	9.9

obtained at three times (May 21, July 31, and September 10) during the growing season to monitor changes in species composition. Four sites were selected for analysis: high level prairie (T. 12S, R. 42W, NW 1/4 sec. 23); gently sloping prairie (T. 12S, R. 42W, NE 1/4 sec. 23); steeply sloping prairie (T. 12S, R. 42W, NW 1/4 sec. 25); lowland prairie (T. 12S, R. 42W, SW 1/4 sec. 13). During each sampling period, 100 points were taken on each of the four sites. Indices calculated included percent cover and percent composition of all species.

A standardized procedure for fecal collection and analysis was followed throughout the sampling period. Observation routes were traveled twice monthly, and pronghorn were observed for at least 15 minutes after they found. During this period, the animals would become nervous and defecate before running. Samples of their feces then were collected, placed in plastic containers with alcohol, and sealed for shipment.

Sampling consisted of two fecal collections semi-monthly from November, 1977, through October, 1978. On each sampling day, six specimens were collected and preserved until sent to the Department of Range and Wildlife Management, Texas Tech University, for standardized microscopic analysis (Sparks and Malachek 1968). An attempt was made on each sample day to obtain fecal specimens representative of the entire population of pronghorn on the research area. For this reason, if pronghorn were dispersed into several groups, samples were taken from as many individuals of as many groups as could be found. These samples subsequently were pooled per sample day.

Trophic diversity *(h)* for each sample was calculated as follows

(Margalef 1958):

$$h = - \sum_{i=1}^{S} (n_i/N) \ ln\ (n_i/N) \qquad (1)$$

where S is the number of species in the sample, N is the total of individuals of all species, and n_i is the number of individuals of the *ith* species. Evenness *(e)* or equitability for each sample also was calculated using the following index (Pielou 1966):

$$e = h/lns \qquad (2)$$

Species richness *(d)* of the diet was defined as the ratio of the total number of species *(s)* to the total importance *(N)* of all species. The index of Margalef (1958) was used to calculate species richness:

$$d = (s-1)\ (ln\ N)^{-1} \qquad (3)$$

Vegetational Analysis

Because no apparent differences in plant composition were found among samples taken in May, July, and September, data from 1,200 points were combined to calculate total species composition. The most abundant plants found in the research area were short grasses. Buffalograss *(Buchloe dactyloides)* and blue grama *(Bouteloua gracilis)* were the most abundant, comprising 38.1 and 34.0% of the vegetation, respectively. Other common grasses were: western wheatgrass *(Agropyron smithii)*, 11.3%; sideoats grama *(Bouteloua curtipendula)*, 5.3%; sand dropseed *(Sporobolus cryptandrus)*, 1.4%; red threeawn *(Aristida longiseta)*, 1.3%; little barley *(Hordeum pusillum)*, 1.2%. Each of the other plant species accounted for less than 1% of the total composition.

Considering only forb species composition data, pricklypear (*Opuntia* sp.), 20.6%, was the most common, followed by scarlet globemallow *(Sphaeralcea coccinea)*, 17.3%, and broom snakeweed *(Xanthocephalum sarothrae)*, 11.8%. Other forb species with values of 1% or more of the forb composition were: Russian thistle, 8.5%; Kansas sage *(Artemisia kansana)*, 4.5%; heath aster *(Aster ericoides)*, 43% upright prairie coneflower *(Ratibida columnifera)*, 3.7%; rush skeleton plant *(Lygodesmia juncea)*, 2.9%; slimflower scurfpea *(Psoralea tenuiflora)*, 2.7%; ball cactus *(Neomammallaria radiosa)*, 2.3%; western ragweed *(Ambrosia psilostachya)*, 1.7%; scarlet gaura *(Gaura coccinea)*, 1.7%; purple poppymallow *(Callirhoe involucrata)*, 1.2%; wavy leaf thistle *(Cirsium undulatum)*, 1.0%; annual sunflower *(Helianthus annuus)*, 1.0%; woolly plantain *(Plantago purshii)*, 1.0%. The remaining 13.6% was dispersed among 38 other forbs.

Fecal Analysis

Analysis of feces of the pronghorn herd from November of 1977 to October of 1978 revealed the presence of 11 species of grasses and 44 forb species (Table 1). The semimonthly data were averaged by month and pooled into five catagories: (1) wheat; (2) other grasses; (3) alfalfa; (4) other forbs; (5) pricklypear (Fig. 2). In each month from October through March, winter wheat made up at least 60% of the diet, ranging from a low of 41.2% on November 5 to a high 100% on February 25. The only other species important during winter were pricklypear, which was utilized throughout most of the year, and alfalfa, which made up more than 10% of the diet of pronghorn at certain other times of the year. On April 27, alfalfa made up 41.6% of the diet of pronghorn; that percentage was the greatest both for that date and for alfalfa.

By April, the percentage of forbs in the diet was nearly equal to that of wheat. Between the latter sample dates in March and April, the abundance of wheat in the diet decreased from 79.9 to 1.7%, whereas the proportion of forbs increased from 20.2 to 96.7%. This was reflected in the increase in dietary diversity and richness from 0.7 to 2.1 and 0.8 to 3.7, respectively (Table 2). By May, more than 83% of the diet consisted of forbs. This trend continued through June (90.4%), July (90.5%), August (78.3%), and September (77.1%), and richness of the species in the diet remained high

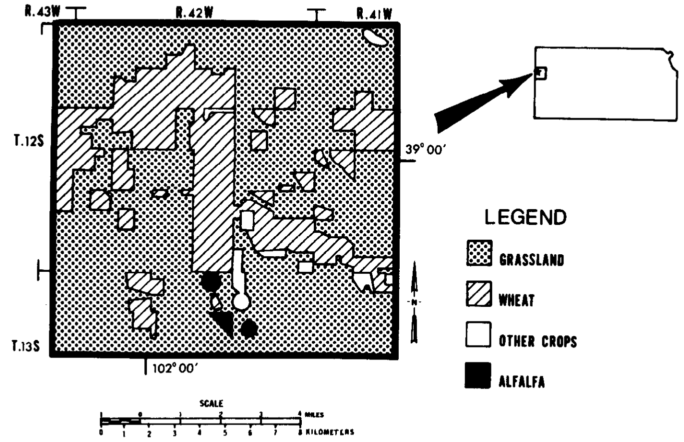

Fig. 2. *Geographic location and vegetation of the research area.*

($\simeq$3.00). On June 24, the sample period with highest diversity, 28 species were identified. The most common of those species were western ragweed (24.9%), purple poppymallow (8.9%), scarlet gaura (9.6%), kochia (6.1%), and slimflower scurfpea (11.2%) (Table 1).

Sand sagebrush *(Artemisia filifolia)* was an important component of the diet from April 27 through June 2, comprising 29.3% of the diet on May 7. Western ragweed constituted an average of 14% of the diet from April 27 through September 9. During the period July 18 through September 9, Kansas sage comprised an average of 14.8% of the diet; on November 5, it increased to 22.2%. Scarlet globemallow was important through most of the spring, summer, and fall: on May 7, it comprised 20.3%; on July 28, 7.0%; on September 9, 7.8%; on September 30, 14.0%; on October 8, 20.7%. Forbs still were an important dietary component in October (30.9%), but had been replaced by wheat (66.7%) as the most abundant constituent. Pricklypear was found in feces in all months of the year and was most abundant (17.3%) in August. Grasses other than wheat were relatively unimportant in the diet, being represented by a percentage only as high as 8.9% in May.

Table 2. Richness, diversity, and evenness of species in diets at each sampling date from November 1977 through October 1978.

Date	Richness	Diversity	Evenness
10 Jan.	2.22	1.03	0.41
21 Jan.	0.62	0.14	0.10
4 Feb.	1.03	0.64	0.36
25 Feb.	0.00	0.00	—
13 Mar.	0.21	0.22	0.31
25 Mar.	0.81	0.72	0.45
8 Apr.	2.96	1.24	0.45
27 Apr.	3.67	2.05	0.67
7 May	4.03	2.30	0.72
23 May	4.32	2.76	0.86
2 June	4.37	2.63	0.82
24 June	4.52	2.52	0.77
18 July	4.02	2.37	0.76
28 July	3.64	2.29	0.75
12 Aug.	4.40	2.54	0.79
26 Aug.	3.66	2.26	0.76
9 Sept.	3.04	2.29	0.81
30 Sept.	4.56	2.63	0.80
8 Oct.	2.92	1.51	0.55
23 Oct.	1.43	0.66	0.32
5 Nov.	1.90	1.52	0.64
24 Nov.	0.62	0.56	0.40
10 Dec.	0.42	0.10	0.09
28 Dec.	1.03	0.50	0.28

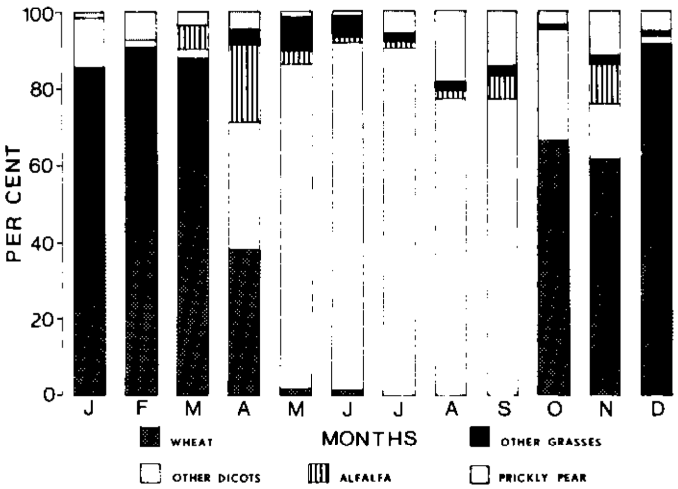

Fig. 3. *Monthly dietary percentages of wheat, other grasses, alfalfa, other dicots, and pricklypear in the diet of pronghorn in western Kansas for the period November 1977 through October 1978.*

Discussion

Forbs constituted an important component of the diet of pronghorn in late spring, summer, and fall. On the study area, forbs made up only 5.2% of the species composition of the short-grass prairie ecosystem but accounted for more than 90% of the diet of pronghorn during certain months of the year. During May through September, an average of 95% of the diet of pronghorn consisted of plants other than grasses. Forbs also were important, but to a lesser degree, in April, October, and November. Similar results have been obtained in other studies of pronghorn on the High Plains of Kansas; Hlavachick (1968), for example, reported that the diet of pronghorn in Kansas consisted of 78% non-grass species, of which pricklypear made up 40% and Kansas sage made up 16%. Two of the forbs (scarlet globemallow and pricklypear) utilized extensively by pronghorn in this study were common on the research area. Sand sagebrush, on the other hand, was an important forage plant during April, May, and June even though it was found growing only in the lower drainages. Pronghorn seldom were seen in those areas except during those months. Barrington (1975) explained that, in southeastern Colorado, "Areas where sand sage was moderately dense and the understory vegetation was vigorous and diverse, seemed to be more heavily utilized by pronghorn does for fawning." Autenrieth (1976) also suggested that fawning often is associated with woody habitats. Most forbs, other than pricklypear, scarlet globemallow, and sand sagebrush, were not plentiful in the vegetation samples but were conspicuous because of their size and showy apearance.

Winter wheat made up a substantial part of the diet of pronghorn during late autumn, winter, and early spring (October through March), and alfalfa was consumed more in April and November than in other months. These observations suggest that pronghorn in western Kansas utilize wheat as a substitute for green forbs during months when green forbs are not available. In spring, when alfalfa emerges but rangeland forbs are not yet abundant, pronghorn use alfalfa to supplement their diet of native dicots. Cultivated crops are an insignificant component of the diet during summer, but increase in importance when green forbs become scarce in autumn. Damage to winter wheat by pronghorn is unlikely. Grazing of wheat by livestock in this region is not common; however, the period (mid-October to mid-April) during which pronghorn consume wheat coincides with the time when wheat might possibly be used for grazing.

Pronghorn, which once occurred throughout most of Kansas but were nearly extirpated after the state was settled, have proven their ability to live and reproduce where at least 30% of the land is cultivated for crops. This ability depends, at least in part, on their consumption of winter wheat and alfalfa (in much the same way as by jackrabbits) during months when native foods are in short supply. Accordingly, the re-established populations of pronghorn have the potential to disperse into many of the regions of Kansas that were inhabited by pronghorn before the arrival of European settlers. Although extensively cultivated regions may prove unsuited for habitation by pronghorn, there is reason to believe that the isolated populations of pronghorn in Kansas eventually might re-establish a continuous gene pool.

Literature Cited

Allen, J.A. 1874. Notes on the mammals of portions of Kansas, Colorado, Wyoming and Utah. Part I. On the mammals of middle and western Kansas. Bull. Essex Inst. 6:43-52.

Autenrieth, R. 1976. A study of birth sites selected by pronghhorn does and bedsites of fawns. Proc. 7th Bien. Pronghorn Antelope Workshop, p. 127-234.

Barrington, M.R. 1975. Habitat factors related to pronghorn productivity on the southern High Plains. Unpubl. M.S. thesis, Oklahoma State Univ., 162 p.

Brennan, L.A. 1932. Mammal extinction in Kansas. I. The pronghorned antelope. Aerend 1932:231-236.

Choate, J.R., and E.D. Fleharty. 1975. Synopsis of native Recent mammals of Ellis County, Kansas. Occas. Paper Mus., Texas Tech Univ. 37:1-80.

Choate, J.R., and M. Sexson. 1981. Historical biogeography of the pronghorn in Kansas. Trans. Acad. Sci. 84:128-133.

Cockrum, E.L. 1952. Mammals of Kansas. Univ. Kansas Publ., Mus. Nat. Hist. 7:1-303.

Hlavachick, B.D. 1968. Foods of Kansas antelope related to choice of stocking sites. J. Wildl. Manage. 32:399-401.

Kellogg, R. 1915. The mammals of Kansas. Unpubl. M.A. thesis, Univ. Kansas, 241 p.

Knox, M.V.B. 1875. Kansas Mammalia. Trans. Kansas Acad. Sci. 4:19-22.

Lantz, D.E. 1905. A list of Kansas mammals. Trans. Kansas Acad. Sci. 19:171-178.

Margalef, R. 1958. Information theory in ecology. Gen. Syst. 3:26-71.

Mead, J.R. 1899. Some natural history notes of 1859. Trans. Kansas Acad. Sci. 16:280-281.

Nelson, E.W. 1925. Status of the pronghorned antelope, 1922-1924. U.S. Dep. Agr. Bull. 1346:1-64.

Owensby, C.E. 1973. Modified step-point system for botanical composition and basal cover estimates. J. Range Manage. 26:302-303.

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. J. Theoret. Biol. 13:131-141.

Sparks, D.R., and J.C. Malachek. 1968. Estimating percentage dry weight in diets using a microscopic technique. J. Range Manage. 21:264-265.

Timber Thinning and Prescribed Burning as Methods to Increase Herbage on Grazed and Protected Longleaf Pine Ranges

GALE L. WOLTERS

Abstract

Selective commercial timber thinning and prescribed burning are effective tools in maintaining a productive forage resource on stocked range of longleaf pine *(Pinus palustris)*. Productive mixtures of herbaceous species can be sustained through periodic timber thinning to maintain 12 to 20 m²/ha of longleaf pine basal area and rotational winter burning, at 3-year intervals. Two to three years of heavy use can be expected after patch cutting if the area of patch cuts constitute a minor percentage of the total grazed range unit. Heavy use may convert patch cuts predominantly to carpetgrass and forested range to a mixture of forbs.

Pine plantations throughout the South can be managed for concurrent production of wood fiber and forage (Pearson et al. 1971, Grelen and Enghardt 1973, and Hart et al. 1970). With proper management, continuous grazing by cattle is not detrimental to establishing and growing artificially regenerated pine plantations (Pearson et al. 1971), nor is forage production seriously diminished by pine canopies until plantations approach 10 years of age (Wolters 1973).

Many longleaf pine *(Pinus palustris)* plantations are rapidly approaching or have already attained commercial timber size and could be thinned to generate immediate cash income. Observations and available literature suggest that selective tree removal or patch cutting within a plantation drastically alters forage production and livestock utilization patterns; thus, the current study was started to determine what effects the rate of tree removal had on concurrent forage production, its botanical composition, and utilization by cattle when the range was burned by controlled backfire every third year. Findings will facilitate development of guidelines to integrate management of timber and forage on longleaf pine ranges.

Study Area

The study was conducted on the Longleaf Tract, Palustris Experimental Forest, in central Louisiana. The 5.18-ha study area was approximately centered in a stand of longleaf pine planted on 1.83-m by 1.83-m spacings during February 1952. In 1969, prior to any timber cutting, the plantation was stocked with an average of 1,194 longleaf pine trees per ha, with a standard error of the mean of 57.3 based on a sample of 24, 0.04-ha plots. The herbaceous understory consisted principally of pinehill bluestem *(Andropogon scoparius* var. *divergens)* and slender bluestem *A. tener),* but other bluestems and several species of panicums (*Panicum* spp.) and paspalums (*Paspalum* spp.) were also common. The study area was located in a 182.1-ha range unit moderately grazed by cattle yearlong, since prior to reforestation. One half of the study area, 2.59-ha, was fenced in 1960 and protected from grazing.

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Experimental Procedure

Both the grazed and protected study units were divided equally into four blocks, each block subdivided into four 0.16-ha plots. Four basal area treatments (0, 12.63, 16.07, and 19.51 m² of pine basal area/ha, referred to as patch cut, low, moderate, and high basal area treatments, respectively) were randomly assigned to the four plots in each block, comprising a complete randomized block design. All pines were removed from the protected patch cuts during winter 1959-1960. Pines were cleared from grazed patch cuts during the 1969 growing season. Forested treatments were thinned initially during the 1969 growing season and again during the 1973 growing season. Pine regeneration did not occur on any treatments during the study.

All vegetation measurements were collected within a 0.04-ha sampling area centered in each 0.16-ha plot. Thus, each sampling area was surrounded by a 10.06-m wide isolation strip. Beginning in 1969, all trees with 2.54-cm diameters (dbh) or greater on the 0.04-ha plots were measured annually during the dormant season. Basal area in m²/ha was calculated from diameter measurements. Herbage standing crop was measured annually from 1969 through 1975 on protected units and from 1970 through 1975 on grazed units. Botanical composition of herbage was determined in 1969 on protected units and in 1972 and 1975 on both grazed and protected units. Herbage standing crop and botanical composition were determined in November of each year from a pooled estimate of eight systematically located 0.472- by 0.472-m (.223-m²) clipping quadrats on each 0.04-ha sampling area. Herbage was clipped, separated by species or species group, bagged, oven-dried, weighed, and converted to kg/ha. On areas grazed by cattle, herbage standing crop and botanical composition was estimated through the use of caged quadrats moved annually similar to the stationary-cage procedure described by Grelen (1967). Cages were constructed of 12-gage woven wire; were approximately 75 cm tall and 120 cm² at the base. Herbage utilization was calculated as the percentage of herbage disappearance determined by the difference in residual herbage remaining on grazed 0.223-m² quadrats compared to standing crop on adjacent caged quadrats.

The plantation was burned by head fire in January 1955 to control brown spot needle blight, and controlled backfires were applied to the plantation every third year, in March, from 1960 through 1975. In addition, the area was prescribed burned by controlled backfire in March 1975 to reduce thinning slash remaining after the 1973 commercial timber harvest.

The experimental area consisted of two completely independent units—one grazed, one protected from grazing. Since only one herd of cattle was involved, vegetation responses to grazing or protection from grazing could not be statistically analyzed, although treatment means are presented. All data were tested by Tukey's *w*-procedure; herbage standing crop association with pine basal area, the independent variable, was tested by regression analysis (Steel and Torrie 1960). Differences were tested for significance at the 5% probability level.

Results and Discussion

Herbage Utilization

In the first two complete growing seasons after removal of pines (1970 and 1971), cattle grazed patch cuts located throughout forested longleaf pine stands more intensively than adjacent forested range (Table 1). From 1970 through 1972, the rate of herbage utilization on forested ranges tended to increase annually, whereas, the rate decreased on patch cuts until 1972, when utilization was similar on patch cut and forested treatments. Following additional tree removal from forested treatments in 1973, a distinct high rate of use, characterized by very short grass stubble, was observed around every freshly cut longleaf pine stump. Observations indicated that cattle also intensively utilized herbage around the base of standing dead trees the first 2 or 3 years after a tree died. Apparently, when a longleaf pine dies, whether due to natural mortality or a severed bole, some chemical change occurs in adjacent herbaceous plants which cattle seek.

Table 1. Herbage utilization (%) by residual longleaf pine basal area treatment and year.

	Residual pine basal area treatment[1]			
Year	High	Moderate	Low	Patch cut
1970	37.8b	8.3b	24.3b	94.3a
1971	35.5b	28.5b	29.8b	79.0a
1972	54.0a	65.8a	59.5a	64.8a
1973	52.0a	51.8a	35.8ab	16.8b
1974	67.3a	60.8a	51.5a	70.0a
1975	52.5a	37.0a	41.8a	12.5b

[1]Within-row values followed by similar subscripts indicate no significant difference at the 5% level of probability.

The utilization rate on the patch cuts in 1973—four growing seasons after the trees were harvested—indicates that cattle generally selected herbage other than that on old patch cuts. In 1974, after the slash reduction burn, utilization on the patch cuts was similar to that on forested sites, as in 1972, the first year after a burn. Patch cut herbage was not utilized again in 1975; however, 1975 was also a first-year burn, but utilization rates were dissimilar on patch cuts and forested range. Apparently, complex time interactions exist between tree mortality and burning that influence herbage preference, but corroborative documentation is lacking.

Herbage utilization rates on patch cuts were greater than reported for cutover range by Duvall and Whitaker (1964). Several factors may have contributed to these unusually high utilization rates: patch cuts were freshly cut and cattle apparently prefer these areas to old cutover range; also, the patch cut areas amounted to only about 2% of the entire grazing unit and even a slight preference for forage on patch cuts would concentrate use on preferred areas.

Evidently herbage utilization patterns can be modified by longleaf pine tree removal; however, additional study is needed to fully quantify these effects. A cut-burn-graze process immediately preceding pine regeneration may prove beneficial by reducing competition from herbaceous vegetation.

Botanical Composition

Pinehill bluestem was the principal herbaceous species on protected range regardless of residual longleaf pine basal area (Table 2). Pinehill bluestem and slender bluestem combined produced about 50 to 60% of the herbage on protected range in 1969 and 1972, but both species tended to diminish in importance in 1975. Residual basal area treatments influenced the proportion of bluestems only in 1975 when slender bluestem occurred in greater proportions on patch cuts than on high or moderate basal area treatments. Other bluestems, consisting of a nearly equal mixture of broomsedge *(A. virginicus)*, Elliott *(A. elliottii)*, fineleaf *(A. subtenuis)*, and paintbrush *(A. ternarius)*, varied considerably within and between treatments and years but generally was not a major component of total herbage production.

Table 2. Percent botanical composition of herbaceous vegetation on protected range by residual longleaf pine basal area treatment and year.

	Residual pine basal area treatment[1]			
Year/herbage component	High	Moderate	Low	Patch cut
1969:				
Carpetgrass	0	0	0	
Pinehill bluestem	52	39	58	43
Slender bluestem	10	6	9	18
Other bluestems	7	24	4	8
Panicums	10	18	10	9
Other grasses and grasslikes	14	6	12	14
Forbs	7	7	7	8
Total	100	100	100	100
1972:				
Carpetgrass	0	0	0	0
Pinehill bluestem	26	56	45	33
Slender bluestem	21	4	7	21
Other bluestem	T[2]	4	1	6
Panicums	21	12	17	7
Other grasses and grasslikes	20	12	13	26
Forbs	12	12	17	7
Total	100	100	100	100
1975:				
Carpetgrass	0	0	0	0
Pinehill bluestem	23	32	35	37
Slender bluestem	5b	7b	9ab	22a
Other bluestems	10	14	9	2
Panicums	22	15	9	4
Other grasses and grasslikes	14	13	4	30
Forbs	26a	19ab	34a	5b
Total	100	100	100	100

[1]Within-row values followed by dissimilar subscripts indicate significant difference at the 5% level.
[2]T equals less than 1%.

Switchgrass *(P. virgatum)* and several species of low panicums were the principal components of the panicums groups. Panicums generally produced in excess of 10% of the herbage on patch cuts, although treatment differences were nonsignificant. The proportion of herbage produced by the other grass and grasslike groups—including cutover muhly *(Muhlenbergia expansa)*, arrowfeather threeawn *(Aristida purpurascens)*, green silkyscale *(Anthaenantia villosa)*, paspalums (*Paspalum* spp.), and species of the sedge *(Cyperaceae)* and rush families *(Juncaceae)*—was highly variable on forest treatments but tended to increase in importance with time on patch cuts. In fact, the proportion of other grasses and grasslikes on patch cuts increased from about 15% in 1969 to nearly 30% in 1975 principally due to the increase in cutover muhly. The proportion of other grasses and grasslikes was, however, similar under all protected treatment.

Forbs, of which the most common were grassleaf goldaster *(Heterotheca graminifolia)*, swamp flower *(Helianthus angustifolius)*, poor-joe *(Diodia teres)*, southern bracken *(Pteridium aquilinum* var. *pseudocaudatum)*, and a mixture of legumes, produced less than 10% of the herbage in 1969. The proportion of forbs increased with time on forested range but remained fairly stable on patch cuts. In 1975, forbs were generally more abundant on forested range than on patch cuts.

Botanical composition differed substantially due to the presence of carpetgrass on grazed range and its essential absence on protected range (Table 3). On grazed range, the proportion of carpetgrass was greater on patch cuts than forested treatments; however, the proportion of carpetgrass was probably influenced only indirectly by residual basal area treatment. Patch cuts probably were converted to carpetgrass primarily due to the high degree of herbage utilization. Earlier studies (Wahlenberg et al. 1939, Duvall and Linnartz 1967, and Wolters 1972) reported that heavy use

Table 3. Percent botanical composition of herbaceous vegetation on grazed range by residual longleaf pine basal area treatment and year.

	Residual pine basal area treatment[1]			
Year/herbage component	High	Moderate	Low	Patch cut
1972:				
Carpetgrass	1b	3b	4b	24a
Pinehill bluestem	24	19	16	8
Slender bluestem	6	5	5	9
Other bluestems	3	3	11	3
Panicums	26	33	18	35
Other grasses and grasslikes	13	22	27	8
Forbs	27	15	19	13
Total	100	100	100	100
1975:				
Carpetgrass	5b	4b	3b	50a
Pinehill bluestem	3	5	8	4
Slender bluestem	9	4	14	7
Other bluestems	1	2	1	9
Panicums	15	22	14	10
Other grasses and grasslikes	21	20	16	14
Forbs	46a	43a	44a	6b
Total	100	100	100	100

[1]Within-row values followed by dissimilar subscripts indicate significant difference at the 5% level.

encourages the spread of carpetgrass, but proportionately rapidly diminishes with light or no use.

The proportions of pinehill bluestem, slender bluestem, and other bluestems were generally not influenced by silvicultural treatment. Although, these grasses generally produced a smaller proportion of the total herbage on grazed range than on protected range. Differences were not apparent in proportion of panicums and other grasses and grasslikes due to a residual basal area treatment on grazed range, although in 1972 a weedy species, pimple panicum *(P. brachyanthum)*, accounted for a large proportion of the panicum group on grazed range.

The proportion of forbs tended to increase with time on grazed range just as they did under protection. Also, in 1975 forbs were more common on forest range than on patch cuts. Poor-joe and white eupatorium *(Eupatorium album)* were the principal forbs under all basal area treatments; however, southern bracken was a common component on forested treatments but rarely existed on patch cuts. Poor-joe, white eupatorium, and southern bracken all appeared to be associated with site disturbance following timber thinning. Differences in herbage botanical composition between forested and patch cut range were discounted as causative factors influencing utilization. Findings suggest that pine overstory and

Table 4. Herbage production (kg/ha) by residual longleaf pine basal area treatment and year on grazed and protected range.

	Residual pine basal area treatment[1]			
Year	High	Moderate	Low	Patch cut
		Protected		
1969	791	1206	1403	2973
1970	498	555	1329	3353
1971	240	447	615	2715
1972	193	262	619	2304
1973	352	418	832	3450
1974	688	1003	1363	3478
1975	1049	1445	1660	3853
		Grazed		
1970	440	720	801	2431
1971	389	723	804	2756
1972	233	546	760	2012
1973	683	913	1342	3067
1974	804	1139	1445	3310
1975	913	1092	1819	2476

rate of utilization influenced botanical composition rather than influencing the utilization rate.

Herbage Standing Crop

Annual standing crop on protected patch cuts averaged 3,161 kg/ha from 1969 through 1975 (Table 4). Standing crop on grazed patch cuts, determined by the cage technique, averaged 2,675 kg annually from 1970 through 1975. Grelen (1967) reported that the stationary-cage technique overestimated herbage yield on grazed southern pine-bluestem range. If the technique does in fact overestimate yield the real differences in annual stand crop between protected and grazed patch cuts would be greater than indicated by the present data. True differences in standing crop on protected and grazed patch cuts was apparently due to either botanical composition, plant vigor, or a combination of both factors.

Forested range treatments produced less herbage than patch cuts. Under trees the standing crop diminished as competition with pines increased if level of residual basal area is used as a relative index to competition.

The association of annual herbage standing crop with residual pine basal area was tested by regression analysis, with all years pooled. The linear regressions explained 78 and 86% of the variation in standing crop in kg/ha on grazed (G) and protected (P) range, respectively (Fig. 1). Level of the two regressions were different and indicate that patch cut treatments protected from grazing were more productive than grazed patch cuts. The differences in stand crop were probably due to differences in botanical composition and plant vigor. Both composition and vigor could have been influenced by repeated defoliation and time since patch cut establishment. Protected patch cuts were established in 1960, thus herbs had 9 years to respond to the absence of pine trees before the study was initiated, whereas, grazed patch cuts were not established until 1969 and the full production potential of herbs may not have been attained throughout the duration of the study.

Conclusions

In the first two growing seasons after a patch cut and burn, herbage utilization by cattle averaged 94 and 79%, respectively. Grazing preference shown by cattle for herbage from patch cuts diminished within 3 years after clearing. Herbage utilization rates

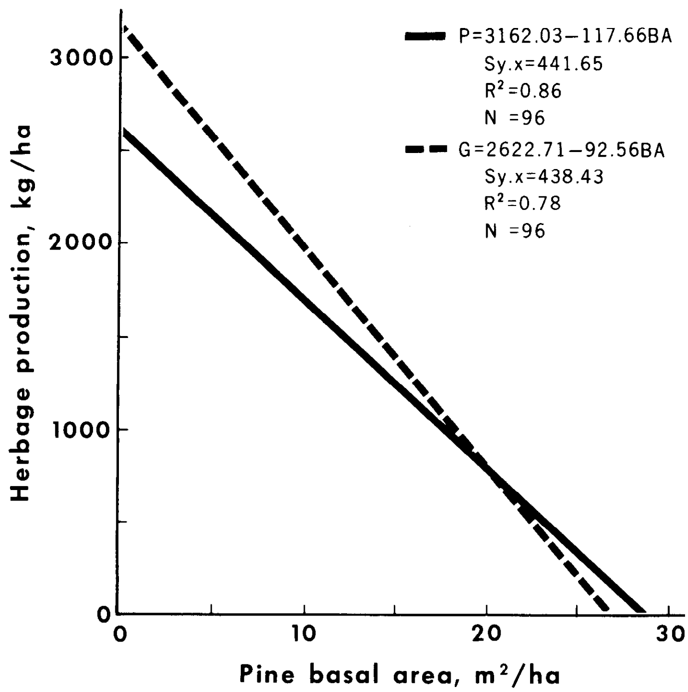

Fig. 1. *Herbage production-pine basal area relationships on protected (P) and grazed (G) longleaf pine range.*

suggested that cattle reject herbage from old patch cuts range when herbage is available immediately adjacent to freshly cut pine stumps.

The amount of trees harvested and the duration lapsed since harvest appeared to be the principal factors influencing herbage utilization. These factors also contributed indirectly to modifying herbage botanical composition.

Pinehill bluestem was the principal forage species on protected range. Botanical composition was modified by grazing on both patch cut and forested range. Excessive use by cattle converted the principally bluestem range to forbs under a longleaf pine canopy and to carpetgrass on patch cuts. Within 3 and 6 years after the patch cut, carpetgrass produced 24 and 50% of the total herbage, respectively, on grazed range. Weedy forbs and grasses increased in proportion to total herbage on forested ranges.

Though apparent differences in herbage production existed on grazed and protected ranges, herbage standing crop declined with increased increments of longleaf pine competition under both conditions. Differences in standing crop on grazed and protected range were probably due to differences in botanical composition and plant vigor. Longleaf pine plantations with 12 to 20 m^2 of residual basal area produced approximately 800 to 1,650 kg/ha of herbage annually.

Literature Cited

Duvall, V.L., and L.B. Whitaker. 1964. Rotation burning: A forage management system for longleaf pine-bluestem ranges. J. Range Manage. 17:322-326.

Duvall, V.L., and N.E. Linnartz. 1967. Influences of grazing and fire on vegetation and soil of longleaf pine-bluestem range. J. Range Manage. 20:241-247.

Grelen, Harold E. 1967. Comparison of cage methods for determining utilization on pine-bluestem range. J. Range Manage. 20:124-126.

Grelen, Harold E., and Hans G. Enghardt. 1973. Burning and thinning maintain forage in a longleaf pine plantation. J. Forest 71:419-420.

Hart, R.H., R.H. Huges, C.E. Lewis, and W.G. Monson. 1970. Effects of nitrogen and shading on yield and quality of grasses grown under young slash pine. Agron. J. 62:285-287.

Pearson, H.A., L.B. Whitaker, and V.L. Duvall. 1971. Slash pine regeneration under regulated grazing. J. Forest. 69:744-746.

Steel, R.G.D., and J.H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., Inc. New York. 481 p.

Wahlenberg, W.G., S.W. Greene, and H.R. Reed. 1939. Effects of fire and cattle grazing on longleaf pine lands as studied at McNeill, Mississippi. U.S. Dep. Agr. Tech. Bull. 683, 52 p.

Wolters, Gale L. 1972. Production and persistence of common carpetgrass in relation to site and harvest frequency. J. Range Manage. 25:360-364.

Wolters, Gale L. 1973. Southern pine overstores influence herbage quality. J. Range Manage. 26:423-426.

In Vitro Digestibility among Accessions of Big Sagebrush by Wild Mule Deer and Its Relationship to Monoterpenoid Content

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Abstract

Results of in vitro digestibility trials indicate that big sagebrush *(Artemisia tridentata)* is a highly digestible browse for wintering mule deer. Subspecies *tridentata* (62.1% digested dry matter) was more highly digested than subspecies *vaseyana* (53.2% digested dry matter) and subspecies *wyomingensis* (51.4% digested dry matter). On an accession level, some accessions of big sagebrush were more highly digested than others. The accessional range was from 44.6% digested dry matter to 64.8%. No relationship was found between total monoterpenoids (essential or volatile oils) content and digestibility.

Some accessions of big sagebrush *(Artemisia tridentata)* have been found to contain significantly higher levels of monoterpenoids (essential or volatile oils) than others (Welch and McArthur 1979, Welch and McArthur 1981). Our interest in the monoterpenoid content stems from the reports of Nagy et al. (1964), Oh et al. (1968), and Longhurst et al. (1969) that in high enough concentrations, these compounds may adversely affect deer digestion. If monoterpenoids of big sagebrush do suppress digestion, we could design breeding and selection schemes aimed at developing strains of big sagebrush low in monoterpenoids. Welch and McArthur (1979) questioned the hypothesis that monoterpenoids cause digestive problems. Our main concern is that it requires a lot of time and effort to select for or against a given characteristic such as low monoterpenoids when in fact they may not be adversely affecting digestion. Therefore, we undertook this study to determine the relation between accessions of big sagebrush with varying amounts of total monoterpenoids and their in vitro digestibility. Other non-monoterpenoid producing browse species were included in the study for comparison.

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Materials and Methods

From a uniform shrub garden at the Snow Field Station[1] at Ephraim, Utah, nine accessions of *Artemisia tridentata* (big sagebrush) were selected to study in vitro digestibility using wild mule deer rumen inoculum. These nine accessions contained different levels of total monoterpenoids (Welch and McArthur 1981). All three subspecies of *A. tridentata* were equally represented (three accessions each). Subspecies were identified by morphological (Beetle and Young 1965, Winward and Tisdale 1977, McArthur et

[1]The Snow Field Station is cooperatively maintained by the Agricultural Experiment Station of Utah State University, Snow College, Utah State Division of Wildlife Resources (W-82-R), and the Intermountain Forest and Range Experiment Station.

al. 1979), and chemical criteria (Stevens and McArthur 1974). Within each accession, five plants were selected at random. Vegetative samples of current-year growth were collected at random over the entire crown of each plant. The tissue collected would represent the portion most commonly consumed by wintering mule deer, that is the first-two terminal inches of the stems with leaves. Collections were made on January 18, 1978. Samples collected from a given plant were placed in a paper bag and frozen on-site with dry ice. All samples were collected within a 90-minute period (1000-1130) to avoid diurnal variation in monoterpenoid concentration (Nicholas 1973). Samples were stored in an ultra-low freezer (-35° C) until needed for grinding. Before grinding, the samples—stems with leaves—from the five plants of a given accession were pooled, ground together, and thoroughly mixed.

Samples were ground with a motorized steel mortar and pestle. Liquid nitrogen was poured over the tissue to aid in grinding the tissue to a fine powder.

After grinding, the samples were placed in plastic bottles fitted with airtight caps and stored in an ultra-low freezer (-35° C).

Current-year growth was collected from five plants of each of the following: *Cercocarpus ledifolius* (curlleaf mahogany), *Cercocarpus montanus* (true mahogany), and *Purshia tridentata* (antelope bitterbrush). Also, hips were collected from five plants of *Rosa eglanteria* (sweetbrier rose). Samples were pooled on a species basis and ground as described for the nine accessions of big sagebrush.

We used the in vitro digestion procedure as outlined by Pearson (1970), except 1.0 g of fresh tissue was placed in digestion tubes. The dry matter content was determined for all plant samples digested. Inoculum was collected from four deer killed by personnel from the Utah State Division of Wildlife Resources. The four deer harvested for this study were killed on January 15, 22, 29, and February 5, 1979. Deer were taken from winter ranges dominated by big sagebrush. This was done to enhance the probability that the deer harvested had been eating big sagebrush long enough to have allowed the rumen microorganisms to adapt fully to the monoterpenoids (Nagy et al. 1964, and Oh et al. 1967).

The data were expressed as percent of digestible dry matter. Percentages were transformed (arcsin) for performing analysis of variance and Hardley's range test. Completely random analysis of variance was used to detect significant differences in digestibility among subspecies of big sagebrush, among nine accessions of big sagebrush, and for all species of browse studied (sagebush, bitterbrush, rose hips, curlleaf, and true mahogany). For significant F ratios, Hardley's range test was used to compare treatment means (Snedecor and Cochran 1967).

The monoterpenoid content for each accession of big sagebrush was determined by using the methods outlined by Welch and McArthur (1981). Correlation analysis and stepwise multiple regression analysis were used to relate monoterpenoid content of nine accessions of big sagebrush to in vitro digestibility (Steel and Torrie 1960). Also, the crude protein content for each accession of big sagebrush was determined by the Kjeldahl method (Association of Official Agricultural Chemists 1965). As with monoterpenoid content, crude protein content was related to in vitro digestibility by correlation analysis and stepwise multiple regression analysis (Steel and Torrie 1960).

We wanted to know what was happening to the monoterpenoids during the digestibility trials. Therefore, we modified the digestibil-

Table 1. In vitro digestibility of nine accessions of *Artemisia tridentata* (big sagebrush) and four other species of browse (hips of sweetbrier rose[1], curlleaf mahogany[2], true mahogany[3], and bitterbrush[4]). Data expressed as percent digestible dry matter.

Big sagebrush accession or other browse species	Date of digestion trials 1/15/79	1/22/79	1/29/79	2/5/79	Average
Clear Creek (t)[5]	69.9	59.8	59.5	70.0	64.8
Dove Creek (t)	67.9	62.0	61.2	67.1	64.6
Loa (t)	61.1	55.5	55.0	56.3	57.0
Indian Peaks (v)	63.3	51.8	55.2	52.7	55.8
Benmore (v)	64.7	53.0	53.6	49.4	55.2
Kaibab (w)	56.3	53.7	55.5	54.1	54.9
Milford (w)	58.9	50.5	58.6	50.4	54.6
Sardine (v)	53.5	48.6	49.0	43.8	48.7
Trough Springs (w)	47.1	40.5	45.0	45.6	44.6
Rose hips[1]	56.3	52.2	40.1	47.6	49.1
Curlleaf[2]	49.5	41.3	45.8	42.0	44.7
Mahogany[3]	26.2	18.2	16.2	18.8	20.0
Bitterbrush[4]	24.7	14.3	21.5	18.7	19.8

[1]*Rosa eglanteria.*
[2]*Cercocarpus ledifolius.*
[3]*Cercocarpus montanus.*
[4]*Purshia tridentata.*
[5]t = *Artemisia tridentata* ssp *tridentata*
v = *A. tridentata* ssp *vaseyana*
w = *A. tridentata* ssp *wyomingensis*

Table 2. Comparisons (Hardley's range test) of the in vitro dry matter digestibility among three plant groupings.

Subspecies of big sagebrush[1]: Subspecies	% digested dry matter	big sagebrush: Accessions	% digested dry matter	9 accessions of big sagebrush and 4 other browse species[2]: Accession or species	% digested dry matter
tridentata	62.1a[3]	Clear Creek	64.8a[3]	Clear Creek	64.8a[3]
vaseyana	53.2b	Dove Creek	64.6a	Dove Creek	64.6a
wyomingensis	51.4b	Loa	57.0b	Loa	57.0b
		Indian Peaks	55.8b	Indian Peaks	55.8b
		Benmore	55.2b	Benmore	55.2b
		Kaibab	54.9b	Kaibab	54.9b
		Milford	54.6b	Milford	54.6b
		Sardine	48.7bc	Rose hips	49.1bc
		Trough Springs	44.6c	Sardine	48.7bc
				Curlleaf	44.7c
				Trough Springs	44.6c
				Mahogany	20.0d
				Bitterbrush	19.8d

[1]*Artemisia tridentata.*
[2]Rose hips-sweetbrier-*Rosa eglanteria*
Curlleaf-curlleaf mahogany-*Cercocarpus ledifolius*
Mahogany-true mahogany-*Cercocarpus montanus*
Bitterbrush-antelope bitterbrush-*Purshia tridentata.*
[3]Values sharing the same letter superscript are not significantly different at the 5% level.

ity trials by adding three digestive tubes that contained only buffer. To these tubes, we added specific amounts of α-pinene and d-camphor–2.5 ug/ul. These tubes were incubated and treated like other tubes except they did not contain plant tissue or rumen inoculum. They also did not receive the acid-pepsin, and sodium carbonate treatments. After the first incubation period, we extracted the solution with absolute ether and used gas chromatography to detect any changes in the monoterpenoid content.

Results

The raw data of the four in vitro digestibility trials are given in Table 1. Significant *F* ratios were detected (Table 2) for the following effects: subspecies of big sagebrush, accessions of big sagebrush, and for all browse species studied. Subspecies *tridentata* (62.1% digested dry matter) was more highly digested by in vitro means than subspecies *vaseyana* (53.2% digested dry matter) and subspecies *wyomingensis* (51.4% digested dry matter). Clear Creek Canyon (64.8% digested dry matter) and Dove Creek (64.6% digested dry matter) accessions of big sagebrush *(Artemisia tridentata)* were more highly digested than the other seven accessions. Rose hips *(Rosa eglanteria)* and curlleaf mahogany *(Cercocarpus ledifolius)* were the only other browse species that were as digestible as some of the accessions of big sagebrush, but were not as digestible as the Clear Creek Canyon and Dove Creek accessions (Table 2). Mahogany *(Cercocarpus montanus)* and bitterbrush *(Purshia tridentata)* were significantly the least digestible of all plants tested (Table 2).

Our findings in relating monoterpenoid content and crude protein content of the nine accessions of big sagebrush to percent digested dry matter are given in Table 3. Total monoterpenoids were not significantly related to digestibility ($r = -0.09$). The concentrations of α-pinene ($r = -0.56$), 1.8 cineol ($r = -0.40$), α-thujone ($r = -0.06$), β-thujone ($r = -0.39$), and terpineol ($r = -0.10$) were not significantly related to percent digested dry matter. Camphene ($r = -0.75$) and camphor ($r = -0.75$) were significantly related to percent digested dry matter, but not at the 1% level. The crude protein level ($r = 0.80$) was significantly related to percent digested dry matter at the 1% level.

Stepwise multiple regression analysis revealed that the content of crude protein accounted for 64% of the variation of digestible dry matter among the nine accessions of big sagebrush. An additional 25% of the variation was accounted for by adding camphor content to the regression equation. Other variables, total monoterpenoids, and individual monoterpenoids contributed only 1% or less to the regression.

We found that 100% of the α-pinene added to control flasks (buffer only) was lost. Loss of camphor was 17.3%. All three control flasks, however, contained a white condensate ring around the neck of the flask. This condensate ringe was located about 70 mm above the surface of the digestion solution and was identified to be camphor.

Discussion

Our results indicate that big sagebrush is a highly digestible food for wintering mule deer. Other workers agree with the results we have obtained (Sheehy 1975, Urness et al. 1977, and Wallmo et al. 1977). Unfortunately, as Wallmo et al. (1977) pointed out, preparatory techniques such as oven drying may result in large losses of monoterpenoids, thus introducing bias. Also, Welch and McArthur (1979) pointed out possible large losses of monoterpenoids due to freeze drying. We ran a test to determine the loss of monoterpenoids due to oven drying and freeze drying. We found that oven drying at 100° C caused a total loss of monoterpenoids. Freeze drying caused a 78% loss. We were able to overcome these preparatory techniques by grinding the big sagebrush tissue (fresh), submerged in liquid nitrogen, with a motorized steel mortar and pestle.

We found very little relationship between digestibility and total monoterpenoid content. Connolly et al. (1980) found similar results using Douglas-fir and deer rumen inocula. On an individual monoterpenoid basis, camphene and camphor had a significant negative effect on digestion. We are unable to explain the significant negative effect camphene and camphor appear to have on digestibility among the nine accessions of sagebrush. Milford, Loa, and Clear Creek accessions contained about the same amount of camphor, but Clear Creek was significantly more digestible than the Milford and Loa accessions. This is also true for camphene. Trough Springs, Sardine Canyon, and Kaibab accessions contained the same amount of camphene but Kaibab was significantly more digestible than the Trough Springs. Our reluctance to accept the statistically significant effects of camphene and camphor on digestions stems from two points: First, we selected the accessions purposely for varying amounts of total monoterpenoids not for individual monoterpenoids—our test for individual monoterpenoids may not be valid; and secondly, in vitro digestibility values for big sagebrush are among the highest recorded for shrubs (Welch and McArthur 1979). In the multiple regression equation, camphor content accounted for about 25% of the digestibility variation among the accessions, whereas, camphene accounted for less than 1%. From a biological point, the impact of these two monoterpenoids must be small. If not, the high percentage of digested matter would not have been obtained. Crude protein levels had a significant positive relation to digestibility.

This lack of a relationship between digestibility and total monoterpenoid content and the high percentage of digested dry matter contrasted with the findings or statements of Nagy et al. (1964),

Table 3. The relationship between percent digestible dry matter (in vitro) and total monoterpenoids (essential oils), individual monoterpenoids, and crude protein of nine accessions of big sagebrush.[1]

Accession	% digested dry matter	Total monoterpenoids	α-Pinene	Camphene	1,8 Cineol	α-Thujone	β-Thujone	Camphor	Terpineol	Crude protein
Trough Springs	44.6	1.41[2]	.09	.09	.08	.00	.00	.89	.02	11.0
Sardine	48.7	1.74	.02	.11	.06	.25	.58	.62	.05	10.5
Milford	54.6	.99	.05	.03	.01	.13	.04	.22	0	11.2
Kaibab	54.9	.93	.11	.11	.02	.00	.00	.63	.01	11.9
Benmore	55.2	2.89	.00	.00	.09	.96	.49	.05	.32	10.0
Indian Peaks	55.8	1.72	.00	.04	.12	.03	.02	.31	.01	11.2
Loa	57.0	1.91	.01	.03	.09	.13	.55	.28	.05	14.5
Dove Creek	64.6	1.70	.00	.00	.02	.07	.71	.13	0	16.0
Clear Creek	64.8	.95	.00	.00	.02	.05	.31	.24	.01	15.3
r	–	–.09	–.56	–.75	–.40	–.06	–.39	–.75	–.10	.80
r^2	–	.008	.31	.56	.16	.003	.15	.56	.01	.64

[1]*Artemisia tridentata.*
[2]Data for monoterpenoids expressed on a percent dry matter basis.

Nagy and Tengerdy (1968), Oh et al. (1968), Dietz and Nagy (1976), Wallmo et al. (1977), Nagy and Regelin (1977), Carpenter et al. (1979). In general, these workers have shown that at certain levels, monoterpenoids suppressed the in vitro growth of rumen microorganisms, rate of cellulose digestion, and the rate of gas and volatile fatty acids production of deer rumen microorganisms. Estimates of the amount of big sagebrush that deer can consume before the monoterpenoids start to interfere with digestion varies from 15 to 50% of the diet (Nagy et al. 1964, Nagy and Tengerdy 1968, Dietz and Nagy 1976, Wallmo et al. 1977).

Although we do not question the results of these in vitro studies or estimates of the amount of big sagebrush that can be safely eaten, we do question whether the suggested suppression by monoterpenoids occurs under range conditions. First, in vivo digestion trials conducted by Smith (1950), Bissell et al. (1955), and Dietz et al. (1962) determined the total digestible nutrients (TDN) content of big sagebrush to be 70.2%, 55.9%, and 58.9%, respectively. Nagy 1979 citing the protein digestion coefficients from these studies concluded that big sagebrush digestibility is poor to fairly poor. We cannot understand how a roughage with a reported mean TDN content of about 59% can be considered poor to fairly poor in digestibility (see review by Welch and McArthur 1979). High quality alfalfa has a TDN content of about 53% (Morrison 1961, National Academy of Sciences 1964). Secondly, we propose that the monoterpenoids are lost from the rumen and therefore do not interact significantly with the rumen microorganisms. This hypothesis is based on our observations that α-pinene was lost from the in vitro digestion tubes and that camphor formed a condensated ring about 70 mm above the surface of the in vitro digestion solution. The force that drove these compounds (pinene and camphor) out of the digestion solution was heat. Apparently 38.5° C, which is close to the normal body temperature of mule deer, is sufficient to volatilize the monoterpenoids (Moen 1973). We can visualize three ways in which monoterpenoid levels in the deer rumen can be greatly reduced: (1) loss through mastication and rumination, (2) heat from the body volatilizing the monoterpenoids resulting in the monoterpenoid being expelled from the rumen by eructation, and (3) possible adsorption in the rumen and excretion through the kidneys (Cook et al. 1952, Annison 1965). We will be testing this hypothesis in the near future. If the hypothesis is true, we will be able to explain the apparent conflict between the in vitro studies showing the monoterpenoid suppress deer rumen microorganisms and the results of our study showing that big sagebrush is a highly digestible forage for deer.

Literature

Annison, E.F. 1965. Absorption from the ruminant stomach. p. 185-197. *In:* Physiology of Digestion. R.W. Dougherty (ed.).

Association of Official Agricultural Chemists. 1965. Official Methods of Analysis, 10th ed. Washington, D.C.

Beetle, A.A., and A. Young. 1965. A third subspecies in the *Artemisia tridentata* complex. Rhodora 67:405-406.

Bissell, H.D., B. Harris, H. Strong, and F. James. 1955. The digestibility of certain natural and artifical food eaten by deer in California. California Fish and Game 41:57-78.

Carpenter, L.H., O.C. Wallmo, and R.B. Gill. 1979. Forage diversity and dietary selection by wintering mule deer. J. Range Manage. 32:226-229.

Connolly, G.E., B.O. Ellison, J.W. Fleming, S. Geng, R.E. Kepner, W.M. Longhurst, J.H. Oh, and G.F. Russell. 1980. Deer browsing of Douglas-fir trees in relation to volatile terpene composition and in vitro fermentability. Forest Sci. 26:179-193.

Cook, C.W., L.A. Stoddart, and L.E. Harris. 1952. Determining the digestibility and metabolizable energy of winter plants by sheep. J. Anim. Sci. 11:578-590.

Dietz, D.R., and J.G. Nagy. 1976. Mule deer nutrition and plant utilization. p. 71-78. *In:* Mule Deer Decline in the West—a Symposium. G.W. Workman and J.B. Low (eds.). Coll. Nat. Resour., Utah Agric. Exp. Sta., Logan. 134 p.

Dietz, D.R., R.H. Udall, and L.E. Yeager. 1962. Chemical composition and digestibility by mule deer of selected forages species. Cache la Poudre Range, Colorado. Colorado Fish and Game Dep. Tech. Pub. 14:76.

Longhurst, W.M., J.H. Oh, M.B. Jones, and R.E. Kepner. 1969. Deer forage palatability, digestibility, and management implications. Paper given: California-Nevada Section of the Wildlife Society Annu. Meet., February 1, 1969, Berkeley, Calif. 10 p.

McArthur, E.D., A.C. Blauer, A.P. Plummer, and R. Stevens. 1979. Characteristics and hybridization of important intermountain shrubs. III. Sunflower family. U.S. Dep. Agr. Forest Serv. Res. Pap. INT-220, 82 p. Intermt. Forest and Range Exp. Sta., Ogden, Utah.

Moen, A.N. 1973. Wildlife Ecology: an Analytical Approach. W.H. Freeman and Co., San Francisco, Calif. 458 p.

Morrison, F.B. 1961. Feeds and Feeding, Abridged 9th Ed. The Morrison Publishing Co., Clinton, Iowa.

Nagy, J.G. 1979. Wildlife nutrition and the sagebrush ecosystem. p. 164-168. *In:* Sagebrush Ecosystem Symposium. G.F. Gifford, F.E. Busby, and J.P. Shaw (eds.). Coll. of Natur. Resour. Utah Agr. Exp. Sta., Logan.

Nagy, J.G., and W.L. Regelin. 1977. Influence of plant volatile oils on food selection by animals. 13th Congress of Game Biologists, 13:225-230.

Nagy, J.G., and R.P. Tengerdy. 1968. Antibacterial action of essential oils of *Artemisia* as an ecological factor. II. Antibacterial action of the volatile oils of *Artemisia tridentata* (big sagebrush) on bacteria from the rumen of mule deer. Appl. Microbiol. 16:441-444.

Nagy, J.G., H.W. Steinhoff, and G.M. Ward. 1964. Effects of essential oils of sagebrush on deer rumen microbial function. J. Wildl. Manage. 28:785-790.

National Academy of Sciences. 1964. Nutrient requirement of domestic animals. No. 5. Nutrient requirement of sheep. A report of the Committee on Animal Nutrition. Nat. Res. Counc. Pub. 1193:31-34. Washington, D.C.

Nicholas, H.J. 1973. Terpenes. p. 254-309. *In:* Organic Metabolites—Phytochemistry Vol. II. L.P. Miller (ed.), Van Nostrand Reinhold Co., New York.

Oh, H.K., T. Sakai, M.B. Jones, and W.M. Longhurst. 1967. Effects of various essential oils isolated from Douglas-fir needles upon sheep and deer rumen microbial activity. Appl. Microbiol. 15:777-784.

Oh, H.K., M.B. Jones, and W.M. Longhurst. 1968. Comparison of rumen microbial inhibition resulting from various essential oils isolated from relatively unpalatable plant species. Appl. Microbiol. 16:39-44.

Pearson, H.A. 1970. Digestibility trials: In vitro techniques. p. 85-92. *In:* Range and wildlife habitat evaluation—a research symposium. H.A. Paulson, Jr., E.H. Reid, and K.W. Parker (eds.). U.S. Dep. Agr. Forest Serv. Misc. Pub. No. 1147.

Sheehy, D.P. 1975. Relative palatability of seven *Artemisia* taxa to mule deer and sheep. M.S. Thesis, Oregon State Univ., Corvallis, 147 p.

Smith, A.D. 1950. Sagebrush as winter food for mule deer. J. Wildl. Manage. 14:285-289.

Snedecor, G.W., and W.G. Cochran. 1967. Statistical Methods. Iowa State Univ. Press, Ames. 593 p.

Steel, R.G.D., and J.H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., New York. 481 p.

Stevens, R., and E.D. McArthur. 1974. A simple field technique for identification of some sagebrush taxa. J. Range Manage. 27:325-326.

Urness, P.J., A.D. Smith, and R.K. Watkins. 1977. Comparison of in vivo and in vitro dry matter digestibility of mule deer forages. J. Range Manage. 30:119-121.

Wallmo, O.C., L.H. Carpenter, W.L. Regelin, R.B. Gill, and D.L. Baker. 1977. Evaluation of deer habitat on a nutritional basis. J. Range Manage. 30:122-127.

Welch, B.L., and E.D. McArthur. 1979. Feasibility of improving big sagebrush *(Artemisia tridentata)* for use on mule deer winter ranges. p. 415-473. *In:* Proceedings of the International Arid Lands Conference on Plant Resources. J.R. Goodin and D.K. Northington (eds.). Texas Tech. Univ., Lubbock.

Welch, B.L., and E.D. McArthur. 1981. Variation of monoterpenoid content among subspecies and accessions of *Artemisia tridentata* grown in a uniform garden. J. Range Manage. 34:380-384.

Winward, A.H., and E.W. Tisdale. 1977. Taxonomy of the *Artemisia tridentata* complex in Idaho. Coll. Forest Wildl., and Range Sci., Univ. of Idaho, Moscow. Bull. 19, 15 p.

Demography and Fire History of a Western Juniper Stand

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Abstract

The age, density, and fire history of western juniper *(Juniperus occidentalis* Hook.) trees growing on range sites of contrasting potentials were investigated. The 1,000-ha study area consisted of 65% big sagebrush [*Artemisia tridentata* Nutt. subsp. *wyomingensis* (Rybd.) Beetle] and 30% low sagebrush (*A. arbuscula* Nutt.) plant communities. Density of western juniper trees was 150 and 28 trees/ha on the big and low sagebrush sites, respectively. The oldest western juniper found growing in the big sagebrush communities became established in 1855, and 84% of the existing trees became established between 1890 and 1920. The oldest trees on the low sagebrush sites had established by 1600, and most of the existing trees established before 1800. At the beginning of the 20th century, the western juniper populations on big sagebrush sites were doubling in density every 3 years. The rate of establishment on these sites has slowed until 1,370 years would now be required to double the population size. The rate of population growth on low sagebrush sites has varied from decade to decade with a trend to double the population every 200 years and trees that become senescent at about 400 years of age. About 0.4% of western juniper on the low sagebrush sites had fire scars, some of which indicated the occurrence of multiple fires. These fire scars indicated that since 1600 there were periods of up to 90 years when no fires scarred the trees. Changes in the frequency of wildfires appear to be the most logical explanation for the sudden invasion of trees into big sagebrush communities, but current technologies for reconstructing fire chronologies are woefully inadequate in this environment.

During the last century there has been a pronounced change in the distribution, density, and age structure of virtually all juniper woodlands in the western United States. For the southwestern United States such changes have been related to the influences of grazing animals and fire suppression (Johnson 1962, Arnold et al. 1964).

Western juniper (*Juniperus occidentalis* Hook.) woodlands are a northwestern extension of the extensive woodlands of the central Great Basin. There are two distinct subspecies of *J. Occidentalis: J. Occidentalis* Hook. subsp. *australis* Vasek, the Sierra juniper, which occurs from Lassen County, California, south through the Sierra Nevada mountains to the San Bernardino mountains of southern California; and *J. occidentalis Hook. subsp. occidentalis,* which occurs in northern California and adjacent Nevada, southwestern Idaho, and southeastern Washington, and reaches its greatest development in central Oregon east of the Cascade Mountains (Vasek 1966). The distribution of this subspecies generally follows that of the Columbia River Basalts (King 1959).

In the words of a land manager, "Where they grow, stands of western juniper are generally accepted as a characteristic part of the landscape. They appear to be well established and form a logical transition between the open plains and the pine timber. They look like they belong. A closer look raises some doubts." (Caraher 1978).

The doubts of many observers have been raised by the observation of even-aged stands with no senescent trees and no reproduction (Adams 1975). The soils of many of these stands appear to be adapted to support communities of big sagebrush (*Artemisia tridentata* Nutt.)/bluebunch wheatgrass [*Agropyron spicatum* (Pursh) Scribn. & Sm.]. At the same time there are stands of western juniper growing on relatively shallow or rocky soils or steep slopes, with all age classes represented, from seedling to senescent.

Our purpose in these studies was to take a distinct land form, stratify the plant communities according to potential, and determine the age, density, and fire history of the western juniper trees present.

Methods

The study area was located in western Lassen County, California. The site, known locally as Juniper Hill, consists of about 1,000 hectares (ha) of rangeland on a low hill that is clearly disjunct from the adjacent forested mountains. The western and northwestern sides of the hill confront cultivated fields of the Big Valley agricultural area. The southern base of the hill touches the alluvial soils of Willow Creek, which are farmed. The eastern flanks of Juniper Hill, which are its steepest portion, meet broad flats of low sagebrush (*Artemisia arbuscula* Nutt.). The valleys around Juniper Hill are about 1,350 m in elevation, and the summit of the hill is 1,430 m in elevation. The hill itself consists of a broken and tilted portion of a basalt flow, with the lowered portion toward the southeast and the raised portion toward the northwest.

Precipitation, occurring almost entirely during the winter and spring, is estimated at 30 cm, based on gauges located on the site and extrapolation from the nearest long-term weather station at Adin, California.

Juniper Hill has traditionally been used to winter cattle and to place cattle in the early spring, when the neighboring farmers begin to till their fields. The herbaceous vegetation and often the shrubs have been completely altered by this continued early grazing. The first settlement on Willow Creek began in the 1860's (Guinn 1906). Juniper Hill is subdivided into nine pastures of different ownership. A historical marker at the base of the hill on the Willow Creek side indicates that Providence School was located on the site in the 1870's to serve the children of homesteaders in the surrounding area.

Using aerial photographs and ground surveys, we mapped the plant communities of the entire hill in two broad categories: juniper/big sagebrush and juniper/low sagebrush. Under pristine conditions, there were probably several communities located on the hill, representing different potentials or habitat types (Driscoll 1964). A few remnant plants of bluebunch wheatgrass are apparent, but the herbaceous vegetation is now dominated by the alien annual grasses cheatgrass *(Bromus tectorum L.)* and medusahead [*Taeniatherum asperum* (Simonkai) Nevski]. It was not possible by working on Juniper Hill alone to reconstruct all pristine communities; therefore, only the broad classifications of big and low sagebrush were used.

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In a portion of the juniper/big sagebrush communities, we randomly established eight plots, each 0.1 ha in area. All trees growing in these plots were cut at the soil surface. The height, maximum crown diameter, trunk diameter above the swollen base, and number of growth rings were determined for each tree. We established 28 other 0.1-ha plots in juniper/big sagebrush communities on Juniper Hill. The same data were collected, except that the trees were not cut and the growth rings were not counted. The age of these trees was estimated with a regression equation based on height and diameter of the trunk. The equation was developed from the data obtained on the cut plots. In both the cut and uncut plots all trees were examined for evidence of fire scars.

In juniper/low sagebrush communities on the hill we established 32 additional 0.1-ha plots. The same data were collected as on plots in the juniper/big sagebrush communities. Fire scars were determined and interpreted by the methods of Arno and Sneck (1977). A separate regression equation was developed for estimating age of the western junipers on low sagebrush sites from tree height and trunk diameter. However, most of the trees on the low sagebrush sites were cut for age determination.

Results

Distribution of Plant Communities

About 66% of the 1,000-ha area of Juniper Hill is covered with western juniper/big sagebrush or big sagebrush-bitterbrush [*Purshia tridentata* (Pursh) DC.] plant communities (Table 1). Decaying stumps of old-growth trees that had been cut many years earlier were found on about 1% of the western juniper/big sagebrush area; no such stumps were found in the remaining portion of this community. Stumps were mainly found on steep, north-facing slopes below a ridge top, with only an occasional stump on top of the ridges (Fig. 1). Most of the old growth areas had low sagebrush communities located below them on the slopes. The remainder of the western juniper/big sagebrush occurred on gentle to slightly undulating slopes. The soils were shallow Typic Haploxerolls derived from basalt. These soils were a heavy clay loam, and soil depth ranged from 25 to 80 cm.

Table 1. Major effective environments on Juniper Hill study area.

Effective environment	Percent of total area
Western juniper/big sagebrush	59
Western juniper/low sagebrush	30
Western juniper/big sagebrush-bitterbrush	6
Rim rocks	4
Cut-over area	1

On aerial photographs, there were two distinct communities composed of open juniper woodlands with a bitterbrush-big sagebrush shrub layer (Fig. 1). The bitterbrush was still vigorous while in the remainder of the juniper/big sagebrush communities only dead bitterbrush plants were found. The density of juniper trees was lower than on the other big sagebrush sites. There were no soil or aspect differences to account for these differences. These areas may be old burns where the juniper population was reduced or eliminated and bitterbrush and juniper trees have reinvaded. We could find no fire records to indicate such a burn, and, despite a careful search, we found no fire scars on the existing juniper trees in these areas.

Dead stumps of bitterbrush plants were apparent throughout the remaining western juniper/big sagebrush woodlands. Historically, according to interviews with neighboring ranchers, Juniper Hill was noted for its excellent stands of bitterbrush. Early in the 20th century, children of neighboring ranchers had to hunt to find the dairy cows that were turned loose daily in the bitterbrush stands (Personal communication from Jerry Parks, Adin, California).

The western juniper/low sagebrush communities constitute 30% of the area and represent a contrasting environment. The soils of the low sagebrush areas are Duric Haplargids or Typic Durargids. The most striking thing about the soils of these low sagebrush communities is the biscuit and swale microtopography. In many of the swales, there is virtually no soil suitable for the growth of plants. The mounds or biscuits may have a soil depth of 10 to 20 cm. Soils in these low sagebrush communities are extremely wet in the spring after the snow melts and are baked hard in midsummer. Although they are contrasting environments, the low sagebrush and big sagebrush juniper woodlands form a mosaic in their physical distribution (Fig. 1).

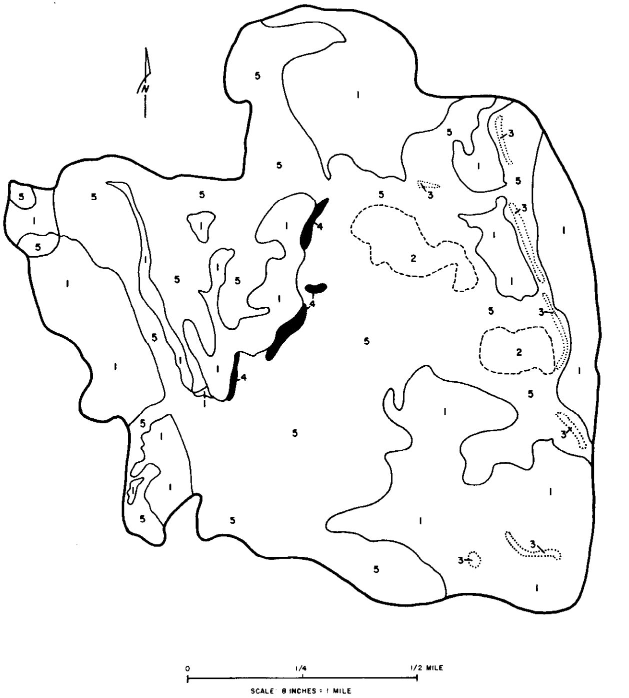

Fig. 1. *Distribution of major groups of plant communities on Juniper Hill study area: (1) western juniper/low sagebrush; (2) area of western juniper/big sagebrush-bitterbrush with a low density of trees; (3) rim rocks; (4) western juniper/big sagebrush with stumps from past utilization; and (5) western juniper/big sagebrush.*

The remaining community or effective environment on Juniper Hill consists of western junipers growing in cracks in basalt rim rocks. The community is not located on top of the rims, but occasional trees have become established and are growing on the near vertical faces of the rims and in the talus at the foot of the rock exposures.

Density of Western Juniper

The western juniper/big sagebrush woodlands are quite dense stands, averaging 150 trees/ha (Table 2). In contrast, the western juniper/low sagebrush communities have only 28 trees/ha, and the areas of relatively recent burns in big sagebrush-bitterbrush communities have only 25 trees/ha. Despite the density of trees in the big sagebrush communities the canopies are not closed. Projected cover of the juniper trees ranged from 40 to 60% in these communities. Although the crowns are not aerially closed, excavations for studies of the rooting habit of the trees have revealed that the interspaces between the trees are filled with tree roots, effectively

Table 2. Density (number per unit area) of western juniper trees in major plant communities on Juniper Hill study area.

Plant community	Density of western juniper trees (no./ha)
Western juniper/big sagebrush	150
Western juniper/low sagebrush	28
Western juniper/big sagebrush-bitterbrush	25

closing the stands (unpublished research, ARS, Reno, Nev.).

Periodicity of Establishments

Of the western juniper trees growing in big sagebrush communities, 84% established from 1890 to 1920 (Fig. 2). The oldest tree established in 1855, and only 6.4% established before 1890. Only 2.8% of the existing trees have established since 1930. We found no naturally dead juniper trees on the big sagebrush sites.

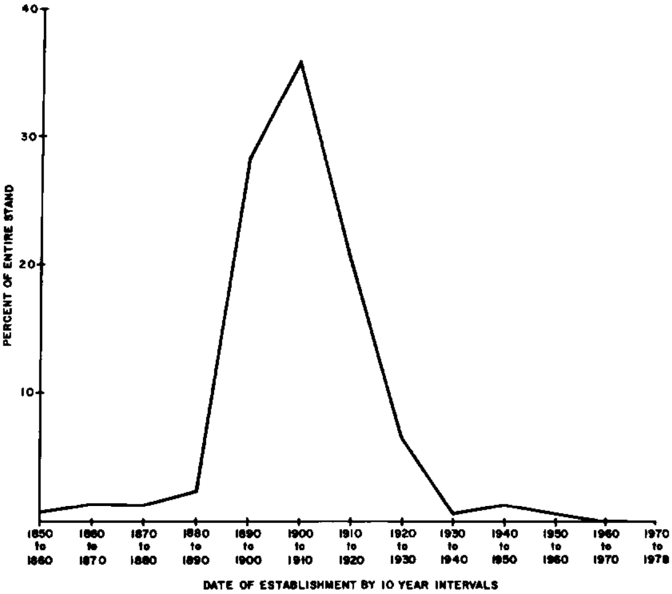

Fig. 2. *Periodicity of establishment of western juniper trees in big sagebrush communities on Juniper Hill, 1850-1978.*

The western juniper growing in the low sagebrush communities had a much greater mean age. The oldest trees, about 2% of the population, established by 1600 (Fig. 3). The centers of the apparently oldest trees were rotten, which prevented definite determinations of the establishment date, but it was no later than 1600. Most of the western juniper trees that were growing in low sagebrush communities established before 1800. From 1850 to 1900 there was a resurgence in establishment, which tapered off after 1900.

When interpreting the establishment curves for western juniper,

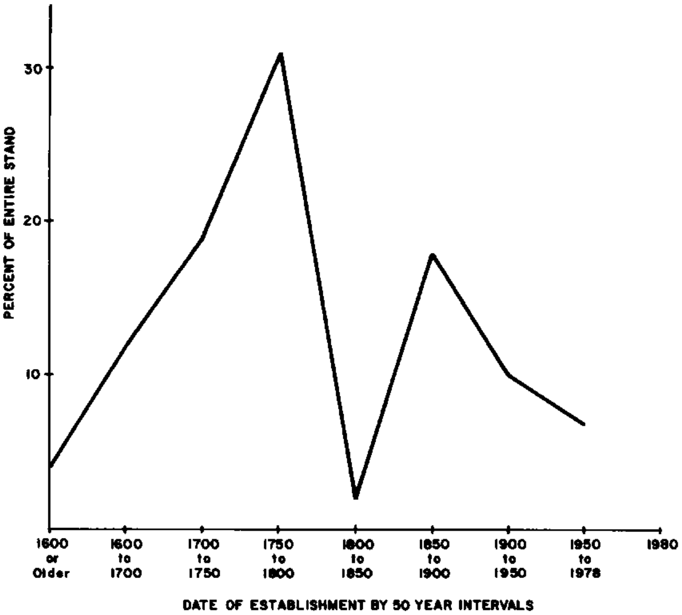

Fig. 3. *Periodicity of establishment of western juniper trees in low sagebrush communities on Juniper Hill, 1600-1978.*

it is important to keep in mind the relative density of the woodland on low and big sagebrush sites. Since 1900 on the low sagebrush sites 17% of the existing stands have become established, but this is roughly only five trees/ha. Since 1900 on the big sagebrush sites 98 trees have become established/ha.

By 1900, 83% of the current western juniper trees in the low sagebrush communities and 35% of those in the big sagebrush communities were established.

Population Growth Rate

Using techniques suggested by Harper (1977) to express the growth rates of populations, we find that since 1910 the populations of western junipers growing on the low and big sagebrush sites have had virtually parallel growth curves (Fig. 4). There is, however, a 10-fold difference in tree density on the two sites.

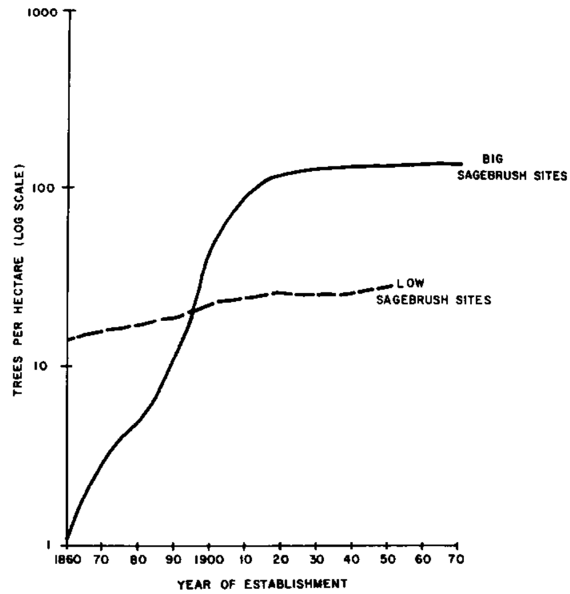

Fig. 4. *Population growth curves of western junipers on big and low sagebrush communities, based on survivors in 1978.*

The rate of population growth can be expressed as the number of years required to double population size (Harper 1977). When the western juniper populations were rapidly invading the big sagebrush sites at the turn of the century, the population size was doubling every 3 years (Table 3). At the same time the junipers growing on the low sagebrush sites required 48 years to double their population size. Since 1900 the population-size doubling rate has been relatively constant on the low sagebrush sites, except in the 1930's, when there was no growth. In contrast, on the big sagebrush sites, the time required for population doubling has consistently lengthened.

Possible Causes of Juniper Invasion

The three major hypotheses about why junipers have invaded shrub-grasslands attribute the invasion to: (a) grazing of domestic livestock, (b) suppression of wildfire, and (c) climatic shifts (Burkhardt and Tisdale 1969). Obviously the plant communities at Juniper Hill have been severely modified by years of intense grazing, but we do not have an ungrazed area to serve as a comparison,

Table 3. The time required for doubling of populations of western juniper growing on low and big sagebrush sites. The populations are those of survivors present in 1978.

	Time (years) to double population at indicated date							
Site	1870	1880	1890	1900	1910	1920	1930	1940
Big sagebrush	7	15	7	3	10	36	423	1370
Low sagebrush	70	160	53	48	230	240	—	250

so it is difficult to test this hypothesis experimentally. Likewise, the influence of climatic shifts is difficult to determine from our data base. At first glance it would appear possible to interpret the width of the annual growth rings on the western juniper trees as an index of climatic shifts, much in the manner of a dendrochronologist working with southwestern conifers (Douglas 1928). The major problems with applying these techniques are that the time span of the invasion is too short a period and the growth rate of a juniper tree in a dense stand reflects competition from neighboring trees as much or more than it does relatively brief climatic changes.

The remaining hypothesis about the sudden invasion of big sagebrush communities by western junipers attributes it to changes in the frequency or intensity of wildfires. Burkhardt and Tisdale (1969) made a very strong case for the influence of wildfires in limiting the spread of western junipers. Trees less than 50 years old are very susceptible to wildfires. Our sample of fire scars consisted of 28 trees from about 250 ha of woodland. There were three decades, 1640 to 1650, 1750 to 1760, and 1830 to 1840, when more than two trees were fire scarred (Fig. 5). Each one of these instances of wildfires probably represents one large fire. The variation in dates within the decade from which scars are identified is probably due to false or missing rings.

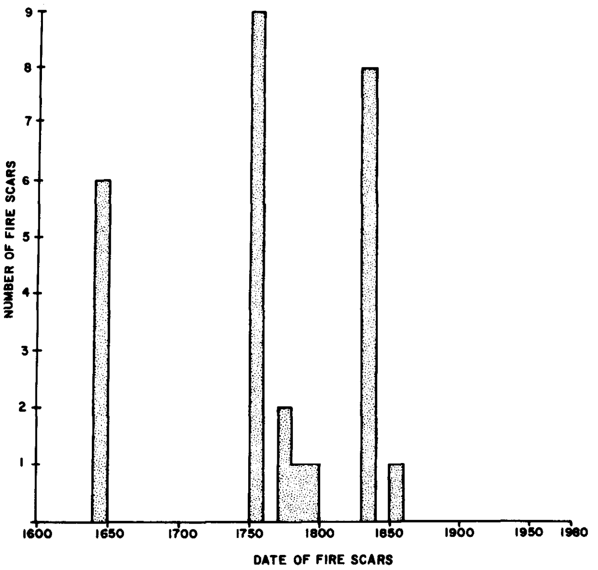

Fig. 5. *Frequency of fire scars on western juniper trees growing on low sagebrush sites.*

We found one remarkable tree that was doubly fire scarred by the fire of 1750 to 1760. The cambium was completely destroyed on opposite sides of the tree. Essentially the tree was divided into two separate trunks at the base. On these twin trunks were separate, but synchronous, fire scars for the decades of 1770, 1780, 1790, 1830, and 1850. The twin trunks differed by one annual growth ring for the century from 1878 to 1978 and by two rings for 1778 to 1878, and from the pith (1665) to 1878 they were identical. Although this tree was in a topoedaphic situation where it was susceptible to fire scarring in five successive fires, it grew from 1655 to 1750 without evidence of fire scarring. This type of evidence is hard to obtain, because successive fires often char through the center of the tree so that fire scars made early in the history of the tree are obliterated. In this case the separation of the trunks left the center of the trunk free of fire damage. If fire alone controlled the spread of western juniper, we suspect that this 100-year fire-free period would have allowed trees to extensively occupy the big sagebrush communities. If so, it seems probable that at least one tree in these areas would have survived.

The determining of fire histories from the occurrence of fire scars is an imprecise science. Not all fires scar all trees and not all trees are susceptible to scarring. As previously noted, juvenile western juniper trees are extremely susceptible to wildfires (Burkhardt and Tisdale 1969). The big sagebrush communities may have been burned by wildfires that failed to scar any of the trees growing on the low sagebrush sites.

Scarring of trees shows no evidence of promiscuous burning on Juniper Hill after settlement. The latest fire scar seen was dated in 1850 to 1860, the time of earliest settlements in this area. Low juniper populations, only 25/ha in two areas of big sagebrush bitterbrush, may be the result of recent burns, but there are no confirming fire scars.

The nine trees with fire scars dating to 1750 to 1760 and the eight trees with fire scars dating to 1830 to 1840 were located in diverse sections of Juniper Hill which indicates that these fires were common to the entire hill.

Old-Growth Tree

About 1% of Juniper Hill big sagebrush communities contained stumps of large western juniper trees. As previously noted, these sites were located on steep north-facing slopes, with low sagebrush flats located at the foot of the slopes. These sites were apparently relatively firesafe; i.e., wildfires burned there only under extreme conditions. However, these were not fireproof, because 85% of the stumps had two prominent fire scars. On the low sagebrush sites only 0.4% of the living trees were fire scarred. The stumps were rotten enough that we could not count annual growth rings to estimate the dates of these fires. From the location of scars on the stumps in comparison with those on living trees that we cut on low sagebrush sites, these stump scars appeared to represent the 1750 and 1830 fires.

We found four trees in this old-growth area that had grown from limbs left below the cut surface of the stump; the limbs gained apical dominance and grew into a vertical trunk. Counts of the rings on these new trunks indicated that their age was 95 to 100 years. This would place the time of cutting of these trees in the late 1870's and early 1880's. Marks on the stumps indicate that the trees were cut with aces, probably by homesteaders making posts.

Why did these trees establish on north-facing, firesafe sites, but not in other big sagebrush communities? The sites' potential for establishment does not appear to be a factor, since all big sagebrush sites were susceptible to juniper invasion after 1880. The sites' potential for fire spread was most likely a determining factor.

We did not observe any past cutting of western junipers growing on low sagebrush sites. However, the old-growth trees that we cut on low sagebrush sites for fire-scar dating were always infested with a brown cubical rot, rendering the trunk unsuitable for split posts (Herbst 1977).

Seed Sources and Dispersal

Burkhardt and Tisdale (1969) followed the dispersal of juniper seeds with radioisotope-labeled seeds. They found that the dispersal was primarily downslope as a result of gravity. This type of dispersal is very evident below rim rocks on Juniper Hill. However, on the broad south- to south-east-facing slopes there were no upslope, old-growth stands to provide a seed source. Analysis of the percentages of stand establishment by decades in relation to distance from the low sagebrush sites revealed no marked differences in date of establishment (Table 4).

Table 4. Percentage of stand establishment of western junipers per decade in plots located at various distances from low sagebrush sites.[1]

	Establishment in indicated site (% of total)					
Decade	1	2	3	4	5	6
1880-1890	2	1	3	2	2	3
1890-1900	28	30	30	26	31	30
1900-1910	36	29	34	38	36	36
1910-1920	20	21	18	22	19	22

[1]Plot 1 was located at the margin of low sagebrush site and plot 6 was the farthest away.

One possible mode of invasion of big sagebrush sites is that a few trees became established and then produced seeds for further invasion. This does not, however, appear to be the case for Juniper Hill. Junipers have polymorphic foliage, with juvenile spines and adult scales. Western junipers do not flower when in juvenile foliage, and the spiny juvenile foliage stage lasts from 5 to 25 years, with a mean of 17 years (unpublished research, ARS, Reno, Nevada). Trees less than 50 years old produce few seeds. We have shown that during the rapid-population-growth phase at the turn of the century, the western juniper populations on the big sagebrush sites were doubling every 3 years. The seed source for this increase must have come from the trees on low sagebrush communities.

Ranchers in the Juniper Hill area report concentrations of robins *(Turdus migratorius)* feeding on juniper berries in the fall. Evidence of bird distribution is found in fencerow populations. At the base of Juniper Hill, soils that originally supported big sagebrush communities are tilled and low sagebrush soils remain in pastures. Fences crossing big sagebrush sites have 1.7 western juniper trees per 10 linear meters of fence; fences crossing low sagebrush sites have 0.1 tree per 10 linear meters. The fencerow juniper population is 100 times as dense on the big sagebrush site as on low sagebrush sites. The population on the fencerows passing through big sagebrush potential sites is 3.8 times as dense as the average population on big sagebrush communities, even though the fences were built on section lines.

All ages of juniper, from seedlings to 80-year-old trees, were found along these fencerows. There appears to be no question that there are juniper seeds dispersed along these fencerows, some of which are 1 km from the closest juniper stand.

Apparently, the seed source for invasion of the big sagebrush-potential sites by western juniper has always come from trees adapted for growth on the contrasting low sagebrush environments. One of the tenets of modern silviculture has been that the plant material most inherently adapted to a given site is that found growing on the site. With western juniper, low sagebrush sites with contrasting environmental potential support trees that produce seeds capable of germinating and establishing on big sagebrush /grass communities.

Less than 1% of the western juniper trees that have established on big sagebrush sites on Juniper Hill currently bear fruit. If the stand is disturbed and trees are removed, some of the pistillate trees will produce abundant seeds. Speculation on stand tenure and development and the testing of hypotheses on causes of the sudden invasion of big sagebrush communities by western juniper are important if management is to prevent such invasions in the future. Of immediate concern to managers is the fate of the dense stands of trees that established at the turn of the century. The longevity of trees growing on adjacent low sagebrush stands indicates that the trees will occupy the site for the next 3 centuries before they succumb to diseases and insect infestations. Sudworth (1908) estimated the longevity of western juniper as ranging from 500 to 800 years. On Juniper Hill, trees approaching 400 years of age appear to be nearing senescence. The stands of western juniper growing on big sagebrush sites may be much more susceptible to insects and pathogens, because of their density, than their older counterparts growing on low sagebrush sites.

Because they have purged their understories of almost all herbaceous and shrub vegetation, the western juniper communities growing on big sagebrush sites are virtually fireproof, except under the most severe burning conditions (Bruner and Klebenow 1979). Herbage production of the herbaceous vegetation in the juniper stands on the big sagebrush sites averaged less than 50 kg/ha.

Once the native perennial grasses were grazed out of the low sagebrush sites, they were virtually fireproof (Young and Evans 1971) and often were used as natural firebreaks in wildfire suppression. Many land managers have commented on this fact while wondering at the occurrence of fire scars on old-growth juniper trees in these communties. Where medusahead has invaded juniper/low sagebrush woodlands, the sites become extremely fire hazardous.

We have observed western juniper seedlings establishing in fully stocked stands of intermediate wheatgrass [*Agropyron intermedium* (Host) Beauv. var. *intermedium*]. These observations support the findings of Burkhardt and Tisdale (1969) that establishment of western juniper is relatively independent of grass density. In the final analysis it is apparent that none of the popular hypotheses about the causes of juniper invasion of former shrub-/grasslands are entirely satisfactory in explaining the sudden establishment of western juniper trees in big sagebrush communities on Juniper Hill. Juniper Hill is a relatively small, specific landform, and theoretical assumptions should fit broad areas more precisely than specific land units. However, practical land management is most often concerned with the latter. Juniper Hill is one concrete example of successional change in plant dominance. It may well share the time scale for change with a majority of the existing western juniper woodlands that have invaded big sagebrush sites in the region. Many scientists have been preoccupied with the period 1890 to 1910, when the majority of the invasions occurred. However in a biological application of Hutton's law, what has happened before is happening now. Each year, juniper seedlings are establishing in big sagebrush communities, but their influence on succession and dominance will not be apparent to land managers for another 25 to 50 years.

A change in the frequency of wildfires is the most probable cause of juniper invasion of the big sagebrush sites, but our current methods for reconstructing fire histories are woefully inadequate for this type of woodlands. The upshot is that there is no simple, single factor that causes wholesale shifts in dominance of rangeland plant communities. Mehringer and coworkers' (1977) ideas for using the stratigraphy of microscopic charcoal deposits for indexing fire frequency may offer a solution to this important problem.

Literature Cited

Adams, A.W. 1975. A brief history of juniper and shrub populations in southern Oregon. Final Report on Federal Aid to Wildlife Restoration Project U-70-R. Oregon State Univ., Corvallis, 33 p.

Arno, S.F., and K.M. Sneck. 1977. A method for determining fire history in coniferous forest of the mountain West. U.S. Forest Serv., Intermountain Forest and Range Exp. Sta., General Tech. Rep. INT-42. 28 p.

Arnold, J.R., D.A. Jameson, and E.H. Reid. 1964. The pinyon-juniper type of Arizona: Effects of grazing, fire, and tree control. U.S. Dep. Agr. Proj. Res. Rep. 84. 28 p.

Bruner, A.D., and D.A. Klebenow. 1979. Predicting success of prescribed fires in pinyon-juniper woodland in Nevada. U.S. Forest Serv., Res. Pap. 219. 11 p.

Burkhardt, J.W., and E.W. Tisdale. 1969. Natural and successional status of western juniper vegetation in Idaho. J. Range Manage. 22:264-270.

Caraher, D.L. 1978. The spread of western juniper in central Oregon, p. 3-7. *In:* Martin, R.E., J.E. Dealy, and D.L. Caraher (Eds.) Proc. Western Juniper Ecology and Management Workshop. U.S. Forest Serv., General Tech. Rep. PNW-74.

Douglas, A.E. 1928. Climatic cycles and tree growth: A study of the annual rings of trees in relation to climate and solar activity. Carnegie Inst. Wash. Publ. 289. 166 p.

Driscoll, R.S. 1964. A relict area in the central Oregon juniper zone. Ecology 45:345-353.

Guinn, A.M. 1906. History of the State of California and Biographical Records of the Sierra. Chapman Publ. Co., Chicago. 781 p.

Harper, J.L. 1977. Population Biology of Plants. Academic Press, London. 892 p.

Herbst, J.R. 1977. Physical properties and commercial uses of western juniper, p. 169-177. *In:* Martin, R.E., J.E. Dealy, and D.L. Caraher (Eds.) Proc. Western Juniper Ecology and Management Workshop. U.S. Forest Serv., Pacific Northwest Forest and Range Exp. Sta.

Johnson, T.N., Jr. 1962. One seed juniper invasion of northern Arizona. Ecol. Monogr. 32:187-207.

King, P.B. 1959. The Evolution of North America. Princeton University Press, Princeton, New Jersey.

Mehringer, P.J., Jr., S.R. Arno, and K.L. Peterson. 1977. Postglacial history of Lost Trail Pass Bog, Bitterroot Mountains. Montana Arctic Alpine Res. 9:345-368.

Sudworth, G.B. 1908. Forest trees of the Pacific Slope. U.S. Forest Serv., Washington, D.C.

Vasek, F.C. 1966. Distribution and taxonomy of three western junipers. Brittonia 183:350-372.

Young, J.A., and R.A. Evans. 1971. Medusahead invasion as influenced by herbicides and grazing low sagebrush sites. J. Range Manage. 23:451-454.

Seasonal Nutrient Content in Food Plants oi White-tailed Deer on the South Texas Plains

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Abstract

From September 1976, through August 1978, 34 white-tailed deer food plants were collected during the months they were eaten by deer on the H.B. Zachry Randado Ranch in south Texas and analyzed for crude protein (CP), P, Ca, K, Mg, and Na. In vitro dry matter digestibility (DMD) was measured on foods collected only during the first year of the study. Mean levels of CP, Ca, K, and Mg were adequate for deer throughout the year. The P levels were generally inadequate except during spring, whereas Na levels probably were deficient throughout the year. However, these may not be as deficient as indicated because deer select higher quality plants and plant parts. Crude protein content of browse species was generally higher than that of forbs and cacti. Forbs were generally higher in P and Na than were browse and cacti. Although pricklypear cactus generally had low levels of CP, P, and Na, it had a higher DMD (≥76%) than all other species. However, because of its high soluble ash content (20%), pricklypear cactus averaged about 56% in vitro digestible organic matter. Our data indicated that range managers should provide a diversity of plant species to provide an optimum habitat for deer.

Intensive management of deer requires a thorough understanding of the benefit they derive from each range forage species. Many studies have been conducted on the food habits of white-tailed deer *(Odocoileus virginianus)* in south Texas (Davis 1951; Davis 1952; Davis and Winkler 1968; Chamrad and Box 1968; Drawe 1968; Everitt and Drawe 1974; Arnold and Drawe 1979). However, deer nutrition was included in only the more recent studies (Varner et al. 1977; Everitt and Gonzalez 1979; Kie et al. 1980). Thus, a more thorough understanding of the nutritive value of important deer foods in south Texas would enhance deer management.

Our objective was to measure the seasonal nutritive value of preferred white-tailed deer foods on the H.B. Zachry Randado Ranch (Zachry Ranch) in the western South Texas Plains. Thirty-four preferred foods were collected during the seasons they were eaten by deer. The foods were selected for study on the basis of studies on white-tailed deer food habits conducted on the Zachry Ranch by Everitt and Drawe (1974), Arnold (1976), and Arnold and Drawe (1979).

Study Area and Methods

The Zachry Ranch is about 44 km southwest of Hebbronville and 40 km northeast of Zapata in Jim Hogg and Zapata Countie It is in the South Texas Plains vegetational region (Gould 1975 The ranch has 3,045 ha of rolling brushland intersected by calich hills and gulleys. Eight soil types and six range sites lie within th ranch, but most of the ranch is a sandy loam site comprised c McAllen (Aridic Ustochrepts) and Brennan (Aridic Haplustalf fine sandy loam soil types (Higginbotham 1975). The area's climat is mild with short winters and relatively warm temperatur throughout the year. The average length of the growing season 300 days (USDC 1970). Average annual rainfall is 52 cm an usually occurs in association with thunderstorms that are unevenl distributed both geographically and seasonally. Occasionall tropical disturbances produce heavy rainfall, thus September ha the highest long term monthly rainfall average with another rair fall peak in May or June from squall-line thunderstorms. Th rainfall is lowest in January or February.

The 34 preferred white-tailed deer plant foods studied are liste in Table 1. Samples were collected mid-monthly from Septembe 1976 until August 1978. Each plant species was collected during th months that it is usually eaten by deer on the Zachry Rancl Several plants were collected every month because they were eate throughout the year. The months were grouped by seasons a follows: spring (March–May); summer (June–August); fall (Ser tember–November); winter (December–February). Plant sample were randomly hand-clipped primarily from the sandy loam sit since the major plants were found on this site and because this sit comprised most of the ranch. However, samples of the most eate plant species also were collected from some of the minor range site and pooled with those from the sandy loam site for chemica analyses. Only leaves and the ends of twigs were clipped fror browse plants but both whole plants and leaves were collected fror forb species because deer consumed various parts of these plant Composite samples of 12 or more plants were washed with distille water, air dried at 65° C, ground in a Wiley mill through a 1-mr mesh screen, thoroughly mixed, and stored in sealed jars.

Plant samples were analyzed for crude protein (CP), P, Ca, Mg K, and Na. Total N was determined by the Kjeldahl method (Peec et al. 1947). Nitrogen levels were multiplied by 6.25 and expresse as percent CP. Levels of Ca, Mg, K, and Na were determined b atomic absorption spectrometry (Boettner and Grunder 1968 Lanthanum oxide was added to Ca and Mg samples to reduc interference. Phosphorus was determined by the rapid digestio method (Bolin and Stramberg 1944). Plant samples were analyze in duplicate, and duplicate results were averaged.

In vitro dry matter digestibility (DMD) was determined by th two-stage technique of Tilley and Terry (1963). Within a week afte collection, duplicate samples of each plant species were treate with rumen inocula obtained from doe deer, killed on the Zachr Ranch. Rumen contents were placed in a prewarmed insulate container and taken to the USDA laboratory at Weslaco, Texas within 2 hours after deer were killed. The DMD percentages wer

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Table 1. Crude protein, phosphorus (P), and dry matter digestibility (DMD) of spring and summer foods of white-tailed deer on the Zachry Ranch in south Texas.

	Spring						Summer					
	Crude protein		P		DMD		Crude protein		P		DMD	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
Browse												
Acacia greggii	21.1	3.9	0.26	0.11	53	11	16.1	0.8	0.12	0.01	45	5
Bumelia celastrina	14.1	2.9	0.19	0.08	49	4	13.4	1.0	0.11	0.01	50	13
Castela texana	10.9	0.8	0.13	0.02	53	4	10.4	0.5	0.10	0.01	59	3
Celtis pallida	22.4	5.2	0.25	0.08	67	10	20.8	2.1	0.17	0.02	67	6
Colubrina texensis	17.8	2.5	0.25	0.08	56	10	15.0	3.4	0.16	0.05	49	8
Ephedra antisyphlitica	12.3	2.7	0.16	0.09	59	2	11.9	1.8	0.13	0.04	55	8
Lantana macropoda	19.0	4.7	0.31	0.07	64	7	18.9	1.5	0.26	0.04	65	1
Leucophyllum frutescens	14.7	2.5	0.24	0.06	63	13	11.6	2.9	0.16	0.03	55	6
Pithecellobium flexicaule	23.1	3.7	0.20	0.10	57	14	20.1	5.6	0.15	0.04	48	3
Porlieria angustifolia	17.9	3.0	0.16	0.06	47	5	16.6	3.3	0.08	0.02	51	3
Prosopis glandulosa[1]	—	—	—	—	—	—	11.2	2.3	0.18	0.06	59	2
Schaefferia cuneifolia	13.6	4.5	0.20	0.09	56	18	12.3	4.1	0.16	0.07	52	3
Trixis radialis	20.7	2.1	0.30	0.06	58	8	15.7	2.7	0.23	0.03	66	3
Zanthoxylum fagara	17.1	4.1	0.23	0.08	63	5	15.6	3.1	0.18	0.03	75	3
Ziziphus obtusifolia	18.5	3.7	0.26	0.10	59	8	14.9	1.1	0.13	0.02	52	3
Mean	17.4		0.22		57		15.0		0.15		57	
Cacti												
Opuntia lindheimeri[2]	8.5	3.6	0.17	0.07	76	7	6.0	1.0	0.09	0.02	76	6
Opuntia lindheimeri[1]	—	—	—	—	—	—	6.2	0.6	0.15	0.04	73	4
Opuntia leptocaulis	8.3	2.3	0.14	0.04	63	10	8.0	1.2	0.14	0.03	62	6
Mean	8.4		0.16	70		6.7		0.13		70		
Forbs												
Ambrosia psilostachya	21.4	3.4	0.37	0.05	56	3	16.5	3.5	0.24	0.05	60	9
Aphanostephus kidderi	10.0	1.2	0.27	0.04	57	8	—	—	—	—	—	—
Aphanostephus riddellii	14.3	5.7	0.30	0.06	57	4	12.6	3.1	0.21	0.06	51	2
Callirhoe involucrata	13.1	1.8	0.31	0.06	59	7	—	—	—	—	—	—
Commelina erecta	13.7	6.4	0.24	0.06	65	2	17.1	3.9	0.24	0.04	62	5
Cynanchum barbigerum	15.4	2.2	0.24	0.06	55	9	13.5	2.3	0.18	0.05	61	5
Euphorbia prostrata	16.7	4.7	0.41	0.04	53	11	16.4	2.3	0.46	0.04	67	4
Gaura brachycarpa	9.3	0.8	0.29	0.06	45	15	—	—	—	—	—	—
Lesquerella gracilis	12.9	2.9	0.23	0.08	63	6	—	—	—	—	—	—
Lepidium lasiocarpum	12.7	3.4	0.24	0.07	60	6	—	—	—	—	—	—
Menodora heterophylla	14.2	1.1	0.30	0.06	67	11	—	—	—	—	—	—
Parthenium confertum	17.8	4.9	0.29	0.06	59	8	17.7	6.4	0.20	0.05	58	4
Physalis viscosa	19.7	5.6	0.24	0.07	58	10	15.2	1.8	0.16	0.03	67	6
Plantago hookeriana	8.9	2.6	0.23	0.10	42	15	—	—	—	—	—	—
Psilostrophe gnaphaloides	13.3	5.5	0.27	0.04	50	1	13.7	4.8	0.24	0.04	56	2
Verbena plicata	13.1	2.3	0.31	0.06	59	2	—	—	—	—	—	—
Xanthisma texanum	7.9	0.4	0.25	0.07	58	1	8.5	1.9	0.20	0.04	52	5
Mean	13.8		0.28		57		14.6		0.24		59	
Overall mean	15.5		0.26		60		13.9		0.18		59	

[1]Fruit
[2]Pads

determined only on those samples collected during the first year (September 1976–August 1977) of this study because the ranch manager allowed us to kill a limited number of deer. In vitro digestible organic matter (DOM) expressed as a percent of dry matter was determined on pricklypear cactus pad samples by personnel of the Range Science Department at Texas A&M University. The DOM was determined on all pricklypear cactus pad samples collected during the 2 years.

We could not statistically compare nutrient quality between years because all species were not available during the same months of both years. Because of a severe freeze in January 1978, some browse species lost their leaves, thus their leaves were not available as food until new growth occurred in March. Also, because of drier conditions in the winter and early spring of 1978, several annual forbs available in March 1977 were not available until April 1978. The mean nutrient content (CP, P, and DMD) and standard deviation was determined for each species during the season it was eaten by deer. Each mean was based on four to six sampling dates. Standard deviations were calculated from within month replicates as well as between month within a season replicates.

Results and Discussion

The seasonal nutritive content and DMD of major foods of white-tailed deer on the Zachry Ranch in south Texas are shown in Tables 1 and 2 and Figure 1. Our data rely heavily on monthly means for all forage classes in the deer diets, as provided by Arnold and Drawe (1979).

Nutritive Value of Spring Foods

White-tailed deer consumed the greatest number of species in the spring (Everitt and Drawe 1974; Arnold and Drawe 1979). The CP, P, and DMD of the spring foods are in Table 1. Crude protein levels ranged from 7.9% in sleepy daisy *(Xanthisma texana)* to 23.1% in Texas ebony *(Pithecellobium flexicaule)*. Nine of the 32 spring foods had less than the minimum protein level of 13% recommended for maximum gain and reproduction of white-tailed deer (French et al. 1956; Murphy and Coates 1966; Verme and Ullrey 1972). The average CP for all foods was 15.5%. Important spring foods such as catclaw acacia *(Acacia greggii)*, granjeno

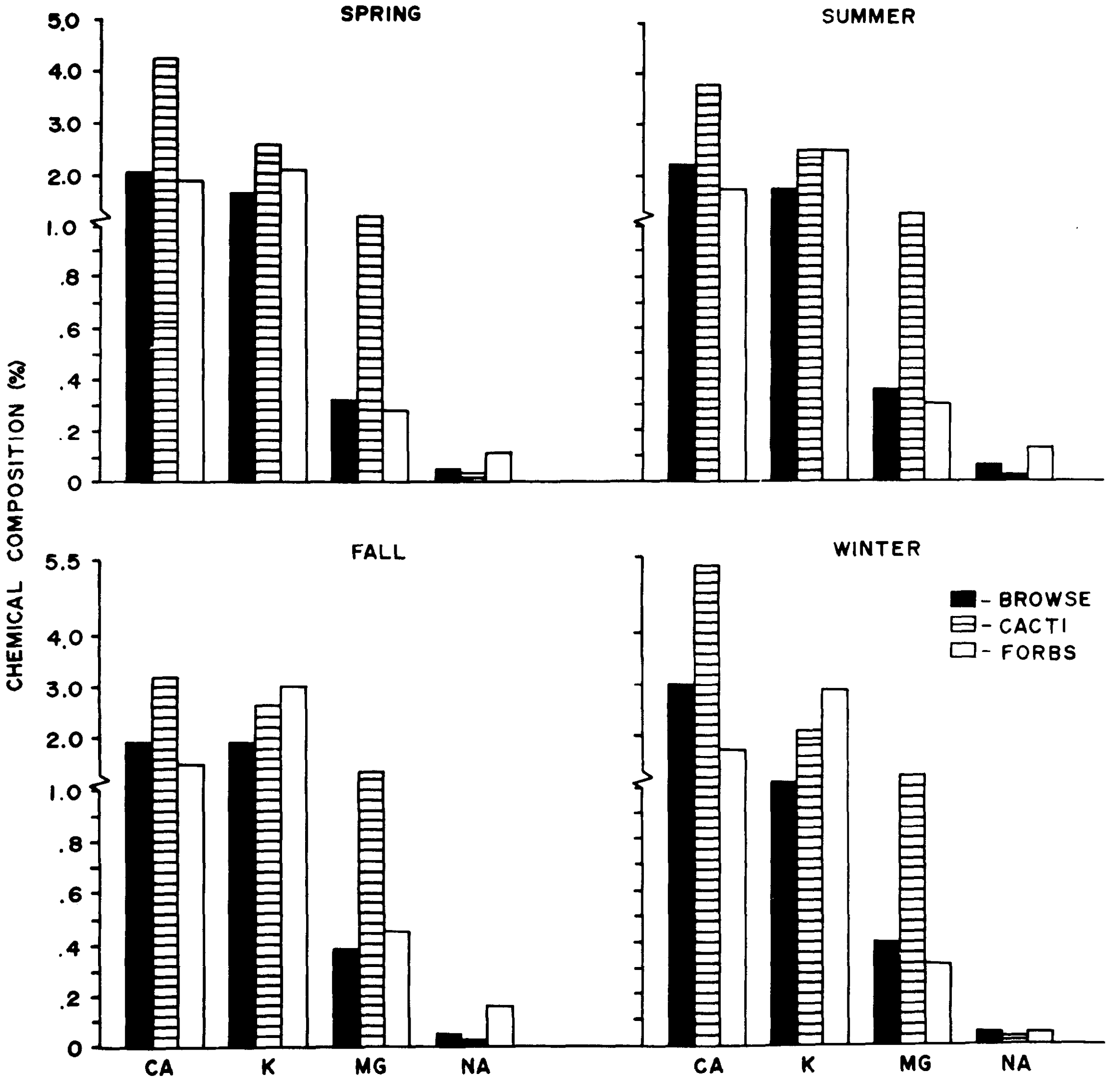

Fig. 1. *Mean levels of Ca, Mg, K, and Na for browse, cacti, and forbs for all seasons of the year on the Zachry Ranch in south Texas.*

(Celtis pallida), coma *(Bumelia celastrina),* perennial lazy daisy *(Aphanostephus riddellii),* groundcherry *(Physalis viscosa),* and winecup *(Callirhoe involucrata)* had adequate CP. Crude protein content of browse was generally higher than that of forbs, which agrees with the findings of Varner et al. (1977).

The P requirements of white-tailed deer are not well defined. Magruder et al. (1957) reported that white-tailed deer bucks will survive on rations containing 0.25% P but best antler growth was obtained on rations containing 0.56% P. Based on this standard, the average P level (0.26%) of the spring foods was only slightly above the minimum requirement for survival and none of the foods reached the P level considered optimum for antler growth (Table 1). Verme and Ullrey (1972) reported that 0.35% P was necessary to support optimum growth and antler development of white-tailed deer bucks from weaning to 1 year of age. Even so, prostrate euphorbia *(Euphorbia prostrata)* and western ragweed *(Ambrosia psilostachya)* were the only spring foods containing adequate P. Phosphorus levels ranged from 0.13% in goatbush *(Castela texana)* to 0.41% in prostrate euphorbia. Forbs generally had higher levels of P than browse and cacti, which agrees with other south Texas studies (Varner et al. 1977; Everitt and Gonzalez 1979). The high P content of forbs combined with high forb use in the spring probably raised the dietary P intake of deer (Everitt and Drawe 1974; Arnold and Drawe 1979). Arnold and Drawe (1979) reported that forbs comprised over 50% of the deer diet from March through May.

Most of the spring foods were high in DMD, from 42% in tallow weed *(Plantago hookeriana)* to 76% in pricklypear cactus (Table 1). The high DMD of forbs, combined with their adequate CP and P content, make these foods important contributors to deer nutrition. Both diet studies conducted on this ranch showed that pricklypear cactus was the most used food (Everitt and Drawe 1974; Arnold and Drawe 1979). Although pricklyper cactus had relatively low levels of CP and P, it had higher DMD than any other plant, and this agrees with the findings of Varner et al. (1977) and Everitt and Gonzalez (1979). However, the high DMD percentage of pricklypear cactus is misleading because of its high soluble ash content (20%). When expressed as DOM, pricklypear cactus averaged about 56%.

The Ca requirements of deer are probably 0.10 to 0.20% of the dry ration (Verme and Ullrey 1972). Based on this standard, the Ca levels of all foods were well above minimum requirements (Fig. 1). A ratio of Ca to P of about 2:1 is important to insure proper intestinal absorption of these minerals (Maynard and Loosli 1969), but it can be wider if the supply of Vitamin D is adequate (Dukes 1955). By these standards, ratios of Ca to P in spring foods were wide, ranging from 4:1 for creeping redbud *(Menodora heterophylla)* and swallowwort *(Cynanchum barbigerum)* to 37:1 for tasajillo *(Opuntia leptocaulis).*

The K and Mg requirements of deer are not known. Maynard and Loosli (1969) stated that the minimum K level needed by ruminants was 0.20 to 0.30% of the dry ration, whereas the Mg

Table 2. Crude protein, phosphorus (P), and dry matter digestibility (DMD) of fall and winter foods of white-tailed deer on the Zachry Ranch in south Texas.

	Fall						Winter					
	Crude protein		P		DMD		Crude protein		P		DMD	
Species	*X*	*S.D.*	*X*	*S.D.*	*X*	*S.D.*	*X*	*S.D.*	*X*	*S.D.*	*X*	*S.D.*
Browse												
Acacia greggii	16.0	0.5	0.13	0.01	37	3	—	—	—	—	—	—
Bumelia celastrina	13.3	0.6	0.11	0.02	44	6	11.9	1.7	0.14	0.02	48	8
Castela texana	11.6	0.6	0.11	0.03	59	3	11.7	0.3	0.14	0.02	60	2
Celtis pallida	19.8	1.6	0.17	0.04	56	1	15.2	1.5	0.14	0.02	63	3
Colubrina texensis	15.4	2.6	0.16	0.04	49	6	—	—	—	—	—	—
Ephedra antisyphilitica	12.9	1.7	0.14	0.04	51	3	11.8	1.1	0.12	0.02	48	9
Lantana macropoda	18.9	1.5	0.27	0.03	57	8	—	—	—	—	—	—
Leucophyllum frutescens	12.5	1.5	0.15	0.05	49	4	12.5	0.9	0.17	0.03	51	4
Pithecellobium flexicaule	22.6	1.4	0.16	0.04	45	2	20.7	0.2	0.16	0.03	46	2
Porlieria angustifolia	17.4	2.2	0.08	0.02	51	2	15.0	1.3	0.10	0.03	50	4
Prosopis glandulosa[1]	12.1	0.6	0.18	0.04	62	4	—	—	—	—	—	—
Schaefferia cuneifolia	12.5	1.3	0.16	0.06	56	3	10.2	1.1	0.14	0.04	54	3
Trixis radialis	17.7	2.6	0.25	0.08	61	1	—	—	—	—	—	—
Zanthoxylum fagara	16.6	1.6	0.20	0.03	71	5	15.8	1.3	0.18	0.04	70	3
Mean	15.7		0.16		53		13.9		0.14		54	
Cacti												
Opuntia lindheimeri[2]	6.6	2.2	0.09	0.02	80	6	6.2	1.1	0.12	0.05	78	3
Opuntia lindheimeri[1]	8.3	1.3	0.11	0.03	58	10	—	—	—	—	—	—
Opuntia leptocaulis	7.6	2.2	0.08	0.03	63	2	7.5	0.9	0.11	0.03	67	4
Mean	7.5		0.09		67		6.9		0.12		73	
Forbs												
Ambrosia psilostachya	15.1	3.6	0.24	0.03	58	8	18.0	7.3	0.26	0.09	57	12
Aphanostephus riddellii	11.6	2.4	0.19	0.04	47	4	14.9	2.5	0.23	0.06	49	6
Cynanchum barbigerum	14.3	1.6	0.18	0.03	60	10	—	—	—	—	—	—
Euphorbia prostrata	17.6	0.7	0.38	0.08	57	6	—	—	—	—	—	—
Parthenium confertum	13.8	2.6	0.17	0.05	50	8	17.2	4.1	0.23	0.06	50	8
Physalis viscosa	19.2	2.8	0.19	0.03	60	8	18.4	2.9	0.21	0.05	69	7
Mean	15.3		0.23		55		17.1		0.23		56	
Overall mean	14.5		0.17		56		13.8		0.16		57	

[1]Fruit
[2]Pads

requirement was only 0.06% of the dry ration. Based on these standards, all spring foods had adequate amounts of K and Mg (Fig. 1).

If the deer Na requirement is like the 0.10 to 0.20% reported for pigs and beef cattle (Maynard and Loosli 1969; National Research Council 1970), many of the spring foods were Na deficient. The generally higher Na content of forbs makes them an important contributor of dietary Na (Fig. 1).

Nutritive Value of Summer Foods

Many foods used in spring also were important during summer; however, most annual forbs had disappeared and the mesquite pods *(Prosopis glandulosa)* and pricklypear cactus fruit had become available. Although 10 of the 27 foods were deficient in CP for optimum white-tailed deer growth, the average CP level for summer foods was adequate (Table 1). Arnold and Drawe (1979) reported that over 36% of the summer diet was comprised of pricklypear cactus. Since pricklypear cactus had low levels of CP, deer would be dependent on browse and forbs to supply the dietary protein for optimum growth.

Prostrate euphorbia and desert lantana *(Lantana macropoda)* were the only species with sufficient P levels for white-tailed deer survival (Table 1). The higher P levels of forbs could offset a serious P deficiency, but forbs usually provide only 10% of the summer diet of deer (Arnold and Drawe 1979). Thus, P is probably deficient in summer. Most foods were relatively digestible with DMD ranging from 45% in catclaw acacia to 76% in pricklypear cactus. Calcium, K, and Mg levels were adequate in all summer foods (Fig. 1). The Ca:P ratio ranged from 3:1 in prostrate euphorbia to 52:1 in guayacan *(Porlieria angustifolia).* Forbs only contained Na levels considered adequate for pigs and beef cattle (Fig. 1).

Nutritive Value of Fall and Winter Foods

The relatively mild cool-season temperature in southern Texas allow several forbs as well as browse and cacti species to remain green during the fall and winter. Mean CP levels of browse and forbs for both the fall and winter were considered optimum for deer growth but CP levels of cacti were below the optimum requirement (Table 2). However, cacti comprised only about 20% of the fall and winter diet (Arnold and Drawe 1979). Since browse and forbs comprised the major portions of the fall and winter diet, dietary protein levels were probably adequate. The higher level of CP in forbs during winter was attributed to their succulent winter rosettes. These findings agreed with those of Campbell et al. (1954), Short (1971), and Varner et al. (1977).

With the exception of a few forbs, most fall and winter foods were low in P, indicating that P was probably deficient during this period. Most foods had relatively high DMD. Calcium, K, and Mg were adequate in all fall and winter foods (Fig. 1). The Ca:P ratios were generally wide in all species. With the exception of forbs during the fall, Na levels were below that considered adequate for pigs and beef cattle (Fig. 1).

Conclusions and Management Implications

Nutritional data on the 34 preferred deer foods from the Zachry Ranch in south Texas showed that there could be nutrient deficiencies in deer diets. Mean P levels exceeded the 0.25% minimum requirement only during the spring season. Other workers have reported P to be deficient in range livestock forages in south Texas and have recommended supplementation (Black et al. 1943; Reynolds et al. 1953). Also, P deficiencies in deer foods are apparently widespread in the United States (Dietz 1965; Blair and Halls 1968; Torgerson and Pfander 1971; Urness et al. 1971; Abell and Gilbert 1974; Short 1977). Although the Na requirement of deer is unknown, with the exception of forbs, mean levels of other forage classes were never above the 0.10% minimum requirement of pigs and beef cattle. Providing salt licks on the ranch and the Na content of well drinking water used by livestock may supplement the Na intake of deer. However, Weeks and Kirkpatrick (1976) reported that white-tailed deer in Indiana had adapted physiologically, morphologically, and behaviorally to counter Na deficiency.

Our results are indicative rather than definitive. Moreover, sample selection by researchers has often been shown to underestimate the quality of food selected by deer, since deer select the most nutritious plant parts (Klein 1962; Longhurst et al. 1968). Rainfall distribution is irregular in south Texas (USDC 1970). Shortly after high intensity rains, short-lived annual forbs become available. These should provide additional dietary nutrients not accounted for in our samples. Since DMD percentages were obtained only on plant samples collected during the first year, these data might seem inconclusive because of climatic differences between the 2 years (climatic difference resulted in some plants not being available during the same months of both years). However, our DMD percentages agreed with those reported for some of the same plant species in other south Texas studies (Varner et al. 1977; Everitt and Gonzalez 1979). Because the vegetation of the Zachry Ranch is typical of the South Texas Plains, these data should provide an index to the nutritional quality of forage selected by deer in south Texas except during a prolonged period of drought.

Range managers should provide a diversity of plant species if they want a good deer habitat. Although deer use cacti and browse for the major portion of their diet in this area of south Texas, the superior quality of forbs is especially important in meeting their nutritional needs. Common brush manipulation practices, like rootplowing, front-end stacking, or other combinations, increase forb diversity and production especially the first few years after disturbance (Hughes 1966; Gonzalez and Dodd 1979). Thus, opening dense stands of brush by cutting small patches or strips can increase diversity along the edge of the openings, and still leave enough cover and browse on the uncut areas. Domestic livestock numbers should be carefully regulated on these cleared areas so that deer can utilize the increased forb crop.

Literature Cited

Abell, D.H., and F.F. Gilbert. 1974. Nutrient content of fertilized browse in Maine. J. Wildl. Manage. 38:517-524.

Arnold, L.A., Jr. 1976. Seasonal food habits of white-tailed deer (*Odocoileus virginianus* Bod.) on the Zachry Ranch in south Texas. M.S. Thesis. Texas A&I Univ., Kingsville. 59 p.

Arnold, L.A., Jr., and D.L. Drawe. 1979. Seasonal food habits of white-tailed deer in the South Texas Plains. J. Range Manage. 32:175-178.

Black, W.H., L.H. Tash, J.M. Jones, and R.J. Kleberg, Jr. 1943. Effect of phosphorus supplements on cattle grazing on range deficient in this mineral. Dep. Agr. Tech. Bull. 856. 14 p.

Blair, R.M., and L.K. Halls. 1968. Growth and forage quality of four southern browse species. Proc. 21st Annu. Conf. Southeastern Ass. Game and Fish Comm. p. 57-62.

Boettner, E.A., and F.I. Grunder. 1968. Water analyses by atomic absorption and flame emission spectroscopy. *In:* Trace Inorganics in Water (R.A. Baker, ed.). Adv. in Chem. Serv., Amer. Chem. Soc. 73. 386 p.

Bolin, O.W., and W.E. Stramberg. 1944. Rapid digestion method for determination of phosphorus. Indus. and Engin. Chem. Analyst. Ed. 16:345-346.

Campbell, R.S., E.A. Epps, Jr., C.C. Moreland, J.L. Farr, and F. Bonner. 1954. Nutritive values of native plants on forest range in Central Louisiana. Louisiana State Univ. Agr. Exp. Sta. Bull. 488. 18 p.

Chamrad, A.D., and T.W. Box. 1968. Food habits of white-tailed deer in south Texas. J. Range Manage. 21:158-164.

Davis, R.B. 1951. The food habits of white-tailed deer on the cattle stocked, liveoak-mesquite ranges of the King Range, as determined by analysis of deer rumen contents. Unpub. M.S. Thesis. Texas A&M Univ., College Station. 97 p.

Davis, R.B. 1952. The use of rumen contents data in a study of deer-cattle competition and "animal equivalence." Trans. N. Amer. Wildl. Conf. 17:448-458.

Davis, R.B., and C.K. Winkler. 1968. Brush vs. cleared range as deer habitat in southern Texas. J. Wildl. Manage. 32:321-329.

Dietz, D.R. 1965. Deer nutrition research in range management. Trans. N. Amer. Wildl. and Natur. Resources Conf. 30:274-284.

Drawe, D.L. 1968. Mid-summer diet of deer on the Welder Wildlife Refuge. J. Range Manage. 21:164-166.

Dukes, H.H. 1955. The physiology of domestic animals. 7th ed. Cornell Univ. Press, Ithaca, New York. 1020 p.

Everitt, J.H., and D.L. Drawe. 1974. Spring food habits of white-tailed deer in the South Texas Plains. J. Range Manage. 27:15-20.

Everitt, J.H., and C.L. Gonzalez. 1979. Botanical composition and nutrient content of fall and early winter diets of white-tailed deer in south Texas. The Southwestern Natur. 24:297-310.

French, C.E., L.C. McEwen, N.D. McGrudger, R.H. Ingram, and R.W. Swift. 1956. Nutrient requirements for growth and antler development in the white-tailed deer. J. Wildl. Manage. 20:221-232.

Gonzalez, C.L., and J.D. Dodd. 1979. Production response of native and introduced grasses to mechanical brush manipulation, seeding, and fertilization. J. Range Manage. 32:305-309.

Gould. F.W. 1975. Texas plants—A checklist and ecological summary. Texas Agr. Exp. Sta., Texas A&M Univ., College Station. MP-585. 121 p.

Higginbotham, I. 1975. Composition and production of vegetation on the Zachry Ranch in the South Texas Plains. Unpub. M.S. Thesis. Texas A&I Univ., Kingsville. 131 p.

Hughes, E.E. 1966. Effects of rootplowing and aerial spraying on microclimate, soil conditions, and vegetation of a mesquite area. Texas Agr. Exp. Sta. Misc. Pub. 812.

Kie, J.G., D.L. Drawe, and G. Scott. 1980. Diet and nutrition of a high density white-tailed deer herd in south Texas. J. Range Manage. 32:28-34.

Klein, D.R. 1962. Rumen contents analysis as an index to range quality Trans. N. Amer. Wildl. and Natur. Resources Conf. 27:150-162.

Longhurst, W.M., H.K. Oh, M.G. Jones, and R.E. Kepner. 1968. A basis for the palatability of deer forage plants. Trans. N. Amer. Wildl. and Natur. Resources Conf. 33:181-189.

Magruder, N.D., C.E. French, L.C. McEwen, and R.W. Swift. 1957. Nutritional requirements of white-tailed deer for growth and antler development. II. Experimental Results of the Third Year. Pa. Agr. Exp. Sta. Bull. 628, 21 p.

Maynard, L.A., and J.K. Loosli. 1969. Animal Nutrition. McGraw-Hill, New York, 613 p.

Murphy, D.A., and J.A. Coates. 1966. Effects of dietary protein on deer. Trans. N. Amer. Wildl. and Natur. Resources Conf. 31:129-138.

National Research Council Subcommittee on Beef Cattle Nutrition, Committee on Animal Nutrition. 1970. Nutrient requirements of beef cattle. Printing and Publishing Office, Nat. Acad. Sci., Washington, D.C. 55 p.

Peech, M.L., A. Dean, and J.F. Reed. 1947. Methods of soil and analysis for fertility investigations. U.S. Dep. Agr. Circ. 754. 25 p.

Reynolds, E.B., J.M. Jones, J.H. Jones, J.F. Fudge, and R.J. Kleberg, Jr. 1953. Methods of supplying phosphorus to range cattle in south Texas. Tex. Agr. Exp. Sta. Bull. 773. 16 p.

Short, H.L. 1971. Forage digestibility and diet of deer on southern upland range. J. Wildl. Manage. 35:698-706.

Short, H.L. 1977. Food habits of mule deer in a semidesert grass-shrub habitat. J. Range Manage. 30:206-209.

Tilley, J.M.A., and R.A. Terry. 1963. A two-stage technique for the in vitro digestion of forage crops. J. British Grassland Soc. 18:104-111.

Torgerson, O., and W.H. Pfander. 1971. Cellulose digestibility and chemical composition of Missouri deer foods. J. Wildl. Manage. 35:221-231.

United States Department of Commerce. 1970. Climatological Summary. Brownsville, Texas. 46 p.

Urness, P.J., W. Green, and R.K. Watkins. 1971. Nutrient intake of deer in Arizona chapparral and desert habitats. J. Wildl. Manage. 35:469-475.

Varner, L.W., L.H. Blankenship, and G.W. Lynch. 1977. Seasonal changes in nutritive value of deer food plants in south Texas. Proc. Annual Conf. S.E. Ass. Fish and Wildlife Agencies. 31:99-106.

Verme, L.J., and D.E. Ullrey. 1972. Feeding and nutrition of deer. *In:* The Digestive Physiology and Nutrition of Ruminants. Vol. 3. D.C. Church, Ed., Dep. Animal Sci. Oregon State Univ., Corvallis. 350 p.

Weeks, H.P., Jr., and C.M. Kirkpatrick. 1976. Adaptations of white-tailed deer to naturally occurring sodium deficiencies. J. Wildl. Manage. 40:610-625.

BOOK REVIEWS

Editor's Note . . . George W. Scotter's review of *Vascular Plants of Continental Northwest Territories, Canada* (JRM 34(4): 344, July 1981), contained two typos. The junior author's name is Cody, not Coty; and the first sentence of the last paragraph should read, ". . . minor shortcomings, . . ." not, ". . . major shortcomings, . . ." Sorry, George!—*Ed.*

Forage Management in the North. (Fourth Edition). By Dale Smith. 1981. Kendall/Hunt Publishing Company, 2460 Kerper Blvd., Dubuque, Iowa 52001. 258 p. $10.95.

This book was designed as a text for a college-level forage problem-forage management course. Also, it provides useful applications for the practicing farmer or range manager. Emphasis is placed on plant physiology, but included are concepts from soil science, chemistry, climatology, and range and pasture management.

The first chapter familiarizes the reader with the section of the country about which the book is written, specifically the North-Central states and the Northern Great Plains. However, many of the management techniques and practices discussed throughout the text could be applied to other parts of the nation. The author provides several chapters on topics such as soil fertility, seeding and establishment methods, and management techniques to control weeds in forage crops.

The survival of crops over winter is obviously a problem in the northern United States; information is given as to changes in plant cells and protoplasm that allow winter survival and management treatments that can be used to reduce winter kill. A good summary of plant physiology principles is presented in the section on plant nutrition and growth. Plant functions and responses to environmental influences are described. Much technical information is discussed in this chapter.

A number of chapters provide specific information about the major species of legumes and hay grasses grown for forage. Details are given about origin, varieties, optimum edaphic and moisture conditions, response to various management practices, and common insect and disease problems. Management guidelines for obtaining high yield, and positive and negative aspects of using each species as a forage crop are enumerated. The author concludes with several chapters on silage, pasture renovation, and range and pasture management. Previous editions lacked information on silage; legume-grass and corn-sorghum are the two silage types discussed.

Most discussions are based on published technical literature. Effective use is made by combining tables, graphs, and photos to illustrate points made in the text. Lead sentences of each new topic are italicized, which facilitates locating main subject matter. A list of references is provided at the end of each chapter so that the reader has an immediate source of information for topics of interest. This book would probably be a valuable supplement to Voight, Hale, and Buckleys' *Bibliography, North Central Section, Society for Range Management* (1980).

This text contains much information in a form that is easy to read and understand. Improved management of pasture plants is of great importance today since these plants alleviate the use of grain for meat production, freeing the grain as a direct food source for the people of this country and others. *Forage Management in the North* would be of value to a farmer, land manager, or student in any part of the nation who is interested in the culture of forage crops.—*Sharon Wooten,* Fort Collins, Colorado.

Heathlands and Related Shrublands, Part B. Analytical Studies. Edited by R.L. Specht. 1981. Elsevier Scientific Publishing Co. 52 Vanderbilt Ave., New York, New York 10017. 385 p. $83.00.

This volume follows the earlier published descriptive studies (Part A) of heathland ecosystems in different regions of the world. This excellent collection of papers considers various aspects of heathlands and associated shrubland functions, dynamics, and conservation needs. Heathlands are different from the millions of acres of typical range shrublands in that they are subjected to mineral stress on oligotrophic soils. Plants are somewhat stunted with sclerophyllous leaves, thick cuticles, sunken stomata, and cells containing resins, essential oils, and other inclusions. Some species form a lignotuber at the junction of the stem and root which can sprout after fire, drought, or grazing.

Five major sections of the book include 26 papers prepared by authors primarily from Australia, Great Britain, New Zealand, and the U.S.A.; also included are South Africa, Norway, North Ireland, Germany, and Venezuela. In the first section, seasonal growth, flowering, and faunal rhythms unique to heathlands in Australia, South Africa, and Europe are illustrated and discussed. In section two, pollination and seed dispersal by wind and insects are discussed in some detail under Australian conditions. Section three, on fire tolerance, discusses mechanisms for both plant and animal survival and evolution of characteristics which confer resistance to the destruction aspects of fire. Section four appears to be a catch-all grouping of papers on climatic stress. It is more limited in scope than would be expected under the broad aspects of climate-related plant influences. Salient problems of wet and dry heathlands are discussed in chapters on reflectivity of solar radiation, general response to waterlogging, and specific morphological adaptation to waterlogging and drought. Two chapters on the effects of water stress on plant morphology and physiological processes are especially valuable as a comparative reference for the traditional rangeland ecologist. The fifth section on nutrient stress gets at the heart of heathland biofunctions. Eight excellent chapters discuss the unique oligotrophic conditions of heathlands: nutrient cycling under the various perturbations, such as fire, grazing, and erosion; advantages of specialized roots of symbiotic origin (mycorrhizae) and non-symbiotic origin proteoid) roots) which apparently give a competitive advantage to associated plants by improving water and phosphorus uptake; the role of polyphosphates in the mineral nutrition of heathland species; mineral toxicities from excess phosphorus; the effects of soil acidity on the nutrient environment, and a brief discussion on chloride toxicity from salt spray effects in coastal areas. The sixth section attempts to cover conservation problems, but consists mainly of chapters dealing with problems of fire, grazing management, and disturbance of heathland communities. A better approach would have been a sustained use analysis for management as in conventional rangeland management. The volume is completed in somewhat of a letdown fashion by a tacked on chapter on phytopthera rootrot.

For land managers interested in woody plant responses to the environment, and understanding how and why heathland maintains itself and accommodates to some unique stresses including management), volume 9B offers some interesting insights to plant processes and adaptations under conditions considerably different from those found in the usual rangeland communities.—*C.M. McKell,* Salt Lake City, Utah.

SYMPOSIA AND REPORTS

Firewood Crops: Shrub and Tree Species for Energy Production. By the Panel on Firewood Crops, Board on Science and Technology for International Development. 1980. National Academy of Sciences—National Research Council, 2101 Constitution Ave., Washington, D.C. 20418. 237 p. Paper-free.

This report was prepared by a 22-member, multicountry ad hoc advisory panel of the Advisory Committee on Technology Innovation, National Academy of Sciences—National Research Council. The Panel on Firewood Crops states that, "More than one-third of the world's population depends on wood for cooking and heating. Eighty-six percent of all the wood consumed annually in the developing countries is used for fuel, and of this total at least half is used for cooking. The situation is growing so desperate that wood is poached from forest reserves; hedges. .; and scaffolding. . ." A total solution to the firewood crisis is not suggested, but one part of the solution is examined. That is, the selection and deliberate cultivation of suitable species as firewood crops in developing countries.

The contents of this report consists of four sections and ten appendixes. Section one discusses the background, management, and recommendations for fuelwood programs. The other three sections deal with 60 fuelwood species for humid tropics, tropical highlands, and arid and semiarid regions. The discussion of each species includes its botanic, common, and family name, main attributes, description, distribution, use as firewood, yield, other uses, environmental requirements, establishment, pests and diseases, limitations, related species, and a photograph. Among other topics, the appendixes deal with the efficient use of fuelwood, two case studies, references, research contacts, and terminology.

The Panel "hope[s] this report will prove useful to developing countries by suggesting potentially significant fuelwood candidates for introduction to suitable environments. This report should stimulate initiatives for restoring our renewable resources and increasing the world's supply of fuelwood."—*Ed.*

NEW PUBLICATIONS

Biophysical Ecology. By David M. Gates. 1980. Springer-Verlag New York Inc., 44 Hartz Way, Secaucus, New Jersey 07094. 611 p. $39.80.

Gates defines biophysical ecology as ". . . an approach to ecology founded upon a thorough understanding of the sciences of energy and fluid flow, gas exchange, chemical kinetics, and other processes." The author states further that "The term biophysical ecology is necessarily redundant because the study of ecology, by definition, includes the physics of the environment and the biophysics of physiological processes. Nevertheless, this is the term that best describes the subject matter to which this book is devoted."

The objective of this volume is to make analytical methods available to students of ecology, and the book is organized to give the reader an overall view of the subject including application examples. The text emphasizes the concepts of energy exchange, gas exchange, and chemical kinetics affecting the interactions of plants and animals with their environments. Fifteen chapters deal with the topics of energy budgets, plant and animal applications, radiation, conduction, convection, evaporation, transpiration, photosynthesis, and temperature. A nine-page section includes Roman, dimensionless, Greek, and chemical reaction symbols. Four appendices, 23 pages of references, and an index conclude this book. The text contains 163 figures and tables.

The reader should gain an understanding of the ecology of plants and animals based on physical and chemical principles. Ecologists, plant physiologists, bio-climatologists, range and forestry researchers, and agricultural meteorologists should find the book invaluable.—*Ed.*

Forest Cover Types of the United States and Canada. Edited by F.H. Eyre. 1980. Society of American Foresters, 5400 Grosvenor Lane, Washington, D.C. 20014. 148 p. $7.50.

This volume is a revised edition of the Society of America Foresters' 1954 publication titled, *Forest Cover Types of North America (exclusive of Mexico).* A total of 145 forest cover types are recognized; 90 in the East, 55 in the West. This revision of the 1954 edition deleted 22 types, added 11 new types, and renamed 27 types. Information was added on understory vegetation and ecological relationships. Hawaiian forest cover types are not included.

The classification of forest cover types is based on existing vegetation. The types are named after predominant tree species; predominance was determined by basal area. The naming of most types is limited to one or two species.

The Introduction includes a definition of and the basis for recognition of types, naming and numbering of types, and the relationship to other classifications in the United States and Canada. The volume is divided into two major sections: Eastern and Western forest cover types. Descriptions for Eastern types are grouped into five forest regions: Boreal, Northern, Central, Southern, and Tropical (Florida). The Western types are arranged starting with the coldest to the warmest regions, recognizing elevation and latitude as group influences. The Western groups are: Northern Interior (Boreal); High Elevations; Middle Elevations, Interior; North Pacific; Low Elevations, Interior; and South Pacific, except for high mountains. The write-up for each type within the groups include definition and composition, geogrpahic distribution, ecological relationships, and variants and associated vegetation. The author of each type write-up is identified.

The book concludes with a literature cited section and two appendixes listing the common and scientific tree names, and a listing of plants other than trees. Included is a colored map of the forest types; no photographs are included.—*Ed.*

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Information for Authors

The *Journal of Range Management* is an official publication of the Society for Range Management. The editor's objective is to publish in every issue something of interest to each member of the Society and to others interested in range ecosystems and their management. Suitable articles from both nonmembers and members may be published upon approval of the Editorial Board.

Articles suitable for publication in the *Journal of Range Management* include high-quality papers concerning any phase of range ecosystems or their management. Short articles concerning research results, experimental equipment, or techniques may be published as a "Technical Note." Review papers on selected subjects also are acceptable but are usually invited.

All papers should be based on new and adequate information. The introduction should state clearly and concisely the purpose of the article and its relation to other work in the same field. Unsupported hypotheses and rambling discussion should be avoided. Organization of the manuscript may vary to accommodate the content of the article, but the text should point any application of the results to range management problems.

For suggestions on writing and the preparation of manuscripts, authors are advised to consult *CBE Style Manual* (Third Edition, 1972) published for the Council of Biology Editors by the American Institute of Biological Sciences, 3900 Wisconsin Avenue NW, Washington, D.C. 20016.

All papers will be critically reviewed by the Editorial Board or other subject matter specialists designated by the editor. Papers returned to authors for revision should be handled promptly. Unsuitable papers will be returned to the authors with an explanatory statement. Prior publication of a manuscript or concurrent submission to another outlet precludes publication in the *Journal of Range Management*.

All manuscripts and correspondence concerning them should be addressed to **Dr. Rex D. Pieper, Dept. of Animal and Range Sciences, New Mexico State University, Las Cruces, NM 88003.**

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1. For guidance on matters not specifically covered in the following paragraphs, see *CBE Style Manual*, cited above.

2. Manuscripts must be typewritten, double spaced with ample margins, on good quality white paper, preferably 8½ × 11 with numbered lines. Use only one side of the paper and number all pages. Three good copies of the manuscripts are to be submitted.

3. The title of the paper and the name, position, and complete address of the author should be typed as distinct, well-spaced entries on a separate page.

4. An Abstract, typed on a separate page, should accompany each manuscript. The Abstract should succinctly state the purpose, major findings or conclusions, and their application.

5. Names of plants and animals must be shown in both common and scientific form the first time they are mentioned in the text; further mention should be by common name only. Authorities for scientific names may be included at the discretion of the author.

6. The metric system should be used throughout the manuscript, but English units may be included in parentheses in the text.

7. Footnotes should be used very sparingly and numbered consecutively throughout the text. All text footnotes should be typed together (double spaced) on a separate sheet.

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Pechanec, Joseph F., and George Stewart. 1949. Grazing spring-fall sheep ranges of southern Idaho. U.S. Dep. Agr. Circ. 808. 34 p.

Sperry, Omer E. 1949. The control of bitterweed (*Actinea odorata*) on Texas ranges. J. Range Manage. 2:122-127.

Titles of journals should be abbreviated in accordance with instructions given in the *CBE Style Manual* (p. 159-160), cited above. Also, helpful standard abbreviation forms may be found in *Style Manual for Biological Journals* (p. 82-87), Second Edition, 1964, American Institute of Biological Sciences, Washington, D.C. Show the total number of pages for books or bulletins cited.

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