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Extended grazing systems for improving economic returns from Nebraska sandhills cow/calf operations

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Abstract

Three winter treatments were cross classified with 2 spring treatments to create 6 feeding and grazing systems utilizing Nebraska sandhills range and subirrigated meadow forage. Systems were evaluated with multiparous crossbred beef cows over 4 years (240 head beginning year 1). Systems were: 1) grazing range during winter; 2) grazing subirrigated meadow during winter; and 3) full feed of meadow hay during winter; in combination with either: a) full feed of subirrigated meadow hay during May, or b) grazing subirrigated meadow during May. From June through November all cows grazed range. The feeding and grazing systems were compared with selected linear contrasts and evaluated with respect to variable input prices. Some differences in cow body weight and body condition occurred but differences were considered small. Throughout the study, cows on all systems generally maintained a body condition score of about 5 (1 to 9 scale) year long. Inputs of hay were reduced by grazing range or subirrigated meadow during winter and during May without affecting pregnancy rate. Weaning weight of calves was increased 5.0 kg by grazing meadow during May compared to feeding hay during May. When opportunity costs were included in the analysis, the most profitable system involved grazing subirrigated meadow during winter and during May. Grazing subirrigated meadow during May enhanced the profitability of all wintering systems.

Key Words: rangeland, subirrigated meadow, beef cattle, partial budgets, stochastic dominance, net returns

Profitability of the beef cattle industry depends in part on its ability to compete with other meat industries. To compete effectively, the industry must continue to lower costs per pound of meat produced (Barkema and Drabenstott 1990). Feeder cattle (i.e., weaned calves) account for about three-fifths of the total cost of finished cattle. Feed costs make up about one-fourth of the costs of raising feeders (Barkema and Drabenstott 1990). An Integrated Resource Management project in Nebraska found that harvested forage costs ranged from 18 to 24% of total cost per weaned calf (Rasby et al. 1989). Reducing the feeding of harvested forage while maintaining or enhancing cow performance could substantially increase the profitability of cow/calf producers and lower overall costs of beef production. Greater reliance on the cow rather than machines for forage harvesting is one method for reducing feed costs (D'Souza et al. 1990). Extending winter grazing on rangeland and/or subirrigated meadows would reduce inputs of harvested forage. In the Nebraska sandhills, a further savings in feed costs might also be realized by grazing subirrigated meadows in early spring, a time when upland range is dormant and hay is usually fed. A survey of Nebraska Sandhills ranches estimated that about 50% contained some subirrigated meadows (Clark and Coady 1992); only 14% of those with meadows grazed them in the spring (Coady and Clark 1993).

A 4-year study was initiated in 1988 to determine the effects of extending common grazing dates for cattle by grazing upland range during winter and subirrigated meadows in May. The 2 major objectives were: 1) to measure the impacts on cow/calf production under alternative forage treatments during the winter (gestation) and between calving and breeding (prebreeding), and 2) evaluate the impacts of the alternative forage treatments on costs and returns to a cow/calf producer. Our hypothesis was that by extending the grazing season in winter and spring, profitability would be increased over traditional systems which use a greater amount of harvested forage.

MATERIALS AND METHODS

Forage and Cattle Procedures

Two-hundred-forty crossbred cows, 3 to 7 years of age, were randomly assigned within age during 1988 to 3 winter treatments and 2 spring (prebreeding) treatments which were cross classified to create 6 forage systems (3 X 2 = 6 systems; Table 1). Treatments were replicated over 4 years. Cows were 1/4 Hereford, 1/4 Angus, 1/4 Simmental and 1/4 Gelbvieh. Year-long management was comprised of 4 periods: a) winter (gestation), 15 November-1 March; b) calving, 2 March-30 April; c) prebreeding, 1 May-31 May; and d) breeding and summer management, 1 June-15 November. A 60-day breeding season began 15 June each year. Winter treatments were: 1) 1.36 kg/cow of a commercial 32% crude protein (0% non-protein nitrogen) supplement fed every other day to cows grazing range, 2) graz-

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Table 1. Treatment (system) description with corresponding management period.

Treatment	Gestation 15 Nov.-1 Mar.	Calving 1 Mar.-1 May	Prebreeding 1 May-1 Jun.	Breeding- Weaning 1 Jun.-15 Nov.
(1) Winter-range May-hay	Range	Hay	Hay	Range
(2) Winter-range May-meadow	Range	Hay	Meadow grazing	Range
(3) Winter-hay May-hay	Hay	Hay	Hay	Range
(4) Winter-hay May-meadow	Hay	Hay	Meadow grazing	Range
(5) Winter-meadow May-Hay	Meadow grazing	Hay	Hay	Range
(6) Winter-meadow May-Meadow	Meadow grazing	Hay	Meadow grazing	Range

ing subirrigated meadow, with the same protein supplement as in treatment 1 fed at 1.36 kg•cow^{-1}•day^{-1} during days of heavy snow or sub-zero temperature, and 3) meadow hay (approximately 8.0% crude protein) fed daily ad libitum. Spring treatments consisted of: 1) meadow hay (about 8.0 % crude protein) offered daily ad libitum, and 2) grazing new growth on subirrigated meadow. The appropriate amount of supplement was fed by a pickup truck with a supplement feeder equipped with an electronic scale. Hay was fed from stacks (about 6.4 metric ton) of long stem hay by a stack mover/feeder pulled by a 100-horsepower tractor; during 1991 and 1992 the feeder/stacker was equipped with an electronic scale to weigh the amount of hay fed.

The study site was sands, choppy sands, and subirrigated meadow sandhill sites on the University of Nebraska-Lincoln Gudmundsen Sandhills Laboratory near Whitman, Nebraska. The dominant grass species were blue grama [*Bouteloua gracilis* (H.B.K.) Lag.ex Griffiths], little bluestem [*Schizachyrium scoparium* (Michx.) Nash], prairie sandreed [*Calamovilfa longifolia* (Hook.) Scribn.], sand bluestem (*Andropogon hallii* Hack.), switchgrass (*Panicum virgatum* L.), sand lovegrass [*Eragrostis trichodes* (Nutt.) Wood], and indiangrass [*Sorgastrum nutans* (L.) Nash]. Common forbs and shrubs include western ragweed (*Ambrosia psilostachya* Dc.) and leadplant [*Amorpha canescens* (Nutt.) Pursh].

The subirrigated meadow soils are classified as Gannett-Loup fine sandy loam (coarse-loamy mixed mesic Typic Haplaquoll). Dominant meadow vegetation was smooth bromegrass (*Bromus inermis* Leyss.), redtop (*Agrostis stolonifera* L.), timothy (*Phleum pratense* L.), slender wheatgrass [*Agropyron trachycaulum* (Link) Malte], quackgrass [*Agropyron repens* (L.) Beauv.], Kentucky bluegrass (*Poa pratensis* L.), prairie cordgrass (*Spartina pectinata* Link), and several species of sedges (*Carex* spp.) and rushes (*Juncus* spp. and *Eleocharis* spp.). Less abundant grass species were big bluestem (*Andropogon geradii* Vitman), indiangrass, and switchgrass. Legumes were a minor component of the vegetation.

Precipitation was measured at the Gudmundsen Sandhills Laboratory at an automated weather data network station operated by the High Plains Climate Center at the University of Nebraska-Lincoln.

Cow body weights and body condition scores were taken precalving (1 March), prebreeding (1 June), and at weaning (15 October). Body condition scores were assigned using visual observations and a scoring system from 1 to 9, with 1 being extremely thin and 9 being extremely fat. Calf weights were taken at birth, 1 June, and at weaning. Cows were pregnancy checked at weaning by rectal palpation, and open cows were removed from the study. Replacement cows were not added to the study.

Treatment, year, and treatment X year were included in the analysis of variance for cow traits; sex of calf, sex of calf X year, and sex of calf X treatment were included in the analysis of calf traits.Pregnancy rates were transformed to logits (Cox 1970), analyzed by weighted least squares, and tested using the chi-square distribution. Treatments were compared with orthogonal contrasts (Table 2); error terms were treatment X year and treatment X year X sex of calf for cow and calf traits, respectively.

Table 2. Linear contrasts for treatment comparisons.

Contrast	Description	Treatment[1]
1	No May grazing vs May grazing	1+3+5 vs 2+4+6
2	Winter-hay vs Winter-range + Winter-meadow	3+4 vs 1+2+5+6
3	Winter-range vs Winter-meadow	1+2 vs 5+6
4	Interaction: did performance on May treatment depend on winter treatment (i.e., grazing or hay)?	2+3+6 vs 1+4+5
5	Interaction: did performance on May treatment depend on winter grazing treatment (meadow or range)?	1+6 vs 2+5

[1] See table 1 for treatment description.

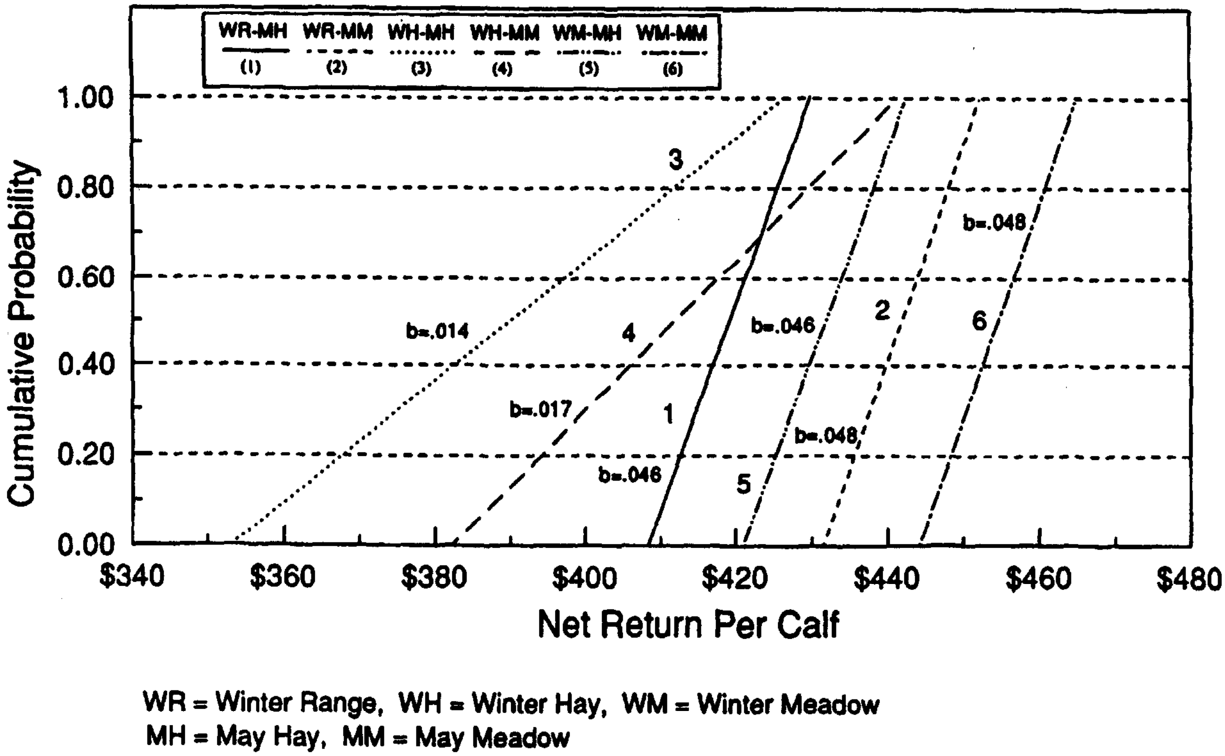

Fig. 1. Cumulative distribution of net returns for 6 forage and grazing systems.

Economic Procedure

Each treatment was evaluated for its potential effect on net returns. The analysis was based on a ranching operation with a resource endowment sufficient to support each forage management alternative. The economic analysis was based on sensitivity of the forage management alternatives to input price variability and was conducted using partial budgeting. Animal performance was incorporated into the economic analysis only through calf production because pregnancy rate was similar (P>0.10) among treatments.

The 4 years of calf weaning weight data were pooled because the treatment X year interaction was not significant. Cow death loss, calf death loss, and cows culled for health reasons were assumed to be random events because none of these losses could be attributed to the imposed treatments. To maintain consistency, aggregate supplemental hay and feed, as well as labor demands, were also pooled across years.

Partial budgeting techniques were used to formulate a net return function for each treatment. Individual calf weaning weights and 1990 feeder calf prices (Wellman 1991) were used to construct gross returns. Prices for weaned calves were based on sex and weight. The partial budgeting cost function consisted of the following parameters::

*Cost/hd = WHay*PHay + WSup*PSup + WRange*PLand + WMeadow*Pland + WMachine Cost + WLabor Cost + MHay*PHay + MMeadow*PLand + MMachine Cost + MLabor Cost,*

Where: W denotes Winter, P denotes Price, and M denotes May.

Hay and protein supplement were charged at their market value to encompass opportunity costs. A land charge was imposed on cows grazing winter range or winter meadows at a rate of half the preceding summer range rental rate on an animal unit month (AUM) basis. An active winter grazing market does not exist; therefore, sensitivity of the results to 25 and 75% of summer rental rate was examined. The alternative winter pasture rates had no impact on the overall results; therefore, 50% of summer rate was used. A land charge was imposed on grazing cattle because cows being fed hay are implicitly charged for land through the hay. The land charge for grazing winter meadows was adjusted upwards, because meadows provide more of the animal's protein requirement than range. The machinery complement for feeding hay included a 100 horsepower tractor pulling a stack mover/feeder. The stack mover is capable of feeding a 6.4 metric ton stack and, assuming a feeding rate of 16 kg of hay•cow^{-1}•day^{-1}, can feed a herd of 400 animals with a single pass; therefore, a 400-cow herd size was assumed for all treatments. Protein supplement was assumed to be fed using a feed truck. Spring costs were handled in a similar manner, except cow/calf pairs grazing meadows in May were charged for land at a rate equal to the summer rental rate. Net returns are returns to factors of production such as health manage-

Table 3. Hay and supplement inputs during gestation, calving and prebreeding of cows on various forage treatments.

Treatments[a]	Gestation	Calving	Prebreeding
	kg/cow		
Winter range - May hay	70 supplement	1188 hay	614 hay
Winter range - May meadow	70 supplement	1188 hay	
Winter hay - May hay	1418 hay	1188 hay	614 hay
Winter hay - May meadow	1418 hay	1188 hay	
Winter meadow - May hay	27 supplement	1188 hay	614 hay
Winter meadow - May meadow	27 supplement	1188 hay	

[a] Weights for hay fed is based on records obtained during 1991 and 1992.

Table 4. Cow body weight, body condition score, and pregnancy rate of 6 forage treatments over 4 years.

	Treatments[a]						Contrasts				
	Winter Range		Winter Hay		Winter Meadow		May	Winter		Interaction (May X winter)	
Item	May Hay	May Meadow	May Hay	May Meadow	May Hay	May Meadow	Hay vs meadow (1)[b]	Hay vs grazing (2)	Range vs meadow (3)	Hay vs grazing (4)	Range vs meadow (5)
No cows	137	138	136	131	125	138					
Cow body weight, kg											
Precalving	552	551	562	565	548	547	NS[c]	NS	NS	NS	NS
Prebreeding	507	511	524	527	512	519	NS	*	*	NS	NS
Weaning	543	553	546	559	542	557	*	NS	NS	NS	NS
Cow body condition score											
Precalving	5.1	5.2	5.3	5.3	5.1	5.2	NS	NS	NS	NS	NS
Prebreeding	4.8	4.9	5.0	5.1	4.7	5. 0	*	NS	NS	NS	*
Weaning	5.4	5.4	5.3	5.5	5.3	5.4	NS	NS	NS	NS	NS
Cow pregnancy rate, %											
Pregnancy	91.2	93.5	93.1	94.6	91.0	96.0	NS	NS	NS	NS	NS

[a] All year effects were significant P<0.01; all treatment X year interactions were nonsignificant $P>0.05$; data not shown
[b] Numbers in parentheses are contrasts as shown in Table 2.
[c] NS = Not significant $P>0.05$.
* Significant $P<0.05$.

ment (veterinarian, vaccinations), production risk (cow death loss, conception), unpaid family labor, labor not attributed to treatment differences, summer grazing, hay fed during calving, equipment, and overhead.

Nutrient requirement tables (NRC 1984) show that cows fed hay containing 8% protein and 55% Total Digestible Nutrients (TDN) require 11.3 kg•head^{-1}•day^{-1} during gestation and 14.4 kg•head^{-1}•day^{-1} during lactation (9 kg milk/day), as fed basis. Over the study period, observed feeding rates for hay averaged 13.5 kg•head^{-1}•day^{-1} over winter and 19.8 kg•head^{-1}•day^{-1} between calving and breeding, representing a feeding regime of 120% and 140% of estimated requirements (NRC 1984) for gestation and lactation, respectively. While some hay wastage is unavoidable, a best attainable hay feeding rate of 110% nutrient requirements during gestation and lactation was assumed for treatments being fed hay for the economic analysis. Assuming hay was fed at 110% NRC requirements biases the results in favor of the treatments being fed hay; however, the assumption allows the analysis to occur assuming high feeding efficiency for all treatments.

Sensitivity of the treatments to input price variability was examined by using a time series of hay prices, supplement prices, and pasture rental rates over the period of 1981-1990 (Johnson and Schroeder 1991, Nebraska Agricultural Statistics 1982-1991). The annual input prices represent 10 separate observed price relationships. The observed input prices were used in all possible combinations (10 hay prices X 10 supplement prices X 10 land rental prices) to create 1,000 input price scenarios with each price scenario assumed to be equally likely. Since the treatment X year interaction for weaning weight was not significant, only a single output price was used in the analysis. The 1,000 input-price scenarios were then coupled with calf weaning weight and calf price to estimate cumulative distribution functions of net returns for each treatment. Common least squares was then used to estimate linear cumulative distribution functions by regressing observations on net returns. The regression procedure has the advantage of simplifying the presentation of cumulative net returns while not altering the relative positions of any of the treatments.

Stochastic approximation methods were used to rank treatments as represented by the regressed, cumulative distribution functions (King and Robison 1984). Stochastic dominance involves pair-wise comparisons of the cumulative distribution functions for net returns of each of the 6 treatments. Ranking of treatments by first degree stochastic dominance (FSD) requires only one assumption, the decision maker prefers more returns to less. First-degree stochastic dominance of one treatment over another holds if the dominating treatment has a greater return at <u>all</u> probability levels compared to the dominated treatment(s). In practice, the cumulative distribution functions are plotted (e.g., Fig. 1). A function that lies completely to the right of another, without any intersections, has FSD over that other curve. The implication for FSD is that the dominating treatment not only has higher average returns, but also higher returns for all price combinations. The dominating treatment, therefore, is also the least risky.

If the curves intersect, then FSD is inconclusive and does not imply dominance. Second degree stochastic dominance (SSD) can be used in some cases to rank treatments when curves intersect. In addition to the assumption of preferring more to less, SSD requires that the decision maker be risk averse. A risk averse individual is willing to give up some potential "uncertain" gain for some lesser "certain" gain. Under SSD, treatment A will dominate treatment B if the accumulated area under the cumulative distribution function for A, at all points, is less than or equal to the accumulated area under treatment B's function.

Results and Discussion

Three of the 4 years of the study were below the 30-year average in annual precipitation and 1 year was near the long term average. Annual precipitation during 1989, 1990, 1991, and 1992 was 203 mm, 367 mm, 551 mm, and 433 mm, respectively, compared to a 30-year average of 535 mm.

Animal Performance

Amounts of supplement and hay fed are given in Table 3. Hay fed during a year varied from 3,220 kg/cow for cows fed hay during winter, after calving, and during May, to 1,188 kg/cow for cows that grazed winter range or winter meadow and grazed meadow during May.

Cow body weight, body condition score, and pregnancy rate are given in Table 4. Interactions between treatment and year and between winter treatments and May treatments were nonsignificant ($P>0.05$) for body weight, body condition, and pregnancy rate of cows. Cow body weight and body condition varied by year. Year effects were not considered large.

Precalving cow weights were similar ($P>0.05$) for all contrasts. Prebreeding cow weights were greater ($P<0.05$) for cows fed meadow hay during winter than for cows on winter grazing treatments (526 kg vs 512 kg), and cows that grazed winter meadows were heavier ($P<0.05$) than cows that grazed winter range (516 kg vs 509 kg). At weaning, cows that grazed meadows in May were heavier ($P<0.05$) than those fed hay in May (556 kg vs 544 kg). Although differences in body weight of cows was observed between forage systems during the 4-year study, differences were small and seasonal and did not increase over time.

Although significant differences in body condition occurred precalving, prebreeding and at weaning, differences were small (0.1 to 0.2 score); and cows on all treatments maintained a body condition score near 5.0 during the study. A body condition score of 5.0 is considered moderate and adequate for a high pregnancy rate (Richards et al. 1986). The relatively small variation in body condition score throughout the year for all treatments indicates that each of the forage systems was effective in meeting nutrient requirements of the cow.

Pregnancy rate averaged 93.2% over the 4 years and across all treatments and was similar to pregnancy rates reported for a 70-day breeding season in the sandhills (Deutscher et al. 1991). All contrasts for pregnancy rate were nonsignificant ($P>0.05$).

The treatment X year interaction was nonsignificant for calf birth date and all body weights (Table 5). Date of birth (an indicator of breeding date) was nonsignificant ($P>0.05$) for all contrasts and years. The year effect was significant ($P<0.05$) for each body weight; but the largest difference between years at weaning was 5 kg. Calf birth weights were greater ($P<0.01$) for calves from cows fed winter hay than for calves from cows that grazed meadow or range during the winter (42.7 kg vs 41.4 kg). Calves that grazed meadow in May were heavier ($P<0.01$) at prebreeding (95.7 kg vs 90.2 kg) and weaning (237 kg vs 232 kg) than calves on the May hay treatment. Calves from cows that grazed range during winter were lighter at prebreeding ($P<0.01$; 90.6 kg vs 93.7 kg) and weaning ($P<0.05$; 232 kg vs 237 kg) than calves from cows that grazed meadow during the winter. At prebreeding calves from cows fed hay during winter were heavier ($P<0.01$) than calves from cows grazing range and meadow during winter (94.7 kg vs 92.1 kg), but the difference was not evident at weaning.

Table 5. Calf birth date and body weight of 6 forage treaments over 4 years

	Treatments[a]						Contrasts				
	Winter Range		Winter Hay		Winter Meadow		May	Winter		Interaction (May X winter)	
Item	May Hay	May Meadow	May Hay	May Meadow	May Hay	May Meadow	Hay vs meadow (1)[b]	Hay vs grazing (2)	Range vs meadow (3)	Hay vs grazing (4)	Range vs meadow (5)
	Julian Date										
Birth date	89.3	89.2	90.1	89.2	89.6	88.0	NS[c]	NS	NS	NS	NS
	Calf body weight, kg										
Birth	41.1	41.1	42.6	42.8	41.8	41.7	NS	**	NS	NS	NS
Prebreeding	87.8	93.3	91.1	98.2	91.6	95.7	**	**	**	NS	NS
Weaning	228	235	232	243	234	238	**	NS	*	NS	NS

[a] All year effects were significant $P<0.01$; all treatment X year interactions were nonsignificant $P>0.05$; data not shown.
[b] Numbers in parentheses are contrasts as shown in Table 2.
[c] NS = Not significant $P>0.05$.
* Significant $P<0.05$.
**Significant $P<0.01$.

Economic Performance

Partial budgeting costs and returns for each treatment, along with the relevant cost ranges, are illustrated in Table 6. Although the average calf weaning weight was highest for winter-hay, May-meadow system, the average gross return was highest for winter-meadow, May-meadow system. This can be explained by the distribution of weaning weights and because prices used for calves are reported in one-hundred pound (cwt) increments (Wellman 1991). Weaning weights for winter-hay, May-meadow system were skewed slightly left, while weaning weights for calves in winter-meadow, May-meadow system were skewed slightly right. The distribution differences and price steps were sufficient to increase gross returns for winter-meadow, May-meadow treatment over gross returns for winter-hay, May-meadow system.

Regression lines illustrating the cumulative set of partial budgeting returns are shown in Figure 1. The cumulative distributions in Figure 1 show the percent of the 1,000 price scenarios which resulted in a given level of net returns for the given output price. For example, for the given output price, 60% of the price scenarios resulted in net returns of between \$353 and \$397 per calf for winter-hay, May-hay and net returns of between \$445 and \$458 per calf for winter-meadow, May-meadow. Cows on winter-hay, May-hay exhibited the lowest returns for all price scenarios while cows on winter-meadow, May-meadow exhibited the highest returns. Winter-range, May-meadow was second best choice. Winter-meadow, May-hay dominated the remaining systems for all price scenarios and winter-range, May-hay dominated winter-hay, May-meadow over approximately 70% of the price scenarios.

In terms of efficiency, winter-meadow, May-meadow has first degree stochastic dominance over all other systems because its cumulative distribution of net returns always had higher values relative to all other systems. Decision makers preferring winter-meadow, May-meadow have a strict preference of more returns to less returns. Likewise, the winter-range, May-meadow had FSD over all systems

Table 6. Partial budgeting return and cost ranges per calf by forage system.

Item	Winter Range: May Hay	Winter Range: May Meadow	Winter Hay: May Hay	Winter Hay: May Meadow	Winter Meadow: May Hay	Winter Meadow: May Meadow
Average gross return per calf ($)	484	496	488	500	493	506
8% meadow hay ($) (110% NRC)	11.4 - 25.1	0.0	57.7 - 126.6	46.3 - 101.6	11.4 - 25.1	0.0
32% supplement ($)	17.2 - 23.2	17.2 - 23.2	0 0	0 0	6.0 - 8.1	6.0 - 8.1
Land charge ($)	18.2 - 29.5	25.3 - 41.1	0 0	7.1 - 11.6	27.5 - 42.1	34.6 - 53.7
Feed machinery ($)	1.76	1.06	4.23	3.53	1.03	0.33
Labor ($)	1.38	0.88	2.91	2.41	0.79	0.29
Return to other factors of production/calf ($)	403 - 434	430 - 452	356 - 424	382 - 441	416 - 447	443 - 464
Average return to other factors of production ($)	419	442	390	412	432	455

except the winter-meadow, May-meadow; and winter-meadow, May-hay had FSD over winter-range, May-hay; winter-hay, May-hay; and winter-hay, May-meadow. Because winter-range, May-hay did not exceed winter-hay, May-meadow at all possible outcomes, winter-range, May-hay did not have FSD over winter-hay, May-meadow. However, as the number of outcomes increase, the accumulated area underneath the graph of winter-range, May-hay will always be less than winter-hay, May-meadow; therefore, winter-range, May-hay treatment did exhibit second degree stochastic dominance (SSD) over winter-hay, May-meadow. Decision makers preferring winter-range, May-hay over winter-hay, May-meadow system are risk averse in that winter-range, May-hay will have a greater probability of higher net returns than winter-hay, May-meadow.

The slopes of the regression lines imply that the different treatments have different risk characteristics. Systems with steeper regression lines have less variation in net returns than systems with regression lines having lower slopes. Winter-hay, May-hay and winter-hay, May-meadow systems exhibited the most variability, while the 4 systems without winter-hay exhibited the least variability. The variability in returns is due principally to the fact that feed costs for systems with winter-hay are heavily dependent on hay price while feed costs for the other systems relied principally on supplement and land rental rates. Net returns for treatment with winter-hay were, therefore, based primarily on the 10 hay prices while net returns for those without winter-hay were based primarily on the 100 supplement-land rental rate price scenarios. The relative risk differences between systems with winter-hay and those without winter-hay are therefore due to the diversity in input types and their price variations.

Economic Implications

Regardless of the winter treatment, grazing meadows in May while upland range is dormant improved economic returns to the cow/calf enterprise. In addition, returns were further improved by having the cow harvest the winter feed by either grazing subirrigated meadows or native range during the winter. The results illustrate that for a ranching operation with adequate meadow and winter range resources, the best forage management strategy involved grazing subirrigated meadows over winter and grazing meadows again in May. However, most ranches face a resource constraint in terms of the availability of subirrigated meadows or winter range. Future research efforts need to be devoted to analyzing the question of how the resource base could impact the forage treatment selection and in particular what the trade-offs are when grazing is substituted for haying on subirrigated meadows.

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Government policy effects on cattle and wildlife ranching profits in Zimbabwe

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Abstract

The profitability of alternative range-based production systems is frequently affected by government policies. Moreover, the comparative profitability of wild and domestic animal production systems on African semi-arid savannas has not been well analyzed. This paper presents a simple method for analyzing government policy effects on ranch profits and reports application of the method to 30 commercial cattle, 7 wildlife, and 13 mixed ranches in Zimbabwe. Ranches were selected in 4 contiguous woodland savanna areas with abundant wildlife and in 2 adjacent open savanna areas with sparse wildlife. Financial profits were calculated from 1989/90 ranch data and economic profits were estimated from the opportunity costs of inputs and outputs. A policy analysis matrix was used to estimate financial-economic profit differences. Cattle ranches in the 2 areas with sparse wildlife were the most profitable group studied. Profits were lower (but similar) for cattle and mixed ranches in the areas with abundant wildlife. The financial profit was higher than economic profit for all ranch types, thus creating production disincentives. However, currency over-valuation and implicit taxes on exported beef created greater production disincentives for cattle than wildlife producers. While the policy interventions negated the government's stated objectives of increasing foreign currency earnings and being self sufficient in beef production, they did appear to have beneficial range management consequences by encouraging fewer cattle on historically overstocked cattle ranches.

Key Words: Economic profit, financial profit, production incentives, rangeland allocation, semi-arid savannas.

Governments regularly intervene in economies as they attempt to achieve particular policy goals. One sector in which almost all governments intervene is agriculture where they try to alter income distributions, stabilize prices, promote food self-sufficiency, or protect their own agriculturalists from world market forces. But these interventions may fail to achieve their goals and can produce unintended consequences, one reason being that market prices influenced by policy interventions may not accurately reflect resource scarcity and may thus encourage economically inefficient resource use (Monke and Pearson 1989).

Given the widespread dependence of Africans on semi-arid savanna resources for their livelihood, efficient and sustainable use of such rangelands is critical for human welfare. Yet, these ecosystems are being increasingly degraded under traditional agricultural practices and increasing human population pressure. Due to their relatively low production potential, economic analyses of the use of such rangelands have, however, been rare and little attention has been paid to government policy effects on land-use patterns. This deficiency will not promote future human welfare.

Semi-arid African savannas provide a heterogeneous forage base which multi-species herbivore communities defoliate more uniformly than cattle alone (Walker 1979; Taylor and Walker 1978). It has thus been argued that game ranching should be more profitable than beef ranching in such areas (Dasmann and Mossman 1961; Clarke et al. 1985; Hopcraft 1986; Child 1988) and that game ranching may be ecologically the most sustainable form of land-use (Child and Child 1986).

Such claims have, however, been based on incomplete economic analyses, virtually none of which have accounted for government policy effects on profitability. Yet simple analytical tools, such as the Policy Analysis Matrix (PAM)(Monke and Pearson 1989), have been used to identify policy-based profit distortions in agronomic production systems. Such distortions tend to promote economically inefficient resource allocation for production because producers tend to oversupply commodities whose profits are inflated by policy interventions and undersupply those with suppressed profits (Masters 1989).

This paper presents the financial profits of cattle and wildlife ranching in Zimbabwe, and it describes the use of the PAM methodology to analyze the effects of government policy on the economic efficiency of these ranches. Since it has a long history of cattle ranching and legislation allowing landowners to commercially use wildlife on their property, Zimbabwe provided an ideal venue for a comparative economic study of semi-arid range use in Africa. Data were collected from commercial ranches in the Midlands Province, which contains the country's most productive semi-arid savannas. Less than 2% of the Midlands is arable but 78% is grazeable (Roth 1990) making it suitable primarily for extensive animal production (Vincent and Thomas 1960).

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Study Description

Survey Popultion and Sample

A survey of independent ranches, where revenue was derived from cattle or wildlife, or both was conducted during 1990/91. The study population was restricted to independent ranches exceeding 1,200 ha (70% of all ranches in the Midlands) because, smaller ranches could not sustain 240 livestock units, the probable minimum herd size for viable commercial cattle enterprises in Zimbabwe. Six agricultural areas with high concentrations of commercial ranches were selected for study. Four were dominated by *Miombo* woodland savanna with abundant wildlife while the other 2 consisted of mainly open, *Hyparrhenia*-dominated grasslands, with low densities of wild ungulates.

Fifty ranches were selected for study ranging in size from 1,424 to 132,840 ha. In the 4 areas with abundant wildlife, data were obtained from most (ca. 80%) of the relevant ranches, including 15 cattle ranches 7 wildlife ranches and 13 ranches with both cattle and wildlife enterprises. In the 2 areas with sparse wildlife, no revenue was derived from wildlife, and 15 cattle ranches (ca. 25%) were randomly selected for study. Data were collected for the 1989/90 production season through personal interviews using a standardized survey questionnaire.

Surveyed cattle ranchers derived virtually all of their income from the sale of beef cattle. Among wildlife enterprises 84% provided revenue from the sale of safari hunting opportunities, 25% from hunting leases, and 25% from the sale of game meat. Hunting clients were 49% American, 40% European and 6% Australian, and hunted species included leopard (*Panthera pardus*) or sable (*Hipotragus niger*), as the main trophy species, and numerous other plains game species.

Analytical Framework

Both financial and economic profits were calculated for each ranch. Financial profit is the actual profit determined by market prices of inputs and outputs and reflects policy distortions. It was calculated from the financial records of each ranch. Economic profit is, by contrast, a hypothetical concept and a function of the opportunity costs of inputs and outputs (Jansen 1989). Such costs reflect resource scarcity values which are independent of government policy interventions. Assuming that financial profits account for all costs including production externalities, financial-economic profit differences thus approximate government policy effects on operational profitability.

The Policy Analysis Matrix (PAM) approach described by Monke and Pearson (1989) was used to estimate the differences between financial and economic profit estimates. One criticism of the PAM method has been that it is theoretically limited for assessing economic efficiency because the indices used to estimate profit are average parameters (Masters 1989). Estimation of economic efficiency dictates the use of marginal rather than average profits. However, where there were many producers with relatively constant short-term returns to scale (as in the case of ranching enterprises), average and marginal values are very similar.

In using a PAM to estimate financial and economic profits, inputs and outputs are separated into tradeable and domestic factors of production. Tradeable inputs are all those which can be traded internationally. Domestic factors of production are those commodities for which international migration is constrained. They include capital, labor, and land.

Estimating Economic Prices of Tradeable Commodities

World prices were used as a proxy for the economic prices (opportunity costs) of tradeable commodities because, due to international market competition, they may be assumed to be free of national policy interventions (Monke and Pearson 1989). The relevant world prices for exports are the free on board (f.o.b.) border prices, and for imports, the cost, insurance, freight (c.i.f.) import prices (Gittinger 1982). These border prices were obtained from official sources where possible. Where the border price of a tradeable commodity was unobtainable, the commodity's economic price was estimated by subtracting transfer payments, such as subsidies and taxes, from its average financial price.

To convert international economic prices of tradeable goods to domestic values, free-market exchange rates must be used (Jansen 1989). During the survey period, the Zimbabwe dollar (Z$) was overvalued relative to that of its main trading partners (Masters 1990) resulting in a black-market exchange rate of double the official rate. Since black-market rates include a risk premium, the mean of the official and the black-market rates was considered to be a conservative estimate of the free-market rate (Jansen 1989, Jansen et al. 1992), representing 50% overvaluation of the Z$. In summary, economic prices for tradeable commodities were calculated from the world/market price conversion ratio, the foreign content percentage, and the Z$ overvaluation correction factor as shown in Table 1.

Estimating Economic Prices of Domestic Factors of Production

The economic values of domestic factor prices (land, labor and capital) are determined from their domestic opportunity cost (Monke and Pearson 1989). In this analysis, management and land costs were excluded and profits were measured as net returns to investment in management and land. Declared management fees were disregarded because they were distorted by income tax structures. Average land prices were imprecise due to wide fluctuations resulting from mandated land redistribution (Murphree and Cumming 1991) and restrictive foreign investment policies.

Net Revenue Adjustments

Since data were collected for 1 year only, adjustments were made to the net cattle revenues to eliminate capitalization of profits or liquidation of capital through changes in cattle herd sizes. Wildlife revenues were not adjusted in the same way because population changes of wild animals on individual ranches were difficult to detect. Eighty percent of wild-animal purchase costs were, however, added back to wildlife revenue since such purchases were irregular and the financial returns from them were assumed to accrue over a 5-year period. Revenues and costs associated with the use of wildlife outside of the Midlands were also excluded.

Table 1. Parameters used to estimate the Z$ economic prices of tradeable commodities.

Financial price	Price ratio		Foreign content	Forex factor	Economic price foreign	local	Total
A	B	C	D	E		F	G
				A•B•C•D		A•B(1-C)	E+F

A = Financial value of tradeable output or input (Z$)
B = world/market price ratio (economic conversion factor)
C = % foreign content of financial value
D = Z$ overvaluation correction factor
E = economic price of the foreign content (Z$)
F = economic price of the local content (Z$)
G = total economic price of tradeable output or input (Z$).

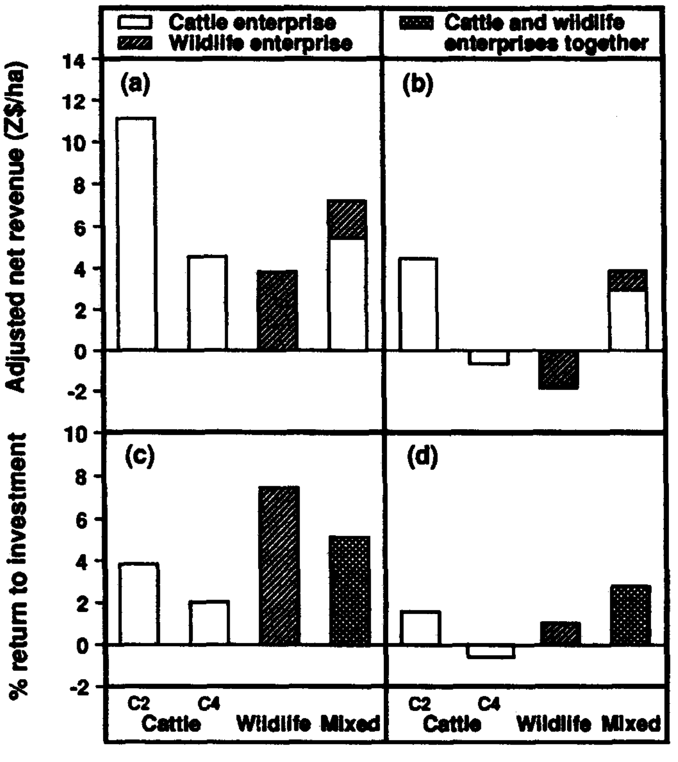

Fig. 1. Financial profits of cattle, wildlife and mixed ranches. [(a) per-ha excluding depreciation, (b) per-ha including depreciation, (c) % return to investment excluding depreciation, and (d) % return to investment including depreciation; C2 and C4 are cattle ranches in areas with sparse and abundant wildlife].

Data Analyses

Uncertainity about the domestic opportunity cost of capital, overvaluation of the Z$, and cattle-revenue price ratios, required the use of sensitivity analyses to determine the effects of assumed values on economic profitability estimates. The small sample size (7-15) of each ranch category and differences in sample variance required the use of non-parametric statistics (Wilcoxon mateched pair and the Mann-Whitney 2 sample tests) to compare sample means (Hollander and Wolve 1973).

Results

Average financial and economic profits for 2 categories of cattle ranches (C2 - in areas with sparse wildlife and C4 - in areas with abundant wildlife), wildlife ranches and mixed ranches are presented. Results are presented in 3 parts: financial profitability; financial-economic profit comparisons; sensitivity analysis of capital opportunity cost, Z$ overvaluation and cattle-revenue price ratio on economic profits.

Financial profitability

The average financial profit of each ranch category is reported here as a reference point for the subsequent discussion of policy effects on profitability. Since capital asset values were uncertain, financial profits were calculated both with and without estimated asset depreciation (Fig. 1).

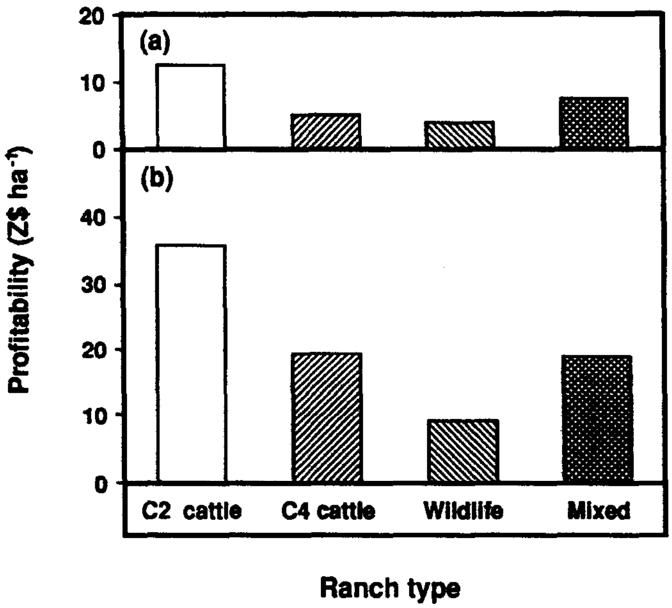

Fig. 2. Comparison of (a) financial and (b) economic profits based on 0% capital opportunity cost, 50% Z$ overvaluation and 1.25 beef-revenue conversion factor.

When depreciation costs were excluded, all 4 ranch types provided positive net returns ha^{-1} (Fig. 1a: C2 cattle Z$11.18, $P< 0.01$; C4 cattle Z$4.53, $P< 0.05$; wildlife Z$3.79, $P< 0.10$; mixed Z$7.20, $P< 0.01$) and positive returns to investments (Fig. 1c: C2 cattle 3.86%, $P< 0.01$; C4 cattle 2.03%, $P< 0.10$; wildlife 7.42%, $P< 0.05$; mixed 5.16%, $P< 0.01$). Due to the small sample sizes, few inter-category profit differences were statistically significant, though net revenue ha^{-1} on C2 cattle ranches was significantly greater than on C4 cattle and wildlife ranches ($P< 0.05$) (Fig. 1a) and the % returns to investment was greater for wildlife than C4 cattle ranches ($P< 0.10$)(Fig. 1c).

When depreciation was included, the financial profits of all ranch categories were significantly reduced ($P< 0.01$), only C2 cattle and mixed ranches providing positive net revenues ha^{-1} (Fig. 1b: C2 cattle Z$4.50, mixed Z$3.88, $P< 0.10$) and only mixed ranches providing significant positive returns to investments (Fig. 1d: mixed 2.78%, $P< 0.10$). Net revenue ha^{-1} was greater ($P< 0.10$) on C2 cattle ranches than on C4 cattle and wildlife ranches (Fig. 1b) and the returns to investments on mixed ranches was greater ($P< 0.10$) than on C4 cattle ranches (Fig. 1d). Comparison of Fig. 1a and 1b shows that only the C2 cattle ranches and the mixed ranches were financially viable when depreciation was accounted for. It also suggests that C2 cattle and wildlife ranchers were, on average, living off depreciation or borrowings to survive financially, neither of which are sustainable practices. Having examined the financial profits of cattle, wildlife and mixed ranches in the Midlands, the next section examines how profitable these ranches might have been without government policy interventions.

Financial-Economic Profit Comparisons

For the initial comparison of financial and economic profits, the following parameter values were used to calculate economic profits: 0% capital opportunity cost, 50% Z$ overvaluation and 1.25 cattle-price conversion ratio. The "real" opportunity cost for capital was assumed to be 0% because the 10% nominal interest rate on savings accounts (the "next best" investment opportunity) was similar to the prevailing

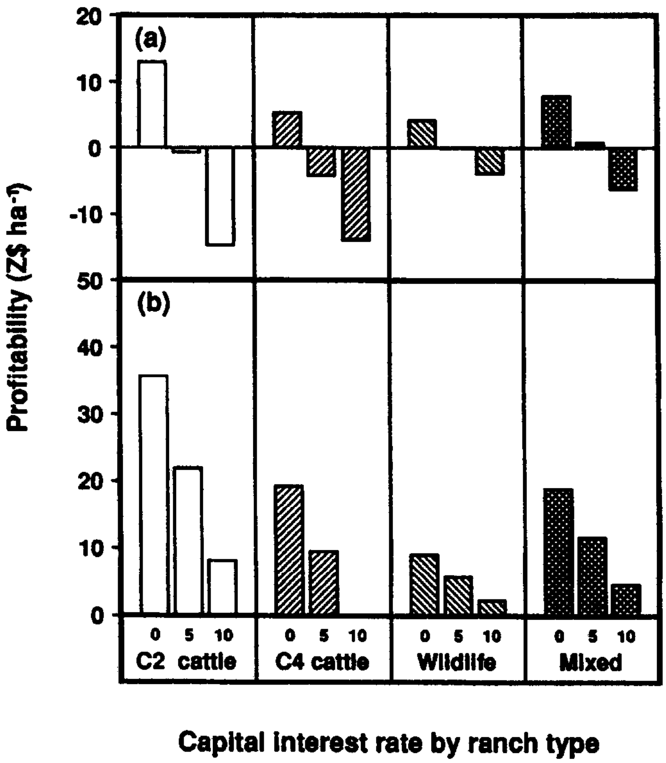

Fig. 3. Effects of assumed capital opportunity cost on (a) financial profitability and (b) economic profitability of ranches. [Assumed capital opportunity costs are 0%, 5% and 10%].

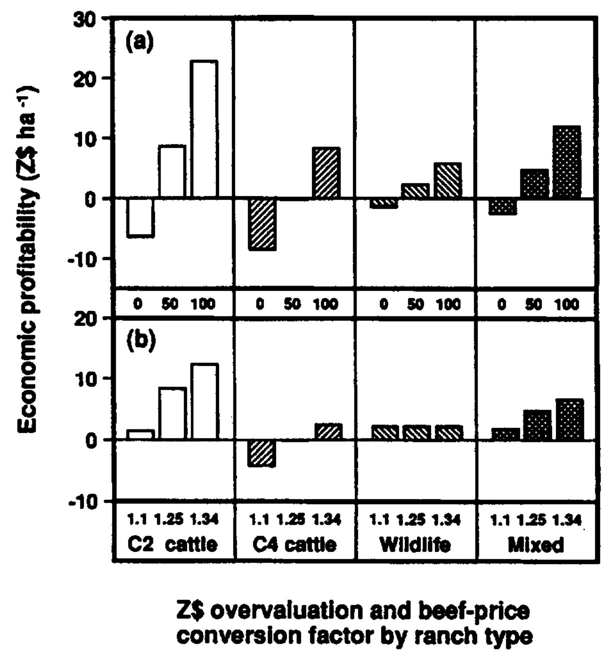

Fig. 4. Effects of assumed (a) Z$ over-valuation and (b) cattle-revenue price ratio on the economic profitability of ranches. [Assumed Z$ overvaluation values are 0%, 50%, and 100%; assumed cattle-revenue price ratios are 1.1, 1.25, and 1.34].

inflation rate (12.6% as measured by the consumer price index). The free-market exchange rate for the Z$ was taken to be the average of the official and black-market exchange rates. The 1.25 cattle-price conversion factor was the ratio of the beef-sales realization of the Cold Storage Commission (CSC - Zimbabwe's central beef marketing authority) and the producer price weighted by the 1990 export and local sales values (Jansen et al. 1992). This conversion value reflected a 25% implicit tax on beef revenue due to Zimbabwe's policy of partial retention of earnings from lucrative beef sales to the European Community (World Bank 1990) to provide an average annual 12% subsidy for meat consumption by low-income consumers between 1985 and 1991 (Jansen et al. 1992).

The economic profits derived using the above conversion parameter values are compared with financial profits (excluding depreciation) in Figure 2. Converting financial to economic prices significantly increased the profits of all ranches ($P<0.01$ except wildlife $P<0.05$), the increases were greater ($P<0.05$) for cattle than wildlife ranches. This was because the average financial revenue of cattle and mixed ranches was greater than on wildlife ranches ($P<0.01$) and the conversion factor for beef revenue was greater than for wildlife revenue. In addition, financial-economic price conversions increased revenue more than costs in all ranch categories ($P<0.01$, wildlife $P<0.05$).

These results imply that the prevailing policy mix (which resulted in an overvalued Z$ and 25% implicit taxes on beef producer prices, and high inflation rates) was creating negative production incentives for all ranchers, particularly cattle ranchers. Both cattle and wildlife were thus possibly being produced at levels below those that would prevail in a policy-neutral climate. In the 4 areas with wildlife, this conclusion was supported by declining cattle herds in the 1980's and a shift to less capital intensive wildlife ranching (Child 1988). However, in areas with sparse wildlife, ranchers appeared to be increasing their herds. In the prevailing inflationary climate they might have had a short-term incentive to increase herd size because the speculative returns on holding cattle appeared to be greater than returns from alternative savings investments.

Sensitivity Analysis

The sensitivity of profit estimates to capital opportunity cost, Z$ exchange rate and the cattle-revenue price ratio was analyzed using three separate values for each parameter. Changing the capital interest rate impacted both financial and economic profit estimates, but varying the latter 2 parameters affected only economic profit estimates.

Capital Opportunity Cost

The 3 capital opportunity costs used in the sensitivity analysis were 0%, 5% and 10%. Zero percent is the assumed "real" opportunity cost previously used, 10% was the average interest rate on savings accounts in Zimbabwe during the survey period, and 5% is an intermediate value, similar to the real discount rate recommended for use in the economic analysis of range improvement projects in the USA (Workman 1986, p 200). The mean financial and economic profits ha^{-1} at each level of capital opportunity cost are presented in Figure 3.

Financial profits calculated using 0% capital cost (Fig. 3a) are identical to those in Figure 2a. When these estimates were adjusted for 10% capital interest, the average values for each ranch category were all negative with cattle ranches sustaining greater losses ($P<0.05$) than mixed and wildlife operations. While economic profits similarly decreased with increasing capital opportunity cost (Fig. 3b), they remained positive for all ranch categories at 10% capital interest. The use of 5% capital cost resulted in intermediate financial and economic profit estimates.

Estimated profits of cattle ranches (especially C2 ranches) were more sensitive to the assumed capital opportunity cost than those of the other ranch categories. This was due largely to inter-group differences in livestock investments; wildlife "assets" being assigned zero capital value because they are state owned and do not represent personal wealth. Yet, despite the inter-ranch differences of capital interest effects on financial and economic profits, the financial-economic profit disparities were only slightly affected by changing the capital interest rate because, for each level of capital interest, the aggregate capital opportunity cost of a ranch was similar in financial and economic terms. This implies that the previous conclusion, that government policy was creating negative production incentivies for all ranchers, is robust with respect to assumed capital interest.

Z$ Overvaluation

The 3 Z$ overvaluation rates used in the sensitivity analysis were 0%, 50%, and 100%. The 1st rate assumes that the free-market rate was equal to the official exchange rate and the 3rd rate represents the prevailing black-market exchange rate relative to the official rate,. The 2nd rate is intermediate between the first 2 and reflects an assumed 50% risk premium in the black-market rate.

Increasing the Z$ overvaluation rate (Fig. 4a) significantly increased ($P < 0.01$ except wildlife $P < 0.05$) the estimated economic profits of all ranch categories, but the effect was greater ($P < 0.01$) for cattle than wildlife ranches. This difference was mainly due to the greater price ratio for cattle revenue than wildlife revenue, each of which was multiplied by the Z$ overvaluation factor to estimate their economic revenues (see Table 1).

These results imply that, with increasing overvaluation of the Z$, cattle enterprises faced an increasing level of implicit taxation relative to wildlife enterprises because overvaluation effects on net earnings in local currency is greater in cattle than wildlife enterprises. If other policy interventions remained constant, use of a free-market exchange rate would thus enhance the profitability of beef production more than wildlife ranching, and might lead to a production shift away from wildlife to beef.

Cattle-Revenue Price Ratio

The 3 ratios were used to convert cattle revenue from financial to economic prices were 1.10, 1.25, and 1.35. As previously described, the 1.25 conversion factor was the CSC-beef-sales-realization/producer-price ratio weighted by actual export and local sales values in 1990. The value of 1.10 was derived using 1989 beef production and price statistics. The 1.35 factor was derived from 1990 statistics but using an adjusted value for export earnings to eliminate the effects of foot-and-mouth disease related export restrictions in 1989/90.

Increasing the cattle-revenue conversion factor (Fig. 4b) significantly increased ($P < 0.01$) the economic profits of cattle enterprise, especially C2 cattle ranches. This implies that the policy of taxing beef export earnings to subsidize consumers had resulted in increasingly greater production disincentives for cattle producers compared with wildlife ranchers between 1989 and 1990. This increase would have been greater if beef exports had not been constrained by the outbreak of foot-and-mouth disease. However, the economic profit differences between cattle and wildlife ranches might have been considerably less if Zimbabwe did not have access to the European Community market.

Discussion

In semi-arid savannas land use is often restricted to domestic and wild animal production due to erratic and limited rainfall. Investment patterns in the use of these rangelands vary according to the relative productivity, capital investment requirements, and risk of different animal production systems. In the prevailing uncertain economic climate in Zimbabwe, direct foreign currency earning potential was also an important determinant of investment decisions.

In the 2 Midlands areas with sparse wildlife, cattle ranching was the only viable range-based production option due to predominance of herbaceous vegetation and a lack of suitable habitats for diverse wildlife communities. Cattle ranches in these areas were financially and economically the most profitable group studied. In the 4 areas with abundant wildlife, mixed ranches were at least as profitable as cattle ranches. Based on 1989/90 data, movement from purely cattle to purely wildlife operations resulted in lower profits but also lower capital investments in livestock (Kreuter 1992).

Government policy interventions produced an overvalued Z$ and an implicit tax on export beef prices. This created negative production incentives for both beef and wildlife ranchers, but these effects were greater for cattle enterprises. Removing the meat subsidization policy might thus result in a shift from wildlife to cattle ranching, assuming that the access to the lucrative European Community market can be retained by Zimbabwe.

Since the wildlife industry was unregulated, safari hunting provided the potential for direct foreign currency earnings. This, together with the fact that diversification spread risk without significantly increasing capital costs, made it rational for cattle ranchers to incorporate wildlife enterprises. For example, beef producers faced recurrent foot-and-mouth related marketing disruptions while potential socio-political instability presented risks to tourist-orientated wildlife enterprises (Cumming 1989). In addition, most ranchers stated that long-term overstocking with cattle was the major factor causing increased rangeland degradation and soil erosion in the Midlands. Since mixed ranches were stocked lower than cattle ranches (Kreuter and Workman 1994), the prevailing policy-driven diversification incentives might inadvertently be improving range condition. The advantages of mixed ranching appear to be reflected by an increase in the number of wildlife enterprises on former cattle-only ranches during the 1980's (Child 1988).

Government regulation of national beef prices resulted in increased beef supply to unregulated rural markets and decreased sales to the central beef marketing authority from nearly 90% of production in 1980 to about 50% in 1990 (AMA 1991). This created meat shortages in some urban areas and reduced beef exports. The production disincentives were thus counteracting the government's stated objectives of maximizing net foreign currency earnings (Zimbabwe 1991) and being self-sufficient in beef production (Rodriguez 1985). By adopting free-market Z$ exchange rates and free-market input and output prices, the state is likely to increase the profitability of all ranches, particularly cattle ranches. This might partially offset the diversification trend.

Conclusion

Claims that wildlife can provide greater profits than cattle in semi-arid savannas have been based mainly on financial analyses of wildlife systems which included valuable big game species, such as buffalo. The Midlands lacks buffalo due to their veterinary conflicts with cattle, the dominant range animal. In areas with abundant wildlife cattle and mixed ranches were similarly profitable, both financially and economically. Since diversification from cattle to mixed ranching spread risk and reduced stocking rates, mixed ranches appeared to be financially, economically and ecologically optimal where wild animals were abundant. Where possible, rangelands in the Midlands should therefore be managed not only to produce a dense herbaceous community for grazers but a diversity of browse also.

Our results emphasize the need to qualify claims that wildlife ranching is more profitable than cattle ranching in African semi-arid savanna ecosystems. Our results also showed that economic studies of policy effects on range-resource allocation can illuminate compatibility or conflict between stated policy objectives, actual policy effects, and economically efficient rangeland allocation.

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Cattle grazing white locoweed in New Mexico: Influence of grazing pressure and phenological growth stage

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Abstract

Locoweed poisoning generally occurs in early spring when other forage is dormant or in short supply and locoweed is the main green plant available to grazing livestock. The objective of this study was to estimate the amount of white locoweed (*Oxytropis Sericea* Nut. ex T&G) consumed by cattle, and to determine if cattle graze locoweed because it is relatively palatable, or if they are forced to graze it because of decreasing availability of other forage. Three grazing trials were conducted that corresponded to the vegetative, flower, and pod phenological growth stages of white locoweed. Four cows were used in Trial 1 (vegetative growth stage), and 7 cows were used in Trials 2 (flower stage) and 3 (pod stage). Pastures were fenced for the 10-day grazing trials, so that forage became limited and grazing pressure increased as the trials progressed. Acceptance of white locoweed at the beginning of each trial, when there was adequate forage, would indicate preference. Rejection of white locoweed at the beginning of the trials, followed by increasing consumption as the trials progressed would indicate that grazing pressure was forcing the cows to select white locoweed. White locoweed was readily accepted by 1 cow in the vegetative trial, and by 2 cows in the flower trial (these cows were termed "loco-eaters"). The remainder of the cows (termed "normal") rejected white locoweed in the vegetative and flower trials until the availability of new growth cool-season grasses decreased, after which they started to select white locoweed. All cows rejected white locoweed at the beginning of the pod trial, but consumed it as availability of other plants decreased. Regression analysis showed that grazing pressure was positively associated with ingestion of white locoweed (r^2 = .46 to .88) by the "normal" cows.

Key Words: grazing pressure, cattle grazing, poisonous plants, white locoweed, *Oxytropis serica*.

Locoweed poisoning was often confused with starvation in early reports (Marsh 1909). The clinical signs of locoweed poisoning (depression, rough hair coat, emaciation) are similar to those of starvation. Furthermore, locoweed poisoning generally occurred in the late winter or early spring (Marsh 1909, Peters and Sturdevent 1908, James et al. 1968, 1969, Patterson 1982) when forage was typically in short supply.

Many locoweed species in the southwestern U.S. are biennials or short-lived perennials that germinate and grow in the fall following late summer and autumn rains (Welsh 1989). They remain green during mild winters, or are the first plants to green up and resume growth in the spring, and they are often the only green plants available among dry, dormant grasses during this period. Ralphs et al. (1993) reported that cattle consumed moderate amounts of white locoweed (*Oxytropis sericea* Nut. ex T&G) throughout the spring, but ceased grazing it when warm-season grasses started rapid growth in June. The objective of the present study was to determine if cattle graze white locoweed because it is relatively palatable, or if they are forced to graze it because of increasing grazing pressure resulting from diminishing forage availability. We hypothesized that white locoweed was not innately palatable and that cattle would not select it if other forage was abundant. We anticipated that cattle would begin to graze locoweed as the forage supply decreased and grazing pressure on the remaining forage increased. Grazing trials were conducted during the vegetative, flower, and pod phenological growth stages of white locoweed, to evaluate the relative palatability of white locoweed at each stage with respect to increasing grazing pressure.

Methods

The study was conducted in eastern Colfax County, 32 km east of Raton in northeastern New Mexico. The site was a northeast exposure, 10% slope, at 2,200 m elevation. Soils were silty clay loam with round volcanic rocks scattered in various densities throughout the site. This appears to be the preferred habitat of white locoweed in this region. Cool-season grasses included: western wheatgrass (*Pascopyrum smithii* (Rybd.) A. Love), squirreltail (*Elymus elymoides* (Raf.) Swezey) and sedge (*Carex* spp.). Warm-season grasses included: blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steudel), sideoats grama (*B. curtipendula* (Michx.) Torr.), little bluestem (*Schizachyrium scoparium* (Michx.) Nash), and 3-awns (*Aristida* spp.). White locoweed dominated the forb component. 10-day grazing trials were conducted during the vegetative, flower, and pod phenological growth stages of white locoweed.

Trial 1, Vegetative Stage, April 16 to 25

White locoweed was actively growing with leaves 8 to 15 cm long. Cool- season grasses were green and actively growing with leaves 8-10 cm long. Warm-season grasses were dormant.

Trial 2, Flower Stage, May 5 to 14

White locoweed leaves were 12-20 cm long and flower stalks were 30 cm tall and flowering. Cool-season grasses were 15 to 20 cm tall

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and growing rapidly. Warm-season grasses were green but had not started rapid growth.

Trial 3, Pod Stage, June 15 to 24

Locoweed pods were immature to fully expanded and were still succulent. Cool-season grasses were headed out and warm-season grasses were growing rapidly. Forbs were abundant and flowering.

Pasture differences were confounded with growth stages in this study. Separate pastures were constructed for each of the 3 trials, and were located side-by-side on the same hill slope in an attempt to minimize differences between pastures. Because pastures were not replicated, results from this study cannot be extrapolated beyond the conditions of this study.

Standing crop was estimated at the beginning and end of each trial. Ten, .25-x 1-m quadrats were systematically placed along each of 2 paced transects bisecting the length of each pasture. Species were clipped at ground level and grouped into the following forage classes: cool-season grasses, warm-season grasses, forbs, locoweed leaves, and locoweed heads. Samples were dried in a forced-air oven at 60C for 48 hour and weighed.

Standing crop at the beginning of each trial was used to calculate pasture size. The amount of feed required to sustain the cows for 10 days was determined from NRC nutrient requirements (9 kgDM/cow/day). Half the grass standing crop was considered available for consumption. The size of the pasture required to provide that amount of feed was calculated and fenced with temporary electric fence. Standing crop, pasture size, and grazing pressure are shown in Table 1. Even though grass standing crop was less in Trial 3 than in Trial 2, the pasture size in Trial 3 was kept at 1.7 ha in anticipation of rapid forage growth during this trial.

Eight Hereford and Angus cows (380 ± 105 kg) were retained from a previous locoweed grazing study (Ralphs et al. 1993). Locoweed consumption by these cows in the previous trial varied from a high of 30% of their diets to a low of 5%. However, 4 of the cows died from residual locoweed toxicity in March before the first trial began; hence Trial 1 (vegetative stage) was conducted with only 4 cows. Three additional cows with histories of eating locoweed were purchased and included in Trial 2 (flower stage) and Trial 3 (pod stage).

All cows had grazed on white locoweed infested ranges and were familiar with the vegetation community. Between trials, the cows were kept in a nearby locoweed-free pasture with vegetation similar to the study pasture. They were denied access to white locoweed between the trials to prevent those that were eating it from becoming severely poisoned and incapable of completing the trials. The cows were supplemented with 0.9 kg/cow of cotton seed cake (protein supplement) every other day throughout the winter and until the end of May. There was sufficient green forage during the pod trial in June to meet their protein requirement. Cows had free access to a trace mineral salt block and water at all times.

Diets were estimated by a bite-count technique (Lehner 1987). Each cow was observed for 4 to 8, 5-min periods during the day whenever the cows were grazing. The number of bites of each forage class was recorded and the percentage of each forage class in the diet was estimated. The amount of locoweed consumed at the beginning of each trial, while there was still adequate forage, was a measure of its relative palatability at that growth stage. Days of the trial represented increasing grazing pressure resulting from the diminishing forage supply. An increase in locoweed consumption as the trial progressed would indicate that grazing pressure forced the cows to select white locoweed.

Each cow was considered an experimental unit because the increasing grazing pressure would be applied to each animal. The percentage of each forage class in the diets was compared between trials and over days of the trials by analysis of variance (ANOVA) in a split-plot design. Trial was the main plot and was tested by the trial-by-animal interaction. Day was the split-plot, and along with the trial-by-day interaction, was tested by the residual error. There were significant trial-by-day interactions in all forage classes ($P< .01$), so the model was reduced and trials were analyzed separately comparing diets over days of the trial and among cows. Percentage data of forage classes in the diet were transformed by arcsin transformation, but non-transformed means are presented in the tables. Where differences occurred ($P< .05$), means were separated by least significant difference (LSD).

Simple linear regression was used to describe the influence of grazing pressure on locoweed consumption. Grazing pressure is the ratio of forage demand to forage supply at a given time. Forage supply on each of the 10 days in the trials was extrapolated linearly from the total standing crop at the beginning and end of each trial. Forage demand was assumed to be 9 kg DM/cow/day and grazing pressure was calculated for each day of the trial. Regressions were calculated between locoweed consumption as the dependent variable and grazing pressure ratio as the independent variable, for the entire study, and for the 3 trials separately. There was also a difference in locoweed consumption among cows in all 3 trials. Two cows preferred locoweed and consumed it for a majority of their diets in Trials 1 and 2, and were labeled "loco-eaters", as opposed to "normal" cows. Regressions were also calculated with all the cows

Table 1. Standing crop (kg/ha ± standard error), pasture size (ha), and grazing pressure ratio on total standing crop at the beginning and end of each trial.

Forage Class	Trial 1, April Vegetative Begin	End	Trial 2, May Flower Begin	End	Trial 3, June Pod Begin	End
Standing crop			kg/ha			
Cool-season grass	131 ± 20	48 ± 17	208 ± 36	56 ± 29	120 ± 24	96 ± 27
Warm-season grass	449 ± 53	358 ± 42	558 ± 46	378 ± 35	404 ± 27	380 ± 26
Forb	236 ± 34	230 ± 38	298 ± 38	182 ± 26	386 ± 37	256 ± 27
Locoweed leaf	284 ± 58	98 ± 28	382 ± 67	242 ± 60	404 + 75	302 ± 75
Locoweed head	-	-	162 ± 31	0	236 + 57	108 ± 34
TOTAL	1150 ± 73	734 ± 62	1608 ± 116	858 ± 71	1550 ± 136	1142 ± 105
Pasture size	1.1 ha		1.7 ha		1.7ha	
Grazing pressure ratio[a]	0.28	.044	.023	.043	.025	.032

[a]Grazing pressure ratio = (forage demand/day)/(forage supply/pasture), based on total standing crop. Trial 1 had 4 cows, and Trials 2 and 3 had 7 cows. Intake was assumed to be at 9 kgDM/cow/day.

included, and with the loco-eaters excluded from the data sets.

Results

Cattle consumed more white locoweed in Trial 2 (flower stage in May) than in the other trials (Table 2). The least amount of locoweed was consumed in Trial 3 (pod stage in June). There were differences among cows (Table 2) in each trial ($P < 0.01$). Cow 54 consumed more locoweed in all 3 trials than other cows. Cow 25 also consumed more locoweed than the remaining 5 cows in Trial 2. These 2 cows were classified as "loco-eaters". Locoweed consumption by the loco-eater and "normal" groups are illustrated in Figure 1 for the 3 grazing trials.

Trial 1, Vegetative Stage

Three of 4 cows rejected locoweed during the first half of the trial (Figure 1a). Cow 54 selected locoweed for about half of her diet throughout the trial. On days 7 and 8, the normal cows started eating locoweed as availability of cool-season grass decreased. The cows also increased consumption of dry, dormant warm-season grasses as availability of cool-season grasses decreased (Fig. 2a).

Trial 2, Flower Stage

The 2 loco-eaters preferred white locoweed at the beginning of the trial and consumed it for a majority of their diets throughout the trial (Fig. 1b). The normal cows rejected locoweed for the first 2 days of the trial but increased consumption of locoweed on days 3 to 5 as availability of cool-season grasses and forbs decreased. All the locoweed flowering heads had been grazed by day 6, indicating that they were the preferred plant part. All the locoweed plants had been grazed by day 8, and locoweed consumption declined thereafter (Fig. 1b). We observed that cattle preferred cool-season grasses that were actively growing at the beginning of the trial, but as their availability and subsequent consumption decreased, cattle switched to green locoweed and then to the dormant warm-season grasses (Fig. 2b).

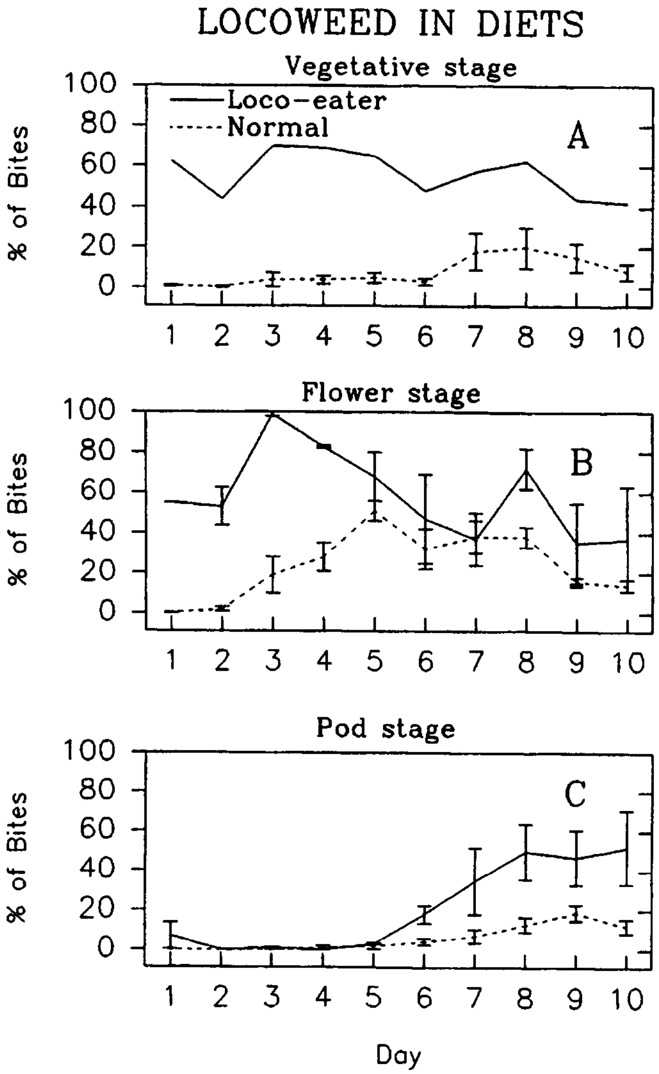

Fig 1. White locoweed in cattle diets: a) Trial 1, vegetative growth stage with one loco-eater and 3 normal cows; b) Trial 2, flower growth stage with 2 loco-eaters and 5 normal cows; and c) Trial 3, pod stage with same groups as Trial 2. Error bars are standard errors.

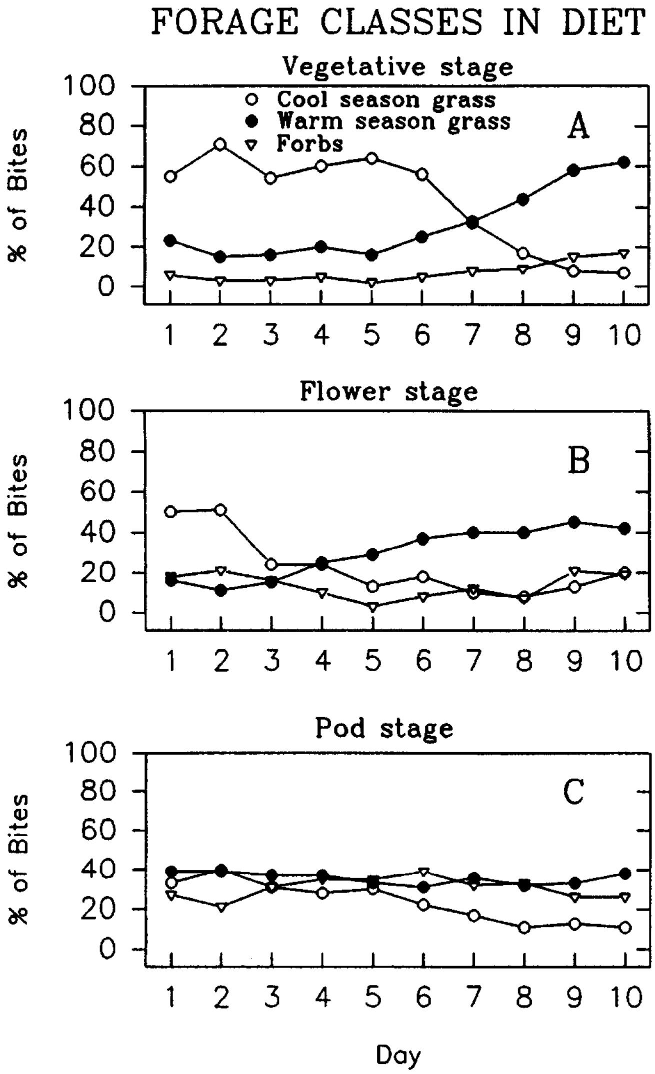

Fig 2. Forage classes in cattle diets: a) Trial 1, vegetative growth stage; b) Trial 2, flower growth stage; and c) Trial 3, pod stage.

Table 2. Percentage of bites of white locoweed in diets of individual cows during 3 grazing trials, and the overall mean for the 3 trials.

Cow	Trial 1 Vegetative	Trial 2 Flower	Trial 3 Pod	Mean
54	54a	69a	30a	51
25	-	50b	17b	32
78	-	29c	14bc	21
53	15b	31c	5bc	16
57	11b	27c	6bc	14
79	-	18c	4c	11
56	0c	16c	3c	6
Mean	20e	34d	10f	21

*Means of individual cows in the same column followed by different letters are significantly different $P \leq .05$).
**Means of trials in the same row followed by different letters are significantly different ($P \leq .05$).

Trial 3, Pod Stage

Locoweed was not consumed by any cows at the beginning of this trial (Fig. 1c). The cows started grazing locoweed on day 6 and increased consumption as the trial progressed. Loco-eaters consumed more locoweed than the rest of the group at the end of the trial. Locoweed leaves and pods were still abundant at the end of the trial, in contrast to the 2 previous trials (Table 1). Warm-season grasses were growing rapidly during this period, and cool-season grasses, warm-season grasses, and forbs were consumed equally (Fig. 2c).

Relationship Between Grazing Pressure and Locoweed Consumption

There was a weak association between grazing pressure and locoweed consumption when all 3 trials and all animals were analyzed together (Table 3). Grazing pressure differed among trials so each trial was analyzed separately. There were also differences among cows as described above, leading to the loco-eater and normal group designation.

In Trial 1 (vegetative stage), there was no relationship between grazing pressure and locoweed consumption when all cows were included in the analysis (Table 3). This resulted from 1 cow consuming locoweed for the majority of her diet throughout the trial. When this cow was removed from the analysis, there was a significant regression indicating a moderate relationship between grazing pressure and locoweed consumption by normal cows ($r^2 = 0.46$).

In Trial 2 (flower stage), there was no relationship between grazing pressure and locoweed consumption when all cows were included in the analysis, or when the loco-eaters were excluded. Locoweed dominated the 2 loco-eater diets at the beginning of the trial. The normal cows increased consumption as the trial progressed, but both groups decreased locoweed consumption during the last 2 days of the trial. All the flowers had been eaten and all of the locoweed plants had been grazed. Even though some locoweed leaves remained at the end of the trial (Table 1), locoweed had been grazed closely and cattle were searching for other feed. If the last 2 days (when locoweed availability was limited) are excluded from the analysis, there was a significant relationship between grazing pressure and locoweed consumption in the normal cows ($r^2 = 0.56$).

There was a strong relationship between grazing pressure and locoweed consumption in Trial 3 (pod stage) ($r^2 = 0.83$ to 0.88). Grazing pressure did not increase as much during this trial (Table 1) because rapid grass growth offset some of the forage consumption. Still, there was enough increase in grazing pressure to shift consumption patterns to white locoweed by the end of the trial.

Table 3. Relationship between grazing pressure and locoweed consumption

Trial	Animals	Coefficient of determination r^2	Probability P	Regression[1] equation
All	All	0.15	0.03	y = 2.3 + 651 x
Vegetative	All	0.04	0.55	y = 10 + 244 x
	Without loco-eaters	0.46	0.03	y = 0.22 + 853 x
Flower	All	0.004	0.85	y = 37 + 140 x
	Without loco-eaters	0.03	0.58	y = 8 + 487 x
	Without last 2 days	0.56	0.03	y = 58 + 264 x
Pod	All	0.88	0.0001	y = 0.95 + 3832 x
	Without loco-eaters	0.83	0.0003	y = -0.55 + 2205 x

[1]y = locoweed in the diets (% of bites), x = grazing pressure ratio.

Discussion and Recommendations

Two cows preferentially selected white locoweed at the beginning of the vegetative and flower grazing trials, while other forage was still abundant. Ralphs et al. (1993) verified the classification of loco-eaters and reported that loco-eaters consumed more white locoweed during April and May than non-eaters. Management options to prevent poisoning from preferred palatable poisonous plants are limited. Animals must be denied access to the plants either by controlling the plant, or removing the animal from the infested area. It is a common practice on locoweed ranges for ranchers to closely observe their cattle and remove those that start grazing locoweed.

The majority of the cows did not accept locoweed at the beginning of the grazing trials when other green forage was adequate. For these cows, white locoweed was apparently not palatable. As the 10-day trials progressed and other forage became limiting, normal cows increased consumption of white locoweed. There were significant regressions with moderate to strong relationships ($r^2 = 0.46$ to 0.88) between grazing pressure and locoweed consumption among these normal cows when availability of white locoweed was not limited.

An alternative explanation for increasing white locoweed consumption by normal cows as the trials progressed might have been their lack of immediate familiarity with white locoweed. The cows were kept in a locoweed-free pasture between grazing trials to prevent those that were eating it from becoming severely intoxicated. Since they did not have access to locoweed immediately before the trials, it may have taken them a few days to accept it. We discount this theory for 3 reasons. First, all the cows were familiar with white locoweed; they had all grazed on white locoweed-infested ranges much of their lives, and had either grazed locoweed in the previous study or had been observed grazing locoweed by the rancher. Second, the loco-eaters showed a distinct preference for white locoweed and began consuming it immediately, indicating that they required no adjustment period. Third, we also observed that the normal cows in the vegetative and flower trials preferred and sought out the green, growing cool-season grasses at the beginning of the trials. As availability of cool-season grasses decreased, the cows started to consume white locoweed. Therefore, we believe that increasing grazing pressure on the diminishing forage, especially on green grass, influenced the normal cows to increase consumption of white locoweed.

Other studies have also reported that grazing pressure influenced cattle to graze locoweed. Ralphs et al. (1993) reported that woolly locoweed (*Astragalus mollissimus* var *mollissimus* Torr.) was not initially accepted by cattle in the spring, but grazing pressure forced them to start consuming it. On high mountain summer rangelands where green grass was abundant, grazing pressure forced cattle to start consuming white locoweed in the flower stage (Ralphs 1987).

Based upon observations from this and other studies, it appears that diminishing forage availability and the accompanying increase in grazing pressure will influence normal cattle to graze locoweed. We suggest that light or moderate stocking rates would ensure adequate forage is available, especially green forage, which will decrease the risk of forcing cattle to graze locoweed.

All the cows in this experiment, even the loco-eaters, were reluctant to eat white locoweed at the beginning of the June grazing trial when green grass was abundant and rapidly growing. Ralphs et al. (1993) also reported that cattle ceased grazing both white and woolly locoweed in June when warm-season grasses began rapid growth. This agrees with other research that suggests that locweed is not addictive (Ralphs et al. 1990, 1991). Locoweed is generally not a problem during the summer because green grass is usually abundnat and relatively more palatable than locoweed. However, heavy stocky rates on locoweed-infested rangelands during the summer will increase grazing pressure and may influence cattle to eat locoweed and become poisoned.

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Storms influence cattle to graze larkspur: An observation

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Abstract

Livestock producers report cattle deaths from larkspur (*Delphinium* spp.) poisoning increase during stormy periods. In controlled grazing studies, we observed cattle increase larkspur consumption during stormy weather. Periods of "gluttonous" larkspur consumption generally coincided with storms during a 1990 grazing study. Cattle consumed larkspur almost exclusively for 20-30 min periods during storms, as opposed to intermittent grazing of larkspur flowers, pods, and leaves. In 1991, weather parameters were measured and correlated with larkspur consumption. Larkspur consumption was negatively correlated with decreasing temperature and barometric pressure (r = -0.45 and -0.60 respectively); and positively correlated with increasing relative humidity, leaf wetness, and precipitation (r = 0.45, 0.74, and 0.27, respectively). Understanding consumption patterns of cattle grazing larkspur will aid in developing management strategies to reduce cattle deaths.

Key Words: Weather, bioclimatic factors, cattle grazing, poisonous plants, tall larkspur (*Delphinium barbeyi* L. Huth).

There is a widespread belief among stockmen that cattle are poisoned by larkspur (*Delphinium* spp.) after rain or snow showers during late spring and summer. Several theories have been offered to explain this phenomena. Wilcox (1899), suggested that cattle pull up larkspur by the root when soils are wet and are poisoned by eating the root. This speculation lead to a widespread misconception that only larkspur roots poisoned livestock. Marsh and Clawson (1916) discounted this idea because larkspur stems readily break off at the crown, and it is highly unlikely that the deep tap root can be pulled up. They noted that cattle gather under trees for protection during storms, where larkspur is abundant, and perhaps eat more of it. Nielsen (personal observation) observed cattle running for shelter of conifer groves as high intensity thunderstorms descended. He speculated that if the cows were eating near lethal doses of larkspur, the extra physical exertion and stress on the respiratory system and skeletal muscle was enough to kill them.

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Cronin and Nielsen (1979) coined the term "gluttonous consumption" to describe the rapid and exclusive consumption of entire larkspur plants, as opposed to routine selection of flowers, pods, and leaves. We observed periods of gluttonous consumption coincided with cold rain showers in controlled grazing studies. Pfister et al. (1988a) reported cattle increased consumption of tall larkspur (*D. barbeyi* L. Huth) after the first 2 rain showers following a prolonged dry period. Pfister et al. (1988b) and Lane et al. (1990) also reported unusual feeding behavior for 15-20 min periods following cold rain showers. Cattle were playful, throwing their tails in the air, running from 1 larkspur plant to another, rapidly consuming larkspur, and occasionally eating the plants down to the ground. Ralphs and Olsen (1992a) reported that waxy larkspur (*D. glaucescens* Wats.) consumption peaked following rain and snow storms in Montana.

The objective of this study was to identify and describe periods of gluttonous larkspur consumption and correlate larkspur consumption to various weather components associated with storms.

Methods

Grazing Trial, 1990

Ralphs and Olsen (1992b) reported tall larkspur in cattle diets peaked during summer thunderstorms on the Wasatch Plateau in central Utah in 1990. A retrospective examination was made of these data to describe periods of gluttonous consumption and their relation to storms.

The study was conducted on the 6-Mile Forest Service Allotment on the Wasatch Plateau, 24 km east of Manti, Ut. The site was in the subalpine vegetation zone (3,050 m elevation). Groves of Engleman spruce (*Picea engelmanii* Parry ex Engelm.) dotted the area, and current (*Ribes montigenum* McClatchie) thickets and elderberry (*Sambucus racemosa* L.) patches were abundant. Tall larkspur dominated the tall forb plant community on snowdrift sites. Mountain brome (*Bromus carinatus* Hook. & Arn.), slender wheatgrass (*Agropyron trachycaulum* (Link) Malte), and daisy (*Erigeron* spp.) dominated the open areas.

Three, 1.5-ha pastures were fenced with temporary electric fence. Twelve 1-year-old Hereford heifers (230 ± 26 kg) were initially divided into 3 groups and grazed separately for 6 days, then the partition fences were removed and they grazed together for 8 days. The study was designed to determine if cattle averted to larkspur would retain the aversion while grazing separately and then when grazing with control heifers that were eating larkspur. Cattle were observed each day during the major morning, midday and evening grazing periods and diets were quantified by scan sample (Lehner 1987). A scan of all animals was made at 2-min intervals and the plant each animal was eating was recorded. This procedure estimated the proportion of time each animal spent grazing larkspur.

Mean daily larkspur consumption was reported by Ralphs and Olsen (1992b). However, events of "gluttonous consumption" were not described in that paper. We define gluttonous consumption as short periods (20-30 min) of almost exclusive larkspur consumption involving all animals compared to incidental or infrequent bites of larkspur intermingled with other forage.

The intermittent recording of 2 min scan samples did not accurately describe the dynamic character of these continuous events. Therefore, we have supplemented the data with a narrative of the events as we observed the cattle.

Grazing Trial, 1991

A grazing study was conducted in 1991 to determine the influence of weather components on larkspur consumption. The study was conducted at the same location using the same protocol as the 1990 study. However, pasture size was increased to 5 ha and four 2-year-old Hereford X Angus heifers grazed the area from 16 August to 12 September. Larkspur was in the flower stage at the beginning of the study, and matured to the pod stage during the study.

A weather station[1] was assembled on site to record: ambient air temperature, relative humidity, precipitation (20 min, 2 hour, and daily accumulation), leaf wetness (percent of time leaves were wet from rain or dew), wind speed and direction, wind gust, barometric pressure and 3-hour change in pressure, and solar radiation. The data were recorded at 10 min intervals. The mean values of the weather components were calculated for the respective grazing periods and used in the analysis. There were 74 grazing periods during the 28-day study. However, the power supply to the weather station failed from 24 to 26 August, and from 29 August to 5 September. A backup system comprised of a wind-up mini-barograph, hygrothermograph and a standard rain bucket measured barometric pressure, relative humidity, temperature, and precipitation. These data replaced the missing data from the weather station for these weather components on these dates.

The proportion of time cattle spent grazing larkspur was correlated with the mean value of each weather component during the corresponding grazing period using the Pearson product-moment correlation (SAS 1985). Correlations were also calculated between the mean daily larkspur consumption and the average daytime values of the weather components.

Results

1990 Grazing Trial

Mean daily larkspur consumption during the 1990 grazing study ranged between 2 and 17% (Fig 1). However, 4 periods of gluttonous consumption occurred during stormy periods. These events generally lasted only 20 to 30 min. The first event (24 August) was associated with a rapidly moving cold front. Although no rain fell, there was a distinct drop in temperature, high gusty winds, and a dense cloud cover. At this time, the heifers were divided into 3 separate pastures and only the control group exhibited gluttonous larkspur consumption. One heifer started eating larkspur pods; 2 others appeared to observe and followed suit. Later, the fourth heifer joined in. They consumed larkspur pods exclusively for about 20 minutes, then went back to eating grass and other forbs.

A mid-afternoon thunderstorm occurred on 29 August when all 12

[1]OmniData Easylogger 800 recorder and monitoring equipment.

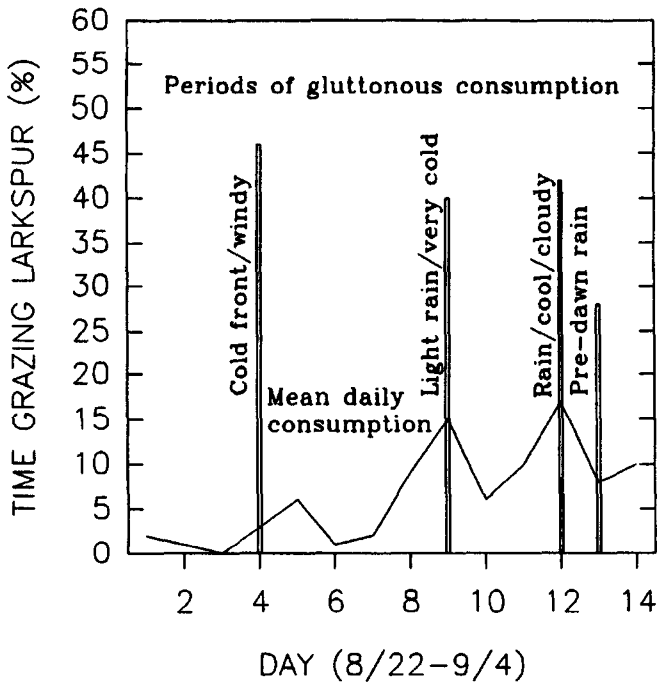

Fig. 1. Mean daily larkspur consumption (% of grazing time), periods of gluttonous larkspur consumption, and corresponding weather events during the 1990 grazing study.

Table 1. Weather components and their correlation with the proportion of time cattle grazed larkspur.

		Grazing periods[1]/		Mean for day[2]/	
		r	*P*	*r*	*P*
Relative Humidity	%	0.27	0.01	0.45	0.01
Precipitation	cm				
2 hour accumulation		0.04	0.86		
24 hour accumulation				0.27	0.16
Leaf wetness	% of time	0.55	0.003	0.74	0.006
Wind speed	m/sec	0.05	0.78	-0.16	0.60
Wind gust		0.11	0.58	-0.15	0.64
Temperature	C	-0.38	0.0009	-0.52	0.004
Barometric pressure	mm mercury	-0.36	0.001	-0.60	0.0007
3 hour change in pressure		-0.04	0.86		
Solar radiation	watts/m²	-0.21	0.31	-0.34	0.27

[1]Correlation between larkspur consumption and the respective weather component during three major grazing periods each day.
[2]Correlation between the mean daily larkspur consumption and the average daytime value of the respective weather components.

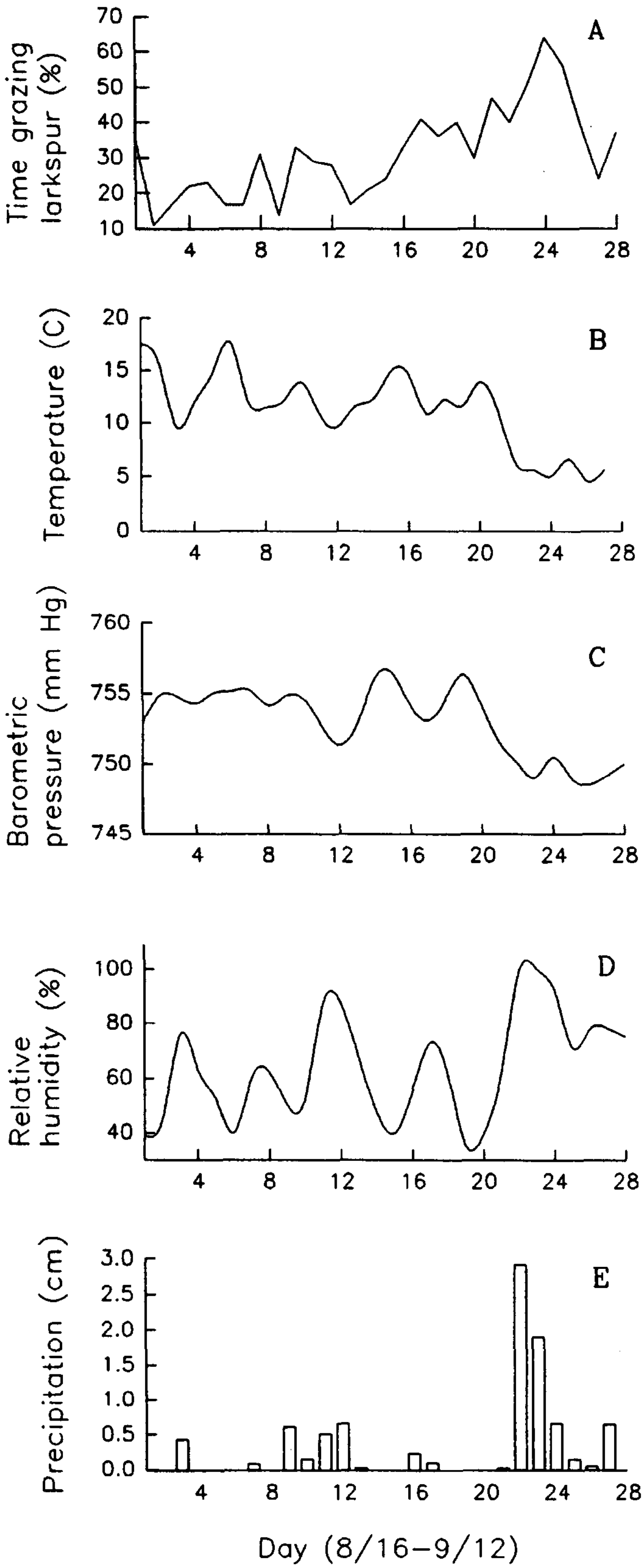

Fig. 2. a) Mean daily larkspur consumption by cattle (% of grazing time) during the 1991 grazing study, b) mean daily barometric pressure (mm mercury), c) average daytime temperature (C), d) mean relative humidity (%), e) and daily precipitation (cm).

heifers were grazing together. Following the storm, while it was still misty, 3 heifers began consuming larkspur. Four others observed, then also joined in. A few minutes later, 2 more started, and by the end of 30 min, all but 1 heifer was eating larkspur.

A heavy thunderstorm occurred during the afternoon of 1 September. It was cold and cloudy during the evening grazing period and all heifers consumed large quantities of larkspur. The following day, 1 heifer showed initial signs of larkspur poisoning and she left the group and laid down in a grove of trees for the entire day. However, she resumed normal feeding the next day.

The morning of 2 September was cold and cloudy and a heavy dew remained on the plants from the previous nights rain. All 12 heifers consumed large amounts of larkspur during this period and ate it exclusively for a 5-min period.

Correlation of Diets with Weather Components

Larkspur consumption ranged from 10 to 60% of grazing time in the 1991 grazing study (Fig. 2a). Correlations between larkspur consumption and the mean daytime values of the weather components were higher than for correlations with weather components during individual grazing periods during the day (Table 1). Mean daily larkspur consumption was negatively correlated with the average day time temperature and barometric pressure (r= -0.52 and -0.60 respectively), and positively correlated with relative humidity, leaf wetness, and 24 hour precipitation (r= 0.45, 0.74 and 0.27, respectively). Temperature (Fig. 2b) and barometric pressure (Fig. 2c) declined during stormy periods, while relative humidity (Fig. 2d) and precipitation (Fig. 2e) increased.

Discussion

Results from these 2 studies, and observations from other grazing studies (Pfister et al. 1988 ab, Lane et al. 1990, Ralphs and Olsen 1992 ab) suggest that cattle increase larkspur consumption during or following storms. This accounts for the reported increase in cattle deaths following storms (Wilcox 1899, Glover 1906, Marsh and Clawson 1916).

The toxic dose of larkspur is determined by the level of the toxic alkaloid methyllycoconitine (MLA) in the larkspur plant and the rate at which cows consume the plant. Weather may affect both animal and plant factors associated with poisoning.

The literature suggests weather can alter livestock grazing behavior by influencing the length and time of feeding periods. Cattle increase feed intake in feedlots as barometric pressure falls preceding storms (L.F. James, personal observation). Livestock reduce grazing time in response to extreme heat or cold (Arnold and Dudzinski 1978). Cattle are more restless, graze less intensely, and travel more in cloudy or stormy weather (Culley 1938). Weather variables associated with storms (temperature, relative humidity, and barometric pressure) decreased feed intake by sheep and accounted for 2 to 20% of variability in intake (Wohlt et al. 1988). Each storm develops its own special shifts in wind direction and velocity. It is preceded and followed by an individualized pattern of changes in barometric pressure, temperature, and humidity. Atmospheric electricity is associated with some, but not all storms. The composition of the air itself may change, becoming either more or less ionized as the storm passes which may influence disposition or mood changes (Richardson et al. 1968, Rosenberg et al. 1983, Tromp 1980). All of these factors, their intensity, and order in which they change, affect the degree of an individual animal's reaction to a storm.

Weather has a major influence on the internal chemistry and toxicity of plants. Frost increases hydrogen cyanide levels in arrowgrass, chokecherry, and sorghum, and tannin content in oak leaves (Kingsbury 1964). Several plant species increase toxin levels following rain, due to increased metabolic activity: nitro toxins increase in columbia milkvetch following rains (Majak et al. 1976), and grass tetany occurs during cool, stormy weather due to the imbalance of magnesium in cool season grasses (Robinson et al. 1989). On the other hand, cloud cover reduced quinolizidine alkaloid levels in *Lupinus albus* L. in the diurnal cycle of alkaloid synthesis (Wink and Witte 1984). Alkaloids in other plants increase during periods of cool cloudy weather and during mild water stress, when photosynthesis decreases and nutrients are shunted to defense chemicals (Bryant et al. 1983, Gershenzon 1984). Larkpsur alkaloid levels vary tremdously (Manners et al. 1993). The toxic alkaloid MLA is highest in early growth, declines as the plant matures, but increases slightly in the pods (Pfister et al. 1994). Larkspur consumption by both cattle and sheep increases as the plant matures, suggesting a negative relationship between alkaloid levels and palatability (Ralphs et al. 1988). We are currently conducting research to determine how toxic alkaloid levels respond to stormy weather.

Based on the results from this study, our observations, and the literature, we hypothesize that weather components affect the internal chemistry of the larkspur plant making it more palatable. The weather components may reduce the level of total alkaloids, making the plant les objectionable. The chilling effect may alter carbohydrate metabolism and increase the sugar levels in the leaves, thus making the plant more palatable. They may alter some chemical that makes the plant attractive. Or the combination of alkaloids may combine for a unique taste which the cattle are seeking (see Molyneux and Ralphs 1992). The rain may also wash off the bitter-tasking wax that builds up on the leaves. These plant factors can be evaluated chemically and tested for their influence on palatability in controlled feeding and grazing trials.

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Defoliation of a northern wheatgrass community: Above- and belowground phytomass productivity

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Abstract

A defoliation study was conducted on a fair condition, clayey range site that is potentially dominated by northern wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn.) in south-central Saskatchewan. Vegetation was subjected to a factorial experiment with an initial defoliation in early-May, June, July, or August and repeated at 2- or 6-week intervals until mid-September in the same plots for 3 years. An undefoliated control was also included. Herbage removed, residual live, dead, total, and root phytomass were measured. Defoliation reduced all yield components, with the exception of herbage removed. Residual live grass was reduced 37, 57, and 46%, respectively, in first, second, and third years; the sedge and forb components of live residual phytomass generally were not affected by defoliation. Compared to control, dead phytomass was reduced 77% in the first year, 67% in the second, and 52% in the third year across treatments. Total herbage yield across defoliation treatments ranged from 68 to 83% of control. Total live phytomass (herbage removed + residual live phytomass) in defoliated plots equaled control. Herbage removal was greatest when initially defoliated in early July and thereafter at 2-week intervals. When defoliated at 6-week intervals residual live and dead phytomass were generally greater than when herbage was removed biweekly. Yields were higher when the first defoliation was delayed and repeated at 6-week intervals. Generally, root phytomass was not different among defoliation treatments, but total belowground phytomass was reduced 30% in the 0-30-cm depth after 3 years of defoliation. This northern mixed prairie ecosystem is sensitive to herbage removal. Maximum forage yield can be obtained if grazing is deferred until after peak growth in July.

Keywords: *Agropyron dasystachyum* (Hook.) Scribn., grazing, litter, mixed prairie, regrowth, roots, yield

Time and intervals of defoliation interact in complex ways on production processes and herbage yield in rangeland ecosystems. Most cool-season bunchgrasses are susceptible to clipping in late spring or during the boot-stage, whereas clipping before internode elongation may be less detrimental (Wilson et al. 1966, Ganskopp 1988). Fescue grassland is best maintained if grazed in late summer or while dormant (Willms 1991, Willms and Fraser 1992).

Frequent defoliation often reduces herbage yield (Reed and Dwyer 1971, Buwai and Trlica 1977), decreases root growth (Crider 1955) and penetration (Svejcar and Christiansen 1987), and alters root-shoot ratios (Richards 1984). When tall wheatgrass (*Agropyron elongatum* (Host) Beauv.) was defoliated every 4 weeks, it produced more herbage than if defoliated at 1 or 2-week intervals (Undersander and Naylor 1987). After grazing or clipping, the amount of dead phytomass also is often severely reduced (Coupland et al. 1973, Sims et al. 1978).

Yield following clipping also varies substantially from year-to-year (Svejcar and Rittenhouse 1982, Willms 1991) because of variation in climate. Therefore, the influences of grazing on phytomass production often may be masked by the effects of climate (Hart and Samuel 1985, Archer and Smeins 1991).

Northern wheatgrass or thickspike wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn.) is dominant in parts of the mixed prairie on the northern Great Plains in Canada (Coupland 1950). In southern Saskatchewan its dominance is best expressed on range sites with loam to clayey soils. Despite the abundance of this rhizomatous perennial, little information is available on the influence of defoliation on above- and below-ground phytomass production and distribution in the aboveground compartment. Therefore, the objectives of this study were to determine: 1) the effects of 4 initial defoliation dates and 2 intervals on the total amount of herbage removed, residual live phytomass, and dead phytomass; 2) relationships among these yield components; and 3) below-ground phytomass.

Materials and Methods

Study Site Description

Research was conducted at the Matador Research Station of the University of Saskatchewan, approximately 70 km north of Swift Current (50°42'N, 107°43'W, elev. 685 m). The area is located within a glacial lake plain near the northern edge of the mixed prairie (Coupland 1950). Soils are Rego Brown and Calcareous Brown Series in the Sceptre Association of the Chernozemic Brown Subground (Aridic Borolls) (Coupland et al. 1974). The study area is a clayey range site (Abouguendia 1990) with northern wheatgrass and western wheatgrass (*A. smithii* Rydb.) potentially producing about 75% of the total phytomass (Coupland et al. 1974). Junegrass (*Koeleria cristata* Pers.), green needlegrass (*Stipa viridula* Trin.) and low sedge (*Carex eleocharis* Bailey) are common while fringed sage (*Artemisia frigida* Willd.) is the most common non-graminoid. About 15 species of forbs are found frequently in the study area, but their distribution and abundance are variable (Coupland et al. 1973). The experiment was conducted from 1988 to 1990 in a pasture that had been heavily grazed during prior summers; range was estimated in fair condition in 1986 and 1987 (J.T. Romo pers. obs.).

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Table 1. Yield response of aboveground phytomass components (g m⁻²) as related to initial times and intervals of defoliationin 1988. Averages across defoliation treatments were compared to control.

	Defoliation treatments									Contrast	
	Initial defoliation (D)										
	May		Jun.		Jul.		Aug.		LSD[1]	Defoliation vs. Control[2]	
	Defoliation interval (I)										
Phytomass Category	2-wk	6-wk	2-wk	6-wk	2-wk	6-wk	2-wk	6-wk			
	-g m⁻²-										
Herbage removed	—[3]	—	—	—	—	—	—	—		—	—
Residual livec											
Grasses	4.5	9.3	6.9	8.5	7.6	6.0	7.6	9.9	1.7(DxI)	7.5	11.9***
Others	5.1	7.2	8.9	6.2	12.2	7.8	11.6	11.7	3.3(D)	8.8	16.7***
Total	9.6	16.5	15.9	14.7	19.8	13.8	19.1	21.6	5.1(DxI)	16.4	28.6**
Dead Phytomass	19.7	22.1	15.6	23.0	22.8	23.6	31.1	27.0	4.3(D)	23.1	29.9**
Total Herbage Yield	29.4	38.6	31.4	37.7	42.6	37.4	50.2	48.6	6.7(D)	39.5	58.4***

[1]Least significance difference among defoliation treatments at $P \leq 0.05$, letters in parentheses following LSD values indicates an effect. D indicates the effect of initial defoliation, I the effect of defoliation interval, and DxI the interaction effect.
[2]Average across defoliation treatments in contrast to control, *$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$.
[3]No data were collected.

Annual precipitation data were obtained from Beechy (50°46'N, 107°19'W, elev. 670 m) approximately 40 km northeast of the study site. In 1988 precipitation was only 70% of the 50-year mean of 373 mm, while in 1989 and1990 it was 106% and 113% of the long-term average.

Experimental Design and Sampling Methods

A 50 x 50 m exclosure was established and 8 clipping treatments with 4 initiation dates and 2 intervals, and an undefoliated control were replicated 4 times in a randomized-complete-block design. Plots were 5 x 6 m with a 1-m buffer maintained on all sides. Plots were defoliated by mowing to a 5-cm stubble with a Jari sickle mower and all harvested plant material was collected. After plots were initially defoliated in early May, June, July, or August, they were defoliated again at 2- or 6-week intervals until mid-September of each year. Treatments were repeated on the same plots each year.

Aboveground Phytomass

Plant materials collected at each defoliation were summed through the season to estimate total herbage removal. In 1988, an extremely dry growing season, plants were usually less than 5 cm tall and no plant material was collected at most defoliation events. Therefore, data for total herbage removed in 1988 are not presented. Plant material, collected in 1989 and 1990, was separated into grasses, fringed sage, and forbs. Low sedge was generally shorter than the 5 cm defoliation height, thus it escaped defoliation and was not collected. Two 0.25 m² quadrants were clipped in each plot at ground level in mid-September each year to determine residual phytomass. The live residual phytomass in 1989 and 1990 was divided into grasses, low sedge, fringed sage, and forbs. Dead residual phytomass was not separated into species groups, and ground litter was not collected. Total herbage yield is the summation of total herbage removed, live residual, and dead phytomass. All samples were oven-dried at 80°C for at least 48 hours immediately after harvest and weighed.

Belowground Phytomass

On 26 September 1989 and 1990, a soil corer (8-cm diameter x 15 cm long) was used to remove a core of underground plant phytomass for the 0-15 and 15-30 cm soil depths in each plot. Shoots and dead material were removed from the surface of the cores, and the underground plant material was separated from the soil by soaking each core in water for at least 12 hours. These samples were hand washed over a soil screen and sieved through a 32-mesh screen. The phytomass in the 0-15 cm cores was further separated into crowns and rhizomes of northern wheatgrass and low sedge, and a fine root fraction in which species could not be identified. Samples were oven dried at 80°C for 48 hours and weighed.

Data Analysis

The effects of defoliation regimes on aboveground and root phytomass were compared to control by linear contrasts with the SAS general linear model procedure (SAS 1985). The effects of time of the initial defoliation and defoliation interval were analyzed with a factorial analysis of variance. Where significant effects were detected ($P \leq 0.05$), Least Significant Difference (LSD) was used to separate treatment means (Snedecor and Cochran 1980). Root phytomass in each depth was within samples. Regression analysis was used to examine relationships among yield components in 1989 and 1990 (Snedecor and Cochran 1980).

Results

Defoliation Effects on Aboveground Productivity 1988

Defoliation reduced all yield components compared to control in 1988 (Table 1). At the end of the growing season, residual grass phytomass across defoliation treatments averaged 63% of control, dead phytomass was 77%, and total yield averaged 68% of the check. The interaction of dates of initial defoliation intervals affected residual grass and total live residual phytomass. When defoliated at 6-week intervals, residual phytomass of grasses was generally greater than when defoliated every 2 weeks, except when first defoliated in early July and biweekly thereafter. When herbage was removed biweekly, residual grass phytomass was greater when initially defoliated after May. With the 6-week interval residual grass phytomass was greater when first defoliated in May or August. Delaying the initial defoliation generally led to greater residual phytomass in other species, dead phytomass, and total herbage yield, with productivity greatest when first defoliated in August.

Table 2. Yield response of aboveground phytomass components (g m⁻²) as related to initial time and intervals of defoliationin 1989. Averages across defoliation treatments were compared to control.

	Defoliation treatments								Contrast		
	Initial defoliation (D)										
	May		Jun.		Jul.		Aug.		LSD[1]	Defoliation vs. Control[2]	
	Defoliation interval (I)										
Phytomass Category	2-wk	6-wk	2-wk	6-wk	2-wk	6-wk	2-wk	6-wk			
	----- g m⁻² -----										
Herbage removed											
Grasses	13.0	21.1	17.1	14.4	24.2	18.5	17.1	22.5	5.0(DxI)	18.5	0***
Fringed sage	2.4	3.6	1.8	7.6	6.3	6.0	8.5	8.2	2.5(I)	5.6	0**
Forbs	1.8	4.0	2.5	3.6	4.6	4.5	3.3	3.5	--	3.5	0***
Total	17.2	28.7	21.4	25.6	35.1	29.1	28.9	34.2	7.3(D)	27.5	0***
Residual live											
Grasses	15.9	23.9	17.8	21.1	18.9	18.3	17.0	23.4	3.5(I)	19.6	45.9**
Low sedge	7.6	8.1	5.3	6.7	5.8	7.2	4.7	4.9	--	6.3	7.3
Fringed sage	2.1	5.4	4.1	3.9	4.6	6.9	6.5	3.6	--	4.6	7.9
Forbs	2.0	7.5	4.4	4.4	3.4	5.0	5.1	4.8	--	4.6	6.7
Total	27.6	44.9	31.7	36.1	32.8	37.5	33.3	36.7	4.4(I)	35.1	67.8***
Dead Phytomass	24.0	32.3	24.5	29.5	25.7	26.0	25.8	30.8	3.7(I)	27.4	40.6***
Total Herbage Yield	68.8	106.0	77.6	91.2	93.5	92.6	88.0	101.7	17.4 (DxI)	90.5	108.4*

[1] Least significance difference among defoliation treatments at $P \leq 0.05$, letters in parentheses following LSD values indicates an effect. D indicates the effect of initial defoliation, I the effect of defoliation interval, and DxI the interaction effect, and indicates no effect.
[2] Average across defoliation treatments in contrast to control, $*P \leq 0.05$, $**P \leq 0.01$, $***P \leq 0.001$

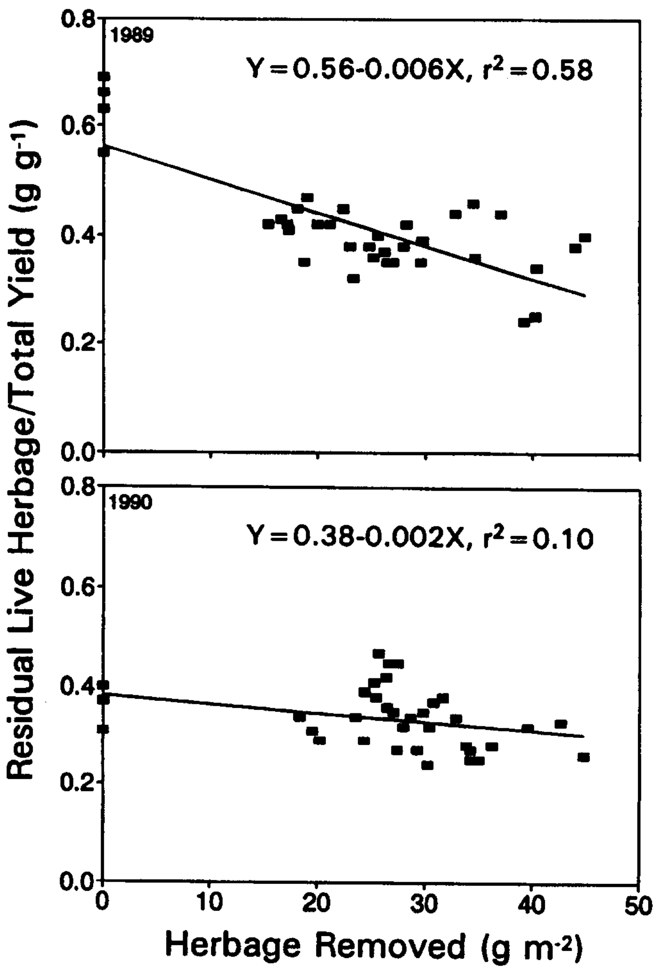

Fig. 1. Relationship between the fraction of residual live phytomass and total herbage removed in 1989 and 1990.

1989

Grasses accounted for 68% of the total herbage removed across defoliation treatments with the most removed when initially defoliated in July and then every 2 weeks (Table 2). More fringed sage was removed by defoliation every 6 weeks than at 2-week intervals. Total herbage removed was greatest when defoliation was begun in July or August. At the end of the 1989 growing season, the residual grass phytomass in the defoliation treatments was on average 43% of control. The residual phytomass of all species was reduced 48% compared to control. Relative to control, dead phytomass and total herbage yield across defoliation treatments were reduced an average of 33 and 17%, respectively. Residual phytomass of low sedge, fringed sage, or forbs were not significantly different among defoliation treatments at the end of growing season. Generally when harvested at 6-week intervals the residual grass, total, and dead phytomass were greater than under the biweekly defoliation. With the exception of the initial defoliation in July, total herbage yield was greater with rest periods of 6 weeks between defoliation than with 2 weeks rest.

1990

The grass phytomass removed by defoliation in 1990 also followed the same pattern as in 1989. When first defoliated in July, the most fringed sage and forbs were removed. Total herbage removal was greatest when defoliated in July and then every 2 weeks (Table 3). Compared to control the same pattern of defoliation effects expressed in 1989 were also observed in 1990 with reductions of 47, 31, 48, and 25%, respectively, in residual grass, total residual, dead phytomass, and total herbage yield. Residual phytomass of grasses was affected by the interaction of dates of initial defoliation and intervals and was greatest when defoliated in May or August and then every 6-weeks. However, when first defoliated in June or July, residual grass phytomass was similar between 2- and 6-week intervals. Dead phytomass and total herbage yield were greater when defoliated at 6-week intervals compared to biweekly.

Table 3. Yield response of aboveground phytomass components ($g\ m^{-2}$) as related to initial times and intervals of defoliation in 1990. Averages across defoliation treatments were compared to control.

	Defoliation treatments									Contrast	
			Initial defoliation (D)								
	May		Jun.		Jul.		Aug.		LSD[1]	Defoliation vs. Control[2]	
			Defoliation interval (I)								
Phytomas Category	2-wk	6-wk	2-wk	6-wk	2-wk	6-wk	2-wk	6-wk			
	$g\ m^{-2}$										
Herbage removed											
Grasses	22.6	30.5	23.6	24.9	33.4	23.7	21.6	23.6	4.8(DxI)	25.5	0***
Fringed sage	2.0	2.3	1.8	2.0	3.5	3.2	2.2	2.3	1.0(D)	2.4	0**
Forbs	0.8	1.3	1.2	1.5	2.3	2.2	1.4	1.4	1.0(D)	1.5	0**
Total	25.4	34.1	26.6	28.4	39.2	29.1	25.2	27.3	5.9(DxI)	29.4	0***
Residual live											
Grasses	18.2	28.2	17.4	19.5	18.8	19.1	19.6	24.4	4.8(DxI)	20.7	38.8***
Low sedge	6.1	2.1	4.8	3.5	5.7	5.1	3.4	5.2	—	4.5	2.5
Fringed sage	22.0	15.4	16.4	17.7	9.2	8.1	10.5	8.3	—	13.4	14.5
Forbs	2.6	2.8	4.1	8.3	7.1	5.0	4.7	4.2	—	4.8	7.3
Total	48.9	48.5	42.6	49.0	40.7	37.2	38.2	42.0	—	43.4	63.1***
Dead Phytomass	47.9	64.0	43.3	61.6	53.7	61.7	60.6	63.8	6.9(I)	57.1	109.5***
Total Herbage Yield	122.2	146.5	112.5	138.8	133.6	128.0	124.0	133.1	9.8(I)	129.9	172.6***

[1] Least significance difference among defoliation treatments at *$P \leq 0.05$, letter in the parentheses following LSD values indicates an effect. D indicates the effect of initial defoliation, I the effect of defoliation interval, DxI the interaction effect, and indicates no effect.
[2] Average across defoliation treatments in contrast to control, *$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$.

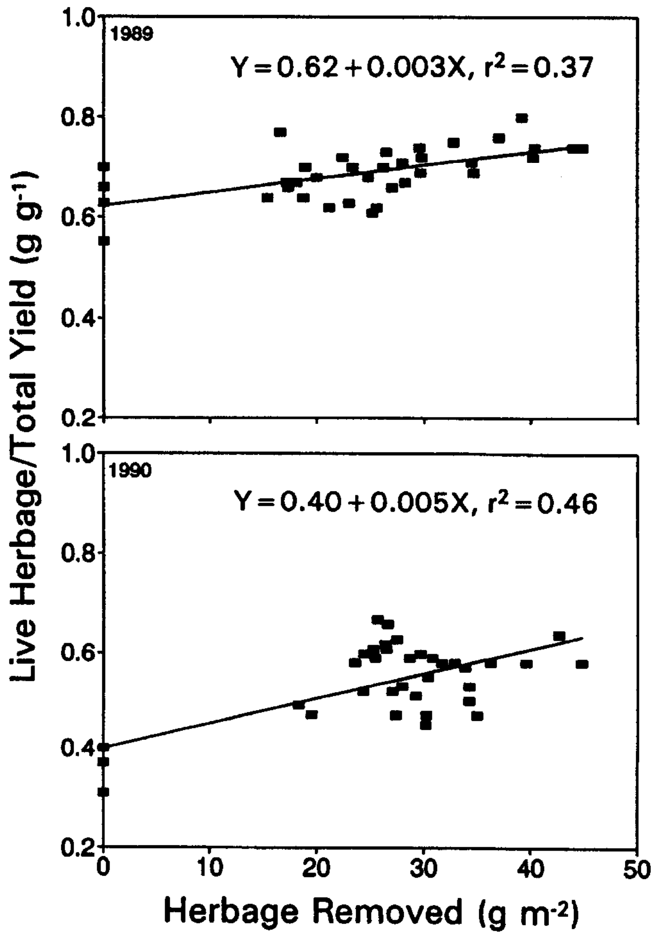

Fig. 2. Relationship between the proportion of live herbage in total yield and total herbage removed in 1989 and 1990.

Relationships Among Aboveground Phytomass Components

As herbage was removed, the proportion of live plant tissue remaining in the canopy declined (Fig. 1). When harvested phytomass was added to residual phytomass, the total live phytomass across defoliation treatments was similar to control in 1989 and 1990. Therefore, the proportion of live plant material in the total yield was greater with clipping than in the control in both years. As more phytomass was removed, the proportion of live material in the total yield also increased (Fig. 2). Dead phytomass did not decrease as the absolute amount of phytomass removed by defoliation increased, and greater tissue removal was not directy responsible for the net loss of dead phytomass in 1989 (r^2=0.02, P=0.39) and 1990 (r^2=0.02, P=0.48).

Defoliation Effects on Belowground Phytomass

Although a trend of reduced belowground phytomass relative to the control was apparent in every category at both depths in 1989, these differences were not significant (Table 4). The frequency and initial timing of defoliation interactively affected crown phytomass of northern wheatgrass, with crowns being heavier when herbage was removed every 6 weeks compared to 2 weeks, except when first defoliated in August. Rhizome weights of northern wheatgrass were greater when defoliated at 6-week intervals than biweekly.

In 1990, all phytomass categories except the crown and rhizome weights of low sedge were severely reduced by defoliation (Table 4). Crown and rhizome weights for northern wheatgrass were reduced 42 and 55% by defoliation, respectively. Weights of fine roots were reduced 24% in the 0-15 cm and 48% in the 15-30 cm depths compared to control. The total mass of roots and rhizomes in 0-30 cm depth was reduced 31% by defoliation. The date of the initial defoliation interacted with the interval of defoliation for low sedge rhizomes, with rhizomes heavier with the 6-week interval than the 2-week interval in July and August. Rhizomes were heavier when plants were initially defoliated in May or June and then biweekly than every 6 weeks.

Table 4. Weights (g m^{-2}) of crowns and rhizomes of northern wheatgrass and low sedge, the fine root fraction, and total mass in the 0-15 cm and 15-30 cm depths of the soil profile in late September 1989 and 1990. Average across clipping treatments were compared to control.

	Defoliation treatments									Contrast	
	Initial defoliation (D)										
	May		Jun.		Jul.		Aug.		LSD[1]	Clipping vs. Control	
	Defoliation interval (I)										
Phytomas Category	2-wk	6-wk	2-wk	6-wk	2-wk	6-wk	2-wk	6-wk			
	g m^{-2}										
1989											
Wheatgrass crowns	49	73	53	146	82	84	89	68	51 (DxI)	81	123
Wheatgrass rhizomes	5	13	9	13	7	10	13	16	9 (I)	11	15
Low sedge crowns	144	82	118	109	128	115	122	97	—	114	135
Low sedge rhizomes	74	28	43	44	40	68	43	29	—	46	56
Fine roots in 0-15cm	1,388	1,215	1,234	1,693	1,651	1,658	1,702	1,412	—	1,494	1,605
Total mass in 0-15cm	166	1,413	1,459	2,006	1,919	1,938	1,917	1,624	—	1,748	1,936
Fine roots in 15-30cm	438	348	408	468	313	526	396	453	—	419	420
Total mass in 0-30cm	2,100	1,762	1,867	2,475	2,223	2,465	2,367	2,078	—	2,167	2,357
1990											
Wheatgrass crowns	68	93	51	51	71	81	71	68	—	69	119**
Wheatgrass rhizomes	14	10	9	4	27	12	21	25	—	15	34**
Low sedge crowns	144	75	109	43	109	105	132	148	—	104	142
Low sedge rhizomes	57	53	46	37	35	48	36	74	24 (DxI)	48	65
Fine roots in 0-15cm	1,024	1,114	771	786	964	857	1,078	914	—	939	1,235*
Total mass in 0-15cm	1,278	1,346	987	922	1,209	1,105	1,340	1,231	—	1,177	1,597*
Fine roots in 15-30cm	242	235	226	229	254	205	292	258	—	243	464**
Total mass in 0-30cm	1,520	1,582	1,213	1,152	1,463	1,310	1,633	1,490	—	1,420	2,061**

[1] Least singificance difference among clipping treatments. at P≤0.05. Letters in parentheses following LSD values indicates an effect. D indicates the effect of initial harvest, I the effect of harvest interval, DxI the interaction effect, and indicates no significant difference between treatments.
[2] Average across clipping treatments in contrast to control, *P≤0.05 **P≤0.01, ***P≤0.001.

Discussion

Most defoliation studies are conducted on plants that have received prolonged rest periods or on rangeland that is in excellent condition. Results of these studies provide information on how vigor of plants declines with herbage removal. However, because less than 25% of the rangeland in southern Saskatchewan is in good to excellent condition (Romo, unpub. data), we chose to examine responses of vegetation that had been heavily grazed and were representative of the condition of large tracts of rangeland. By conducting studies on deteriorated range, beneficial effects of defoliation regimes might reflect growth and productivity of plants that should indicate how previously grazed vegetation responds to altered grazing management.

Repeated defoliation reduced the total herbage phytomass compared to control as shown elsewhere (Reed and Dwyer 1971, Buwai and Trlica 1977). The effects of the initial timing and frequency of defoliation influenced yield components within years, but these impacts were not consistent between years. As a result conclusive statements cannot be made regarding the influences of initial timing and frequency of defoliation on relative responses of yield components in this northern mixed prairie ecosystem. These variable responses are attributed to differences in environmental conditions between years, the cumulative effects of defoliation in preceding years, or both.

When total herbage removed and residual phytomass components were combined, the total yield of live plant material was similar to control in 1989 and 1990. Thus, the discrepancies in total herbage phytomass between control and defoliation treatments can be attributed to variances in dead phytomass. Increased removal of tissue was not directly responsible for the net loss of dead phytomass in 1989 and 1990. These differences may have been caused by reduced senescence and transfer of leaves to the dead phytomass following defoliation (McNaughton 1979, Caldwell et al. 1981, Li and Redmann 1992) and modification of the microenvironment which increased decomposition of dead plant materials (Naeth et al. 1990). As a consequence, the proportion of total live phytomass in the total yield was greater with increased herbage removal.

The greatest amount of grass was removed when first defoliated in early July and every 2 weeks. Because these grasses are C_3 species, they usually produce maximum growth by July. Harvesting in July removes the maximum amount of phytomass before it is transferred to the dead phytomass and litter compartments. However, annual removal of peak amounts of phytomass is not recommended to maintain forage productivity in northern mixed prairie. Allowances must be made to allow for transfer of phytomass to the litter because litter plays critical roles in forage production (Willms et al. 1986, 1993) and the hydrologic cycle (Naeth et al. 1991a, b).

After herbage removal plants often allocate more phytomass to shoot growth than other parts (Santos and Trilica 1978, Burleson and Hewitt 1982, Painter et al. 1989). Defoliation of northern wheatgrass also increased tillering and longevity of tillers (Zhang 1992). Because plants compensated for loss of herbage by initiating tillering, the absolute amount of herbage removed and the proportion of herbage removed in total yield both increased. This regrowth of shoots apparently had a cumulative negative effect on residual live phytomass, roots, and crowns as reflected in the substantial reduction of their weights after 3 years of defoliation. In a greenhouse study, Li and Redmann (1992) reported that a single clipping of northern wheatgrass substantially reduced crown phytomass relative to the control.

Lack of responses in root phytomass to herbage removal in 1989, the second year of study, suggests that plants may have attempted to maintain their root systems in coping with defoliation. Richards

(1984), however, proposed that maintenance of roots following defoliation may reduce the carbon that can be invested in regrowth of shoots and may affect the plant's grazing tolerance. After 3 years of defoliation in the present study, root phytomass declined dramatically, presumably reflecting cumulative effects of defoliation and a carbon deficit (Caldwell 1984). The reduction in root phytomass observed for northern wheatgrass in 1990 may have reduced its competitive position in the community and may partially explain its diminished dominance.

Management Implications

The similarity in total live yield across defoliation treatments at 2- or 6-week intervals and control should not be interpreted that this northern mixed prairie ecosystem can support multiple periods of grazing. As evidenced by the significant reductions in total herbage yield, rhizome and root phytomass, this range can be quickly (in the present study 3 years) damaged by repeated herbage removal, regardless of the timing. Six weeks or less of rest following grazing was an inadequate recovery period for this range. Zhang (1992), however, concluded that aboveground standing crop and belowground phytomass in this grassland can recover with 2 to 3 years of complete rest.

Continued interruption of the transfer of dead phytomass into litter could result in unsustainable production. Therefore, this grassland probably should be grazed only once each year and the timing of grazing should be deferred until peak growth is reached, usually after July.

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Runoff and erosion in intercanopy zones of pinyon-juniper woodlands

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Abstract

In semiarid pinyon-juniper environments, the principal mechanisms of redistribution of water, sediments, nutrients, and contaminants are runoff and erosion. To study the phenomena underlying these mechanisms, we established six 30-m² plots, in intercanopy zones, for monitoring over a 2-yr period (1991-1993). Two of the plots were severely disturbed; 4 were undisturbed.

We measured the most runoff from these plots during mid summer (generated by intense thunderstorms) and late winter (from snowmelt and/or rain-on-snow). Runoff accounted for 10 to 28% of the water budget over the 2-yr period—a higher proportion than that observed in most other pinyon-juniper woodlands, which is probably explained by the smaller scale as well as the higher elevation of our study area. Runoff accounted for 16% of the summer water budget the first year, with above-average precipitation (and thereby higher soil moisture content) and 3% the second year, when precipitation was about average. Winter runoff was substantial both years as measured on the small scale of our study (no winter runoff was observed in the nearby stream channel). Interestingly, even though precipitation was lower the first winter, runoff was higher. This may be because snowmelt set in about 20 days earlier that year—while the soils were still thoroughly frozen, inhibiting infiltration.

Differences between disturbed and undisturbed plots were most evident in the summer: both runoff and erosion were substantially higher from the disturbed plots.

On the basis of our observations during this study, we suggest that the following hypotheses proposed about runoff and erosion in other semiarid landscapes are also true of pinyon-juniper woodlands: (1) Runoff amounts vary with scale: runoff decreases as the size of the contributing area increases and provides more opportunities for infiltration. (2) The infiltration capacity of soils is dynamic; it is closely tied to soil moisture content and/or soil frost conditions and is a major determinant of runoff amounts. (3) Soil erodibility follows an annual cycle; it is highest at the end of the freeze-thaw period of late winter and lowest at the end of the summer rainy season, when soils have been compacted by repeated rainfall.

Key Words: range hydrology, streamflow generation, water budget, sediment budget

In semiarid ecosystems, the relationship between the total quantity and the importance of runoff presents a fascinating paradox (Graf 1990): runoff is quite sporadic and generally makes up a small portion of the water budget, yet it is a primary mechanism by which these lands are shaped. Processes such as chemical and nutrient cycling, erosion, and contaminant transport are closely tied to runoff. In addition, runoff may be a sensitive indicator of ecosystem change, as suggested by Dahm and Molles (1992), who examined historical runoff in New Mexico for clues to climate change.

In spite of its importance, however, runoff is a poorly understood phenomenon in that our predictive capabilities are mediocre at best (Hromadka and Whitley 1989), especially in arid and semiarid landscapes (Yair and Lavee 1985). A process-based understanding of runoff (i.e., one capable of prediction) is needed for effective evaluation and resolution of the myriad environmental problems that characterize semiarid landscapes (National Research Council 1991). This kind of understanding requires not only careful application of theoretical concepts, but also long-term, continuous, and detailed monitoring of these environments on different spatial and temporal scales (as well as ongoing refining of the underlying concepts on the basis of data obtained).

The study described in this paper is a pilot study designed to provide basic information about runoff and erosion in a particular semiarid ecosystem, the pinyon-juniper woodlands of New Mexico. The insights gained will be a valuable addition to our knowledge base for

- developing and testing theories that will improve our ability to predict how erosion and runoff will behave, and what effects they will have, in semiarid intercanopy zones;
- estimating parameters for runoff-prediction models and providing data for validation of those models; and
- guiding future studies aimed at developing a process-based understanding of runoff in this ecosystem.

Past Hydrological Research in Pinyon-Juniper Woodlands

Most of the watershed- and hillslope-scale hydrologic studies in pinyon-juniper woodland environments were conducted in the 1960s and 70s (Table 1). The management objectives of the day did not call for a process-based understanding of runoff and erosion; rather, the impetus for most of these studies was to test the hypothesis that removing the pinyon-juniper overstory would increase both water yield and forage production.

The best-documented of the watershed-scale studies was done at

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Table 1. Watershed- and hillslope-scale hydrologic studies in pinyon-juniper enviroments.

Location	Number of sites	Size	Years active	Study purpose	Precipi-- tation	Runoff		Dominant runoff season/event	References
		(ha)			(mm)	(mm[a])	(%)		
Watershed studies									
Beaver Creek (AZ) (Watersheds 1, 2, 3)	3	51-146	22	Evaluate effect of P-J control (cabling, hand-slashing, burning, herbicide)	458	27	6	Winter (85%) (rain-on-snow, prolonged rain, snowmelt)	Clary et al. 1974; Baker 1982
Beaver Creek (AZ) (Watersheds 4, 5, 6)	3	24-140	22	Evaluate effect of P-J control (cabling, hand-slashing, burning, herbicide)	526	121	23	Winter (97%) (rain-on-snow, prolonged rain, snowmelt)	Clary et al. 1974; Baker 1982
Carrizzo Creek (AZ)	1	61,382	12	Evaluate effect of P-J control (chaining, hand-slashing, burning)	457	18	4	Winter (90%)	Collings and Myrick 1966
Corduroy Creek (AZ)	1	55,166	12	Evaluate effect of P-J control (chaining, hand-slashing, burning)	457	24	5	Winter (93%)	Collings and Myrick 1966
Mexican Springs (NM)	9	1391-3437	6-20 2-6	SCS[b] characterization of P-J environment	283	13	5	Summer	Dortignac 1960
Sante Fe (NM)	3	31-319	10	SCS[b] characterization of P-J environment	327	7	2	Summer	Dortignac 1960
Hillslope studies									
Beaverhead (NM)	20	0.04	2	Evaluate impact of fuelwood cutting and burning	325	28	8	Runoff data collected only during the summer	Wood 1991
Baird (TX)	6	0.02-0.19	2	Evaluate impact of burning of juniper	613	23	4	Summer and winter	Wright et al. 1976
Milford and Blanding (UT)		0.04	3	Evaluate effect of P-J control (chaining, win-rowing; chained debris left in place)	246	3	1	Summer (high-intensity thunderstorms)	Gifford 1975a

[a]= Data are for untreated (control) areas except where no control data were available.
[b]= SCS = Soil Conservation Service

Beaver Creek, Ariz. (Clary et al. 1974; Baker 1982; Baker 1984). It was initiated following a severe drought in the 1950s, when several researchers began optimistically forecasting water-yield improvements from clearing of pinyon-juniper cover (Barr 1956). Several treatments, including herbicide application and mechanical removal, were applied to small watersheds dominated by Utah juniper (1,585- to 1,680-m elevations) and alligator juniper (1,889- to 1,950-m elevations). Water yields increased slightly in the herbicide-treated areas, but not in the areas where trees were removed mechanically. Baker (1984) suggested that this was because the trees killed by herbicide not only had ceased to draw water from the soil, but were still providing shade, both of which had the effect of reducing evapotranspiration. Later, when the dead trees were removed, water yield diminished.

The hydrologic impact of pinyon-juniper removal was also examined in Arizona on a much larger scale (Collings and Myrick 1966). Like Beaver Creek, these studies showed that there was little if any increase in water yield from such removal. At Beaver Creek, dramatic increases in runoff were seen at the higher elevations, where evapotranspiration is lower (as shown in Table 1, runoff was about 5 times higher from the alligator-juniper watersheds than from the Utah-juniper watersheds).

Dortignac (1960) compared the early Beaver Creek findings with those of some little-known watershed work conducted in New Mexico (Table 1) and concluded that the runoff regimes of the Arizona and New Mexico watersheds were different—that whereas in New Mexico most of the runoff is generated by intense summer thunderstorms and is of short duration, in Arizona it is generally a winter phenomenon, produced by frontal rain storms, rain-on-snow, and/or snowmelt.

The effects of clearing of pinyon and juniper on surface runoff and erosion has also been examined in several hillslope-scale studies. Wood (1991) and Gifford (1975a) found that runoff was greater if slash and debris were removed. When these were left in place, runoff was lower—presumably because the increased surface storage capacity allows more time for water to infiltrate. Wright et al. (1976) found that in central Texas, burning of juniper increased runoff on steeper slopes for a period of 15 to 30 months (until regrowth took hold) but produced little change on smaller-gradient slopes.

A number of rainfall simulation studies have been conducted on pinyon-juniper woodlands. Some of the earlier studies compared infiltration and erosion patterns within different plant communities (Smith and Leopold 1942, Blackburn and Skau 1974, Blackburn 1975); others evaluated the effects on hydrologic events of pinyon-juniper control strategies (Williams et al. 1969, Gifford et al. 1970, Williams et al. 1972, Roundy et al. 1978). More recent rainfall simulation studies in pinyon-juniper woodlands have focused on the development of parameter values for hydrologic and erosion models (Ward 1986, Ward and Bolin 1989a, Ward and Bolin 1989b, Ward and Bolton 1991).

As Hawkins observed (1986), pinyon-juniper woodlands exist in diverse climatic, edaphic, topographic, and geologic settings. For this reason, there is no unique hydrologic behavior for the areas characterized by this plant community. Very generally, we can say that in pinyon-juniper woodlands, evapotranspiration is the dominant mechanism of water loss. Runoff typically accounts for less than 10% of the water budget (the high-elevation pinyon-juniper regions are probably an exception—for example, the Arizona alligator-juniper watershed studies, where runoff was around 20%—Table 1). Attempts to increase runoff by removing the overstory cover, in the hope of reducing evapotranspiration, have not been successful. Increases in runoff have been achieved when soils were disturbed and/or compacted to the point that infiltration capacity was reduced—but such artificial means are generally not desirable: they lead to ecosystem degradation both by aggravating soil erosion and by diminishing the quantities of water available for plants.

We can also say that in pinyon-juniper woodlands streamflow is usually ephemeral; it is generated by intense summer thunderstorms, prolonged frontal storms, or melting snow, but the underlying mechanism by which water reaches stream channels has been little studied. It is probably mostly Hortonian overland flow rather than subsurface flow. A possible exception to this is the sustained winter streamflow, lasting several months, seen in the higher-elevation pinyon-juniper woodlands of Arizona (Clary et al. 1974 and Baker 1982), which may be the result of subsurface flow (the mechanisms of runoff generation at these sites was not explicitly discussed).

Finally, groundwater recharge is generally believed to be very small to nonexistent in pinyon-juniper woodlands, because of the high rates of evapotranspiration (Dortignac 1960, Gifford 1975b).

Current and Future Research

Over the last decade, there has been a dramatic shift of focus of hydrological investigations in pinyon-juniper woodlands. The traditional resource issues of increasing water yield and grazing capacity through vegetation manipulation have given way to issues of ecosystem sustainability, the effects of climate change, soil and water contamination, and impacts on riparian areas. Recognizing that the then-current understanding of pinyon-juniper hydrology was inadequate, Schmidt (1986) called for a comprehensive network of watershed studies in pinyon-juniper woodlands across the United States. These would employ a much more detailed investigative methodology, aimed at acquiring a process-based understanding of hydrological events.

Carrying out this type of study is especially challenging in semiarid environments (Pilgrim et al. 1988). One major problem has been the difficulty of maintaining and monitoring equipment in remote locations (but recent advances in data acquisition technology have greatly ameliorated this problem). Another problem is that development of a suitable hydrologic record could take decades, because runoff events are usually infrequent and of short duration, making important events easy to miss. Despite the challenges they present, studies of this kind are the only means for significantly advancing our understanding of water dynamics in semiarid ecosystems.

Study Area Setting

The study area lies within the Los Alamos National Laboratory's Environmental Research Park on the Pajarito Plateau of north-central New Mexico (Fig. 1). Formed by a series of violent volcanic eruptions beginning some 1.4 million years ago (Crowe et al. 1978), the plateau ranges in elevation from 1,910 to 2,730 m. To the west, it butts up against the Jemez Mountains. To the east, a parallel drainage network has created a series of finger-like mesas separated by deep canyons, through which intermittent and ephemeral streams flow to the Rio Grande. Average annual precipitation varies with elevation from about 330 to 460 mm, of which about 45% occurs in July, August, and September (Bowen 1990).

The 111-km^2 Environmental Research Park includes extensive tracts of pinyon-juniper woodlands and ponderosa pine forests (Allen 1989). Juniper coverage decreases and pinyon increases with elevation (Padien and Lajtha 1992).

Our study area, at an elevation of 2,141 m, is near the upper limit for pinyon-juniper on the Pajarito Plateau (Barnes 1986). Soils at the site are described by Nyhan et al. (1978) as Hackroy series (Alfisols of the subgroup Lithic Aridic Haplustalf and family Clayey, mixed, mesic). These are shallow soils that have developed on the volcanic tuff parent material and are characterized by a loam or sandy-clay-loam surface texture with a strong clay or clay-loam argillic horizon at a depth of about 10 cm.

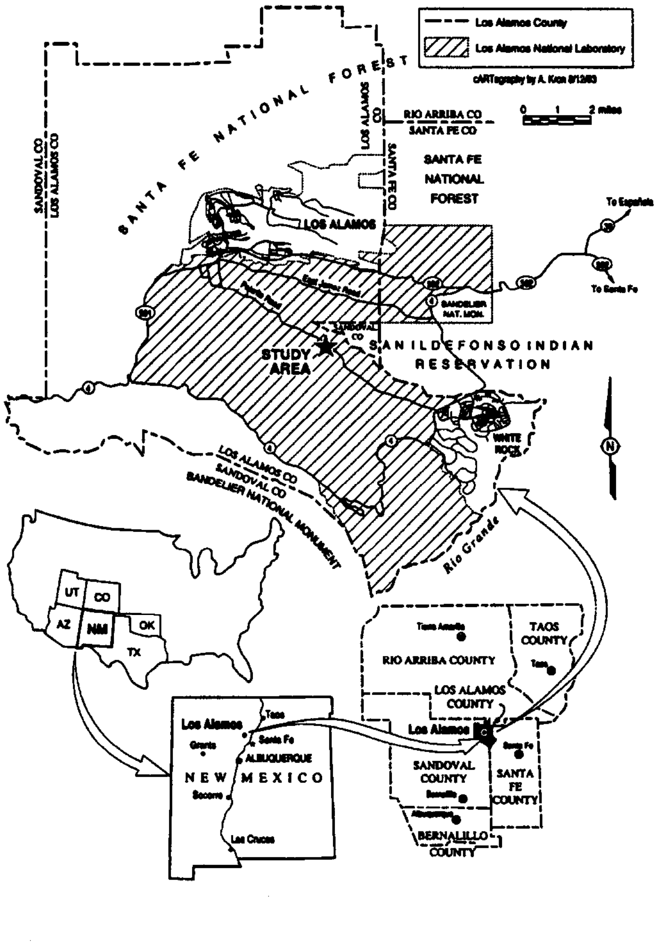

Fig. 1. Location of study area.

Experimental Design and Methodology

Naturally occurring runoff and erosion were monitored for 2 years in intercanopy zones of a pinyon-juniper woodland. (Intercanopy zones were selected for study because they are assumed to be the major source areas for runoff.)

Plot Description

We established 6 plots for monitoring, each measuring 3.04 x 10.64 m. Four of these plots (C, D, E, and F) had been used earlier for rainfall simulation studies associated with the development of the WEPP soil erosion model (Simanton and Renard 1992). All vegetation (including root crowns), cryptogamic crust, litter, and rock cover had been removed from 2 of these (C and F) in 1987; there has been regrowth, but grass cover—and especially cryptogamic crust cover—is much more sparse and bare ground is more extensive than on the other plots (Plot F recovered the least and has the most bare ground). Vegetation on plots A, B, D, and E was left undisturbed. The dominant grass species on all the plots is blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.], and common semi-shrubs and forbs are bitterweed [*Hymenoxys Richardsonii* (Hook.) Cockll.], fringed sagebrush (*Artemisia frigida* Willd.), Navajo tea [*Thelesperma filifolium* (Hook.) Gray] and Indian paintbrush (*Castilleja integra* Gray). Although grazing by domestic livestock had a profound effect on the original composition of the vegetation in this region, such grazing has been prohibited for the past 50 years.

All 6 plots were modified in July 1991 to collect naturally occurring runoff. A metal gutter was installed across the width of each plot at the downslope end. Two collection tanks, a primary and an overflow, having a combined capacity of about 600 liters, were placed 20 to 30 m downslope, and each was calibrated such that the water volume can be estimated from the depth. A drainline connected to a hole in the bottom of the gutter carries the runoff to the tanks, which are kept covered with plywood to prevent evaporation. (The degree of slope and the extent of basal cover of each plot are given in Table 2.) Basal cover was determined from point measurements taken every 5 cm along 5 transects running the width of each plot (at intervals of 2 m).

Throughout the study, the plots were inspected regularly for signs of leakage under the collection plate, and soil was added at the juncture if needed. (Such leakage is most pronounced in late winter, when frequent thawing and refreezing increases the likelihood of separation of the collection plate from the soil.)

Runoff and Sediment Collection

Runoff and erosion data were collected from July 1991 to March 1993. Runoff volume was measured for each event, including snowmelt. Because only plots A and B were completely operational during the first 2 runoff events of 1991, volumes for those events for the other 4 plots were estimated using a regression relationship (Plot B runoff vs that of plots C through F for the next 6 runoff events). The coefficient of determination (R^2) was found to range from 0.70 to 0.88.

We were unable to collect any winter runoff from Plot C because of recurrent freezing of the drainline. In the case of Plot E— and possibly F as well—leakage problems during the second winter (1992-93) lowered the amount of runoff water collected in the tanks.

To calculate rates of erosion, we collected sediment samples from each plot for each summer runoff event (except, for the first event, no samples were obtained; and for the second, samples were obtained from plots A and B only). Because sediment concentrations are much less variable during the winter, samples were taken only for selected events, on the basis of which a mean concentration was calculated for each plot. These sediment concentration values were generally based on 3 samples from each plot, but in some cases only 1 or 2 samples were collected.

Precipitation Collection

Summer precipitation was measured on a daily basis using on-site volumetric precipitation collectors. These gauges are not suitable for measuring snowfall, for which we used a heated, tipping-bucket rain gauge located about 3 km southeast of the site.

Results and Discussion

Runoff

A monthly summary of runoff from April 1991 to March 1993, averaged across all the plots, is presented in Figure 2 (although no data were collected until July 1991, we were able to extend the record back to April because on-site observation confirmed that no runoff had occurred in the interim). These data show clearly that runoff in pinyon-juniper woodlands in northern New Mexico typically has 2 "seasons": mid summer and mid to late winter. Summer runoff is generated from intense thundershowers, and winter runoff is produced by snowmelt augmented by frozen soil conditions and, at times, rain-on-snow. Runoff and precipitation amounts for the 2 seasons are compared in Table 3. Figure 3, which compares the frequency of summer and winter runoff events with the amount of runoff, shows that (1) large runoff events were much less frequent than small runoff events, and (2) the largest runoff events occurred during the summer months. During the 2-yr study period, runoff accounted for 10 to18% of the water budget for undisturbed plots and up to 28% for disturbed plots (Table 3), which is a higher proportion than at most of the pinyon-juniper sites studied to date (see Table 1). The most likely explanations are the small scale of our study (as will be discussed

Table 2. Plot slope and basal cover conditions.

Plot	Slope	Degree of disturbance	Basal cover: Grass	Shrub	Forb	Cryptogamic crust, moss	Litter	Bare ground	Other*
	(%)		%						
A	4.4	Negligible	12.3	2.7	0.3	51.6	20.5	12.0	0.6
B	4.8	Negligible	8.1	1.0	1.4	43.7	16.3	26.8	2.8
C	4.4	Severe	5.4	6.5	2.2	29.1	10.1	46.8	0.0
D	5.2	Negligible	22.7	1.4	1.7	50.2	17.9	6.2	0.0
E	5.3	Negligible	10.8	3.1	1.0	53.9	18.0	13.2	0.0
F	5.7	Severe	4.4	4.1	1.0	26.6	2.4	61.1	0.3

*= includes rock, lichen, and cactus

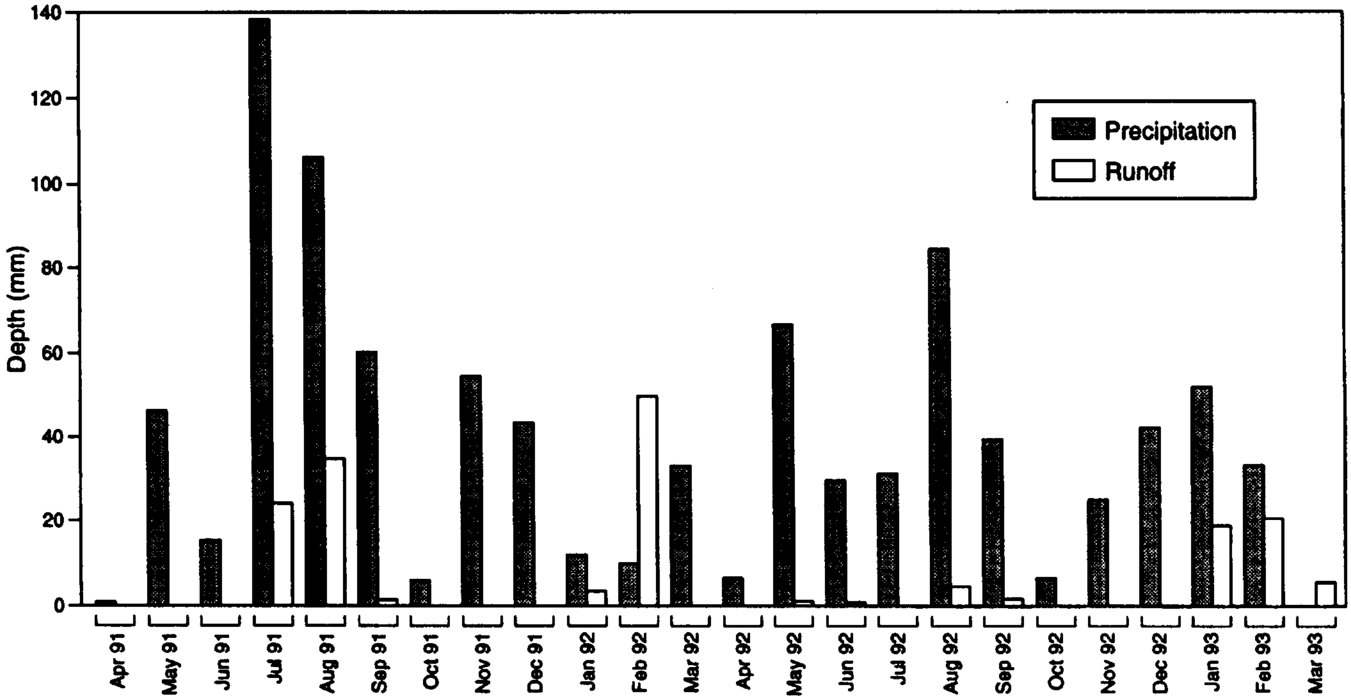

Fig. 2. Monthly precipitation vs runoff (totals averaged for all plots) April 1991-March 1993.

later) and the high elevation of the study area, which is near the limit for pinyon and juniper (as was seen in the Beaver Creek studies, runoff increased dramatically at the higher elevations).

Summer Runoff

The amount of runoff collected the first summer (1991) represented a significant portion of the summer water budget—in contrast with the second summer (1992), when runoff was almost negligible (Table 3). Long-term precipitation data (1911-1992) collected at a Los Alamos site about 300 m higher than our study site indicate that summer 1991 was wetter than average, whereas summer 1992 precipitation was about average (Fig. 4). We conclude from this that

Table 3. Runoff and precipitation by season.

Season	Precipitation (mm)		Plot runoff A	B	C	D	E	F	Average
Summer									
1991	365	Total (mm)	26.9	50.0	86.1	42.2	60.9	87.7	59.9
		(%)	7.4	13.7	23.6	11.6	16.7	24.0	16.2
1992	247	Total (mm)	2.1	1.1	7.4	2.5	1.8	24.6	7.0
		(%)	0.8	0.4	3.0	1.0	0.7	10.0	2.8
Winter									
1991-92	118	Total (mm)	47.8	25.6	*	41.8	71.8	74.0	52.2
		(%)	40.5	21.7	*	35.4	60.9	62.7	44.2
1992-93	151	Total(mm)	31.7	18.0	*	60.4	32.5	74.5	43.4
		(%)	21.0	11.9	*	40.1	21.6	49.4	28.8
Totals									
Apr 91-Feb 93	929	Total (mm)	108.5	94.7		146.9	167.0	260.8	
		(%)	11.7	10.2		15.8	18.0	28.1	

*= Plot C was not operational during the winter.

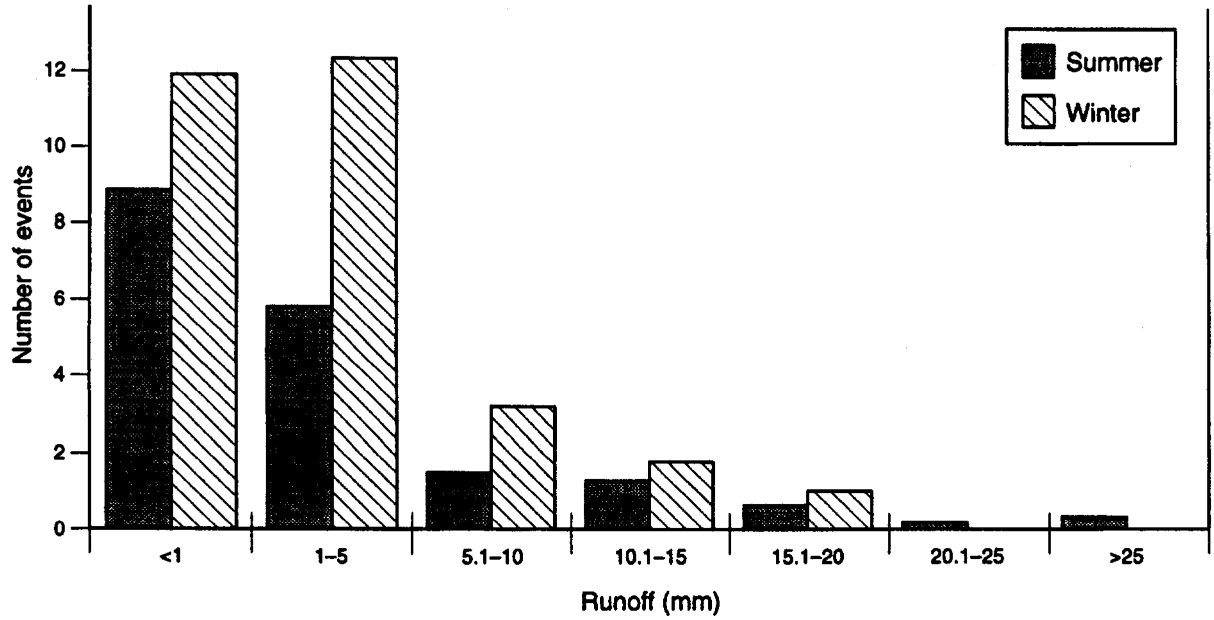

Fig. 3. Frequency distribution of summer and winter runoff events (averaged across all plots) April 1991-March 1993.

summer runoff in 1991 was higher than average. Figure 5 shows the relationship between precipitation and runoff amounts during the summer of 1991 for Plot F, where the greatest amount of runoff was measured. Note that from about mid July to mid August, when thundershowers were very frequent, runoff amounts were much higher with respect to precipitation amounts than during previous drier periods, and some runoff was generated during almost every precipitation event. The likely explanation for this is that as soil moisture increases, soil infiltration capacity decreases—a phenomenon well documented in the rangeland hydrology literature (e.g., Wilcox et al. 1988). Soil moisture data collected during the summer of 1991 from a woodland area adjacent to the study site shows that soil moisture increased from around 15% in May to about 35% in early August (Barnes et al.1992).

Figure 6 compares cumulative precipitation with cumulative runoff by plot for both summers, 1991 and 1992. The very different patterns of precipitation are evident: not only was there less precipitation overall in 1992 than 1991, it was also more spread out. The other

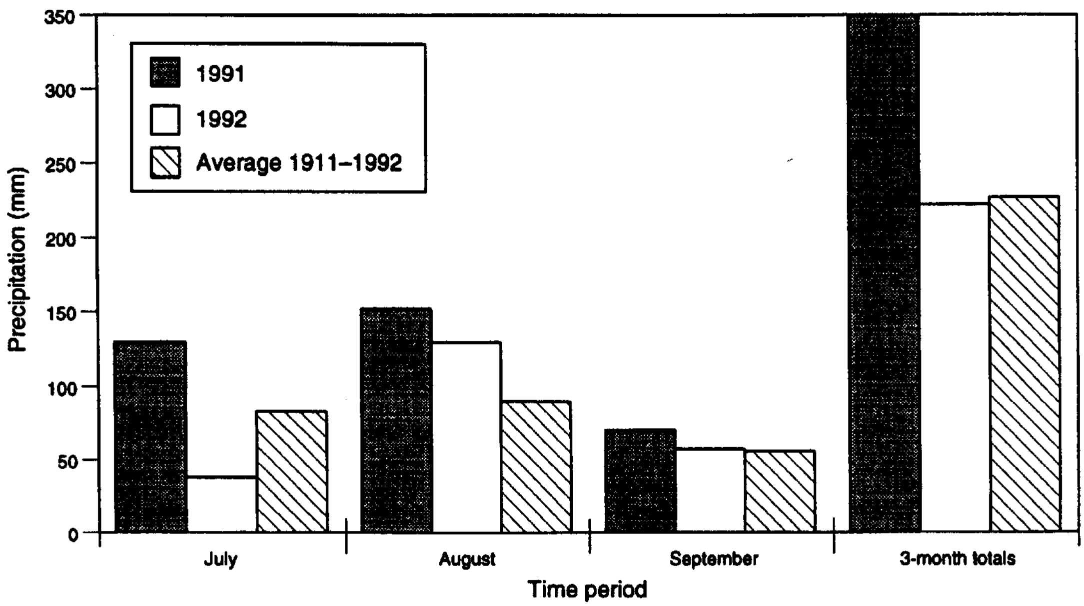

Fig. 4. Comparison of 1991, 1992, and average (1991-1992) summer precipitation amounts.

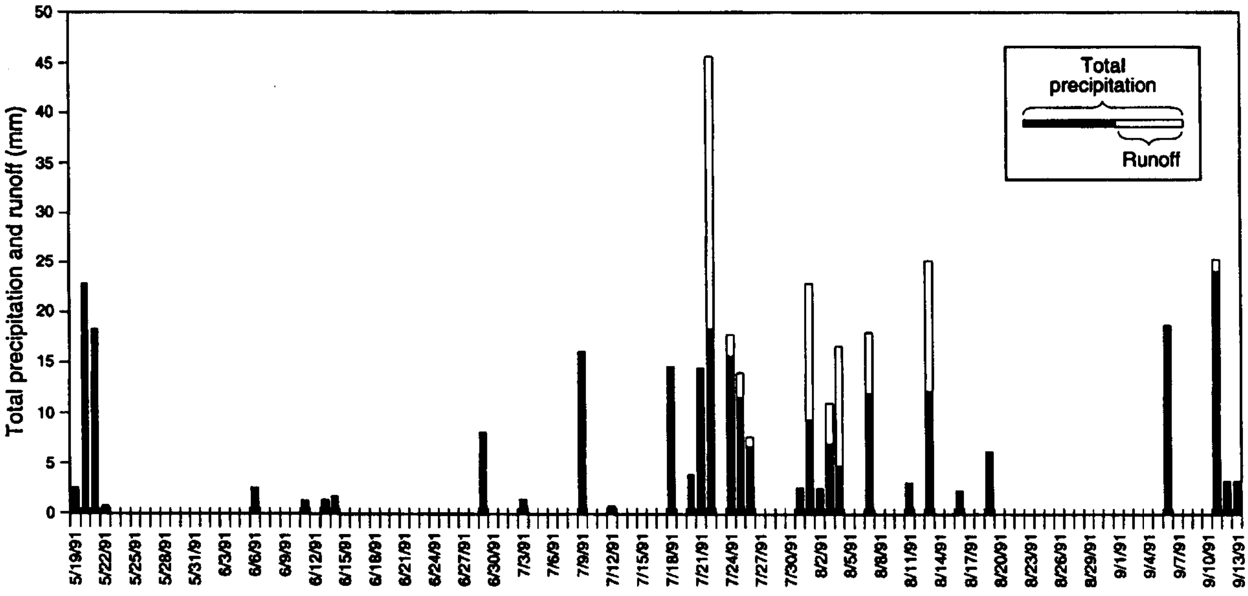

Fig. 5. Precipitation-runoff relationship for Plot F, summer 1991.

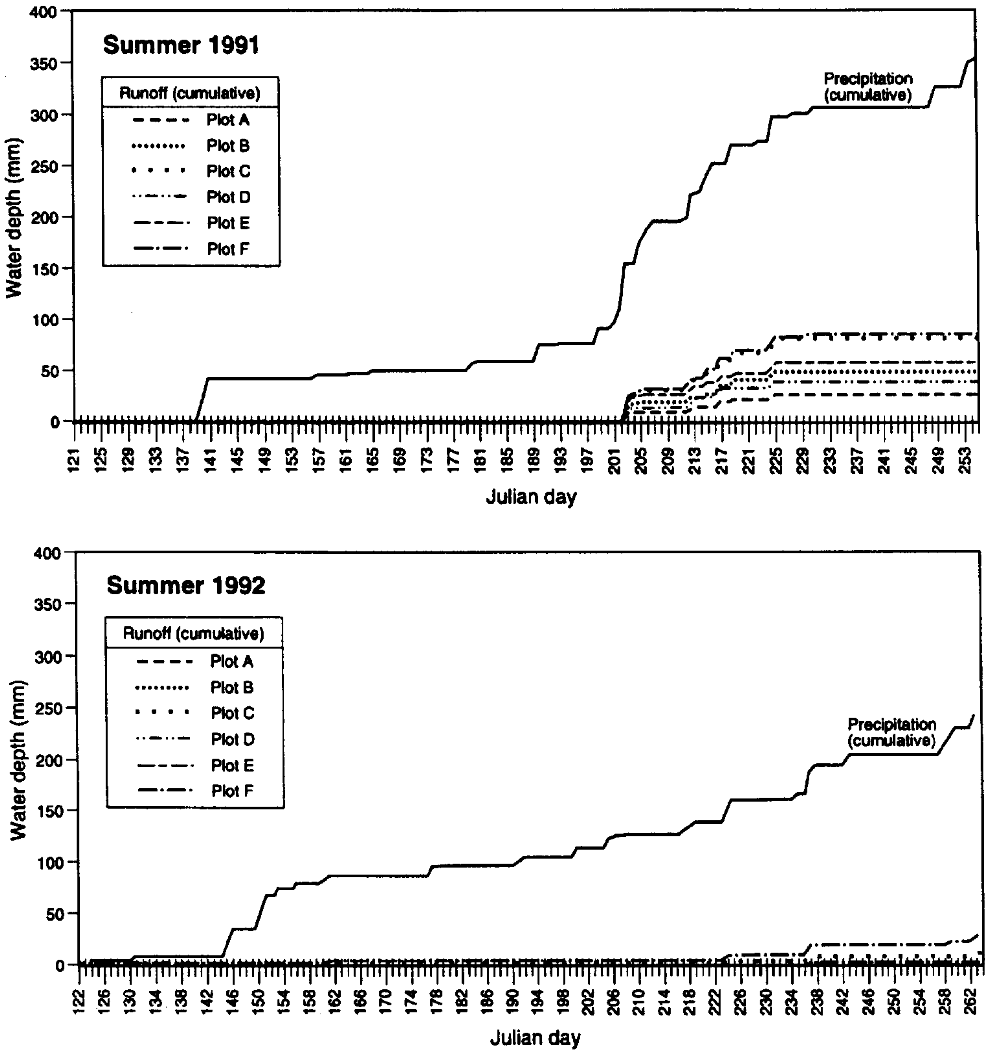

Fig. 6. Cumulative summer precipitation vs runoff, 1991 and 1992.

major observation was the difference in runoff between the undisturbed and the disturbed plots. Runoff amounts for both summer seasons were substantially higher for plots C and F than for the other plots (see also Table 3). It was especially high for plot F, where there was less regrowth of vegetation (Table 2).

Winter Runoff

Runoff measured during the 2 winter seasons (1991-92 and 1992-93) was appreciable, averaging more than 52 mm for winter 1991-92 and nearly 43.5 mm for winter 1992-93 (Fig. 2, Table 3). Even though the amount measured during the second winter was probably somewhat underestimated because of leakage problems at plots E and F—especially E—the overall results show higher runoff the first winter. This is particularly clear in the case of plots A and B, where we are reasonably certain there was no leakage. The only plot where more runoff was measured the second winter was Plot D. What is especially interesting is that the winter with the higher runoff was also the winter with the lower precipitation (Table 3); as a percentage of the winter water budget, runoff accounted for more than 44% the first winter vs less than 29% the second winter.

A more comprehensive picture of winter runoff patterns is presented in Figure 7, where cumulative runoff for each plot is compared with cumulative precipitation. This figure shows, first, that during the winter of 1991-92, most of the runoff came from snowmelt in the absence of precipitation; during the following winter, most of the runoff was produced by rain-on-snow events (as seen in the figure, at least 3 such events were recorded, on Julian days 7, 39, and 50). Second, general snowmelt began about 20 days earlier the first win-

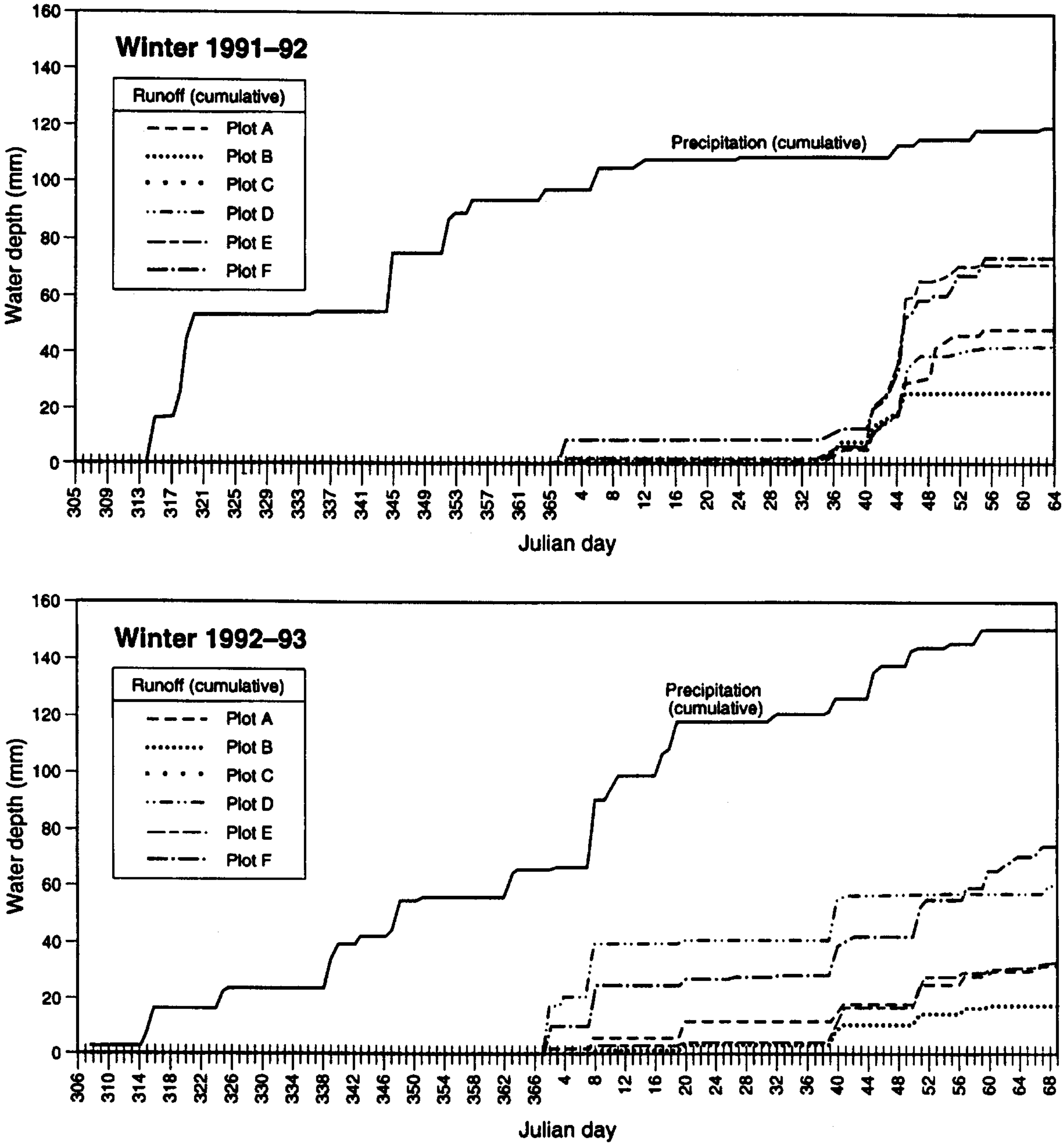

Fig. 7. Cumulative winter precipitation vs runoff, 1991-92 and 1992-93.

ter than it did the second. In early February of 1992, we began to observe a daily thawing and refreezing of the upper 5-10 cm of soil (which, when thawed, was completely saturated). Below that depth, the soils remained frozen through the period of active runoff. The second winter, snowmelt did not begin until late February, by which time the soil was probably more deeply thawed. No definite pattern of nightly refreezing was apparent.

On the basis of these observations, we theorize that soil frost dynamics in combination with the timing of general snowmelt could explain the higher amounts of runoff (despite lower precipitation) during the winter of 1991-92. Although no specific data were collected to support this idea, the earlier snowmelt in concert with frozen soils, which would inhibit infiltration, almost certainly contributed to the increased runoff measured the first winter. On the other hand, the later snowmelt combined with more deeply thawed soils the second winter would have encouraged more infiltration of water into the soil.

With respect to the effects of plot disturbance on winter runoff, the results of our study are not decisive because 1 of the disturbed plots (Plot C) malfunctioned both winters. Winter runoff was greatest from other plots that were not disturbed (Table 3).

Our study also yields some data relevant to another discussion. Dortignac had concluded, on the basis of data from earlier watershed investigations, that in the pinyon-juniper woodlands of northern New Mexico runoff is mainly a summer phenomenon. The large amounts of winter runoff we measured contrast sharply with that earlier data, and we believe the difference is explained by effects of scale: whereas Dortignac's conclusions were based on data collected from watersheds of 30 to 3,000 ha and focused on measurement of runoff in the stream channel, our study used plots many orders of magnitude smaller. Even during the periods of most active winter runoff, we found no water in the stream channel several hundred meters downslope of the plots. Apparently it was being absorbed en route, into "sink" or recharge areas such as pinyon-juniper canopy spaces, snow drifts, and/or alluvial-flood-plain sediments.

In other words, winter runoff appears to be locally important as a mechanism of redistribution of water, but these effects can be seen only at the smaller scales. Amerman and McGuinness (1967) were among the first to note the effects of scale on measured runoff and cautioned against "scaling up" plot data to predict hydrologic behavior at larger scales. Other researchers have also observed that the generation of runoff in arid and semiarid environments can vary greatly with scale. In the southwestern United States this phenomenon is usually attributed to channel transmission losses, primarily on the basis of work conducted at the Walnut Gulch Experimental Watershed in Arizona (Renard 1970). More recent work in Israel (Yair and Lavee 1985) has demonstrated that scale-related differences in measured runoff are also a function of differences in the infiltration capacity of hillslope soils. Because of these differences, some areas (lower-infiltration) function as *source areas* for runoff while others (higher-infiltration) serve as *sinks* for runoff.

Our observations indicate that redistribution of water by runoff is occurring in pinyon-juniper communities. Ecological investigators have suggested that this phenomenon is a major determinant of vegetation patterns in semiarid environments, and hydrological/ecological interactions is an area of active research (Yair and Danin 1980; Moorhead et al. 1989; Schlesinger et al. 1989; Cornet et al. 1992).

Erosion

The extent of erosion varied considerably, both by season and by plot (Table 4). Over the 2-year study, most of the erosion resulted from a few large events the first summer. (Other studies have also found that erosion was produced mainly by large runoff events—e.g., Hjelmfelt et al. 1986). Another finding, that sediment concentrations tended to decrease as the summer runoff season advanced—which we observed the first summer, when there were a large number of precipitation events—is similarly reflected in other studies. For example, Yair et al. (1980) observed that in arid regions of the northern Negev, sediment concentrations decreased progressively with repeated runoff events. In pinyon-juniper areas, it is possible that fine particles loosened by the freeze-thaw cycle of the previous winter are washed away early, and the remaining surface soil then becomes compacted. Schumm and Lusby (1963) demonstrated for the Mancos Shale that seasonal variations in soil erodibility and infiltration capacity were tied to variations in frost dynamics and the force of rainfall. This is probably equally true of pinyon-juniper woodlands and other semiarid environments.

Erosion rates were very high from the most disturbed plot, Plot F (Table 4), which had much more bare ground than the other plots. However, 1 undisturbed plot (E) also showed a quite high erosion rate. The reason for this is not obvious.

Finally, we noted that even when runoff was higher during the winter than the summer, snowmelt runoff produced very little erosion.

Table 4. Erosion of plots by season.

	Sediment			
Plot	Summer 1991	Summer 1992	Winter 1991-92	Winter 1992-93
	-kg/ha-			
A	313	13	53	56
B	560	5	10	32
C	1089	42	*	*
D	280	5	67	107
E	2868	25	79	57
F	10831	255	118	131
Average	2656	58	65	77

*= Plot C was not operational during the winter.

This is consistent with the finding of Ellison (1948) that erosion is much lower in the absence of rainfall impact on the soil surface.

Conclusions

The measurements made during our study support the following conclusions about runoff and erosion in intercanopy areas of pinyon-juniper woodlands in northern New Mexico.

Runoff takes place during 2 times of the year: mid summer (generated by thunderstorms) and mid to late winter (generated by snowmelt). At least on smaller scales, runoff can make up a substantial part of the winter water budget. During the 2-yr study period, runoff accounted for between 10 and 18% of the water budget for undisturbed sites (up to 28% for disturbed sites). This is higher than has been observed for many other pinyon-juniper studies (Table 1), which is probably explained partially by the high elevation of our site and partially by the small scale of our study.

Erosion from intercanopy pinyon-juniper sites having little bare ground is minimal, and increases as the extent of bare ground increases. Most of the erosion is produced by large summer thunderstorms. Erosion is slight during the winter, even when runoff is high, because of the absence of raindrop impact.

Both runoff and erosion are greater on disturbed sites during the summer. The effect of disturbance (extent of bare ground) is less pronounced during the winter.

Observations made during the course of this study suggest that the following hypotheses proposed for other semiarid landscapes are applicable to pinyon-juniper woodlands as well.

Hypothesis 1: *Runoff amounts vary with scale: runoff decreases as the size of the contributing area increases (and provides more opportunities for infiltration).* Other investigators have noted that in semiarid regions runoff varies with scale—because of either transmission losses in the stream channel or differences in soil infiltration capacities. We believe that in the pinyon-juniper communities of New Mexico, effects of scale are especially pronounced during the winter because runoff is generated from discrete points in the landscape (snowmelt will vary depending on topographic position). Our study allowed us to observe that winter runoff can be substantial locally, but that the water travels little distance before being absorbed into "sink" areas.

Hypothesis 2: *The infiltration capacity of soils is dynamic; it is closely tied to soil moisture content and/or soil frost conditions and is a major determinant of runoff amounts.* Rainfall simulation studies, such as those of Thurow et al. (1988), have demonstrated the dynamic nature of infiltration capacity. We believe that at our site, the two most important factors affecting soil infiltration capacity are soil moisture changes during the summer and soil freezing during the winter. The impact of soil frost on runoff in other semiarid environments is well recognized (for example, the sagebrush steppe—Johnson and McArthur 1973, Seyfried et al.1990); but the phenomenon has been little studied in pinyon-juniper landscapes.

Hypothesis 3: *Soil erodibility follows an annual cycle. It is highest at the end of the freeze-thaw period of late winter and lowest at the end of the summer rainy season, when soils have been compacted by repeated rainfall.* Our observations suggest that this hypothesis, proposed by Schumm and Lusby (1963) for the Mancos Shale areas in western Colorado, also applies to pinyon-juniper woodlands. During the first summer of our study, when runoff was frequent, sediment concentrations tended to decrease as the summer advanced.

These conclusions and hypotheses have important implications, among them that surface runoff is an important mechanism for the redistribution of water, sediments, nutrients, and contaminants in pinyon-juniper woodlands, especially on a local scale. In these environments, it may be said that runoff is often a small-scale phenomenon, and that on the small scale, it can make up a large portion of the total water budget. Adequate prediction of surface runoff in these environments will require models that appropriately simulate both the spatial (Hypothesis 1) and the temporal (Hypotheses 2 and 3) variability of these environments—one of the major challenges currently facing hydrological researchers.

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Vegetative response to burning on Wyoming mountain-shrub big game ranges

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ABSTRACT

Information on vegetative productivity and nutritive responses to burning in mesic, high elevation big sagebrush (*Artemisia tridentata* Nutt.) communities is limited. We investigated the effects of 2 wildfires and 3 prescribed fires on current year's production of herbs and selected shrubs for 3 years post-burn, and forage quality for 2 years post-burn in high elevation big sagebrush habitats in southcentral Wyoming. Production of perennial herbs on burned sites averaged twice that on controls, while production of annual herbs varied little 2-3 years post-burn. Burn-induced mortality of Saskatoon serviceberry (*Amelanchier alnifolia* (Nutt.) Nutt. ex Roem.) was ≤15%, but a 6-fold increase in twig production more than compensated for plant losses. Mortality of true mountain mahogany (*Cercocarpus montanus* Raf.) and antelope bitterbrush (*Purshia tridentata* (Pursh) DC) averaged 25% and 55%, respectively, but these losses generally were compensated by increases in browse production. Crude protein content of herbs from late spring through early fall was significantly higher on burns for 2 years post-burn. These results suggest well-managed prescribed burning programs have potential to improve May through September diets of large herbivores in southcentral Wyoming mountain-shrub communities.

Key Words: browse production, burning, forage production, forage quality, nutrition, shrub survival.

Fire suppression in the northcentral Rocky Mountains during the last 75 years generally has favored the establishment of mountain-shrub communities often dominated by old decadent shrubs (Roughton 1972) with considerable standing dead organic matter. Reduced accumulations of standing dead matter (Hobbs and Spowart 1984, Jourdonnais and Bedunah 1990), improved productivity of herbs and shrubs (Leege 1969, Peek et al. 1979, Wright 1985), and increased nutrient concentration (DeWitt and Derby 1955, Stransky and Halls 1978) can provide superior foraging conditions for wild ungulates after burning. But the results from studies of vegetative productivity and nutritive response to fire are highly variable (DeWitt and Derby 1955, Lay 1957, Launchbaugh 1964, Leege 1969, Stransky and Halls 1978, Merrill et al. 1980; 1982, Wood 1988, Uresk et al. 1980, Meneely and Schemnitz 1981, Demarchi and Lofts 1985, Jourdonnais and Bedunah 1990). Pre-burn vegetative composition, soil moisture and fertility, fire intensity, precipitation and grazing following burning, and other factors likely contribute to variations in vegetative response among studies (Wright 1985).

Both the effects of fire on vegetative productivity and nutrient content have not been reported as far as we are aware for mesic, high elevation (≥ 2,300 m) montane big sagebrush (*Artemisia tridentata* Nutt.) communities. The relatively unique environmental features of these communities, such as high precipitation (e.g., >35 cm), large fuel volumes, and high productivity likely preclude extrapolation of burn-response data more commonly collected from big sagebrush communities at lower elevations in the Great Basin. Thus, detailed assessments of the influence of fire on vegetation in these high elevation communities is warranted, and can assist the development of habitat management plans by range and wildlife managers.

We investigated the effects of 2 wildfires and 3 prescribed burns on productivity of herbs and selected shrubs, and nutrient values of herbs on high elevation montane big sagebrush ranges important to wild ungulates in southcentral Wyoming. Data were collected during the first 2-3 years after burning.

METHODS

Study Areas

We studied post-fire vegetative responses on 5 burned sites located within 30 km of Encampment, Wyo.: Douglas Creek, Encampment, Prospect Mountain, and the West Encampment 1988 and 1989 burns. The Encampment site was divided into 2 sampling units (Encampment NE and Encampment SW) based on differences in aspect (northeast vs. southwest) and vegetative communities. Site characteristics, burning dates, and weather at time of burning for each site are presented in Table 1. All sites except Encampment SW occurred on east-facing slopes and were dominated by mountain big sagebrush (*Artemisia tridentata vaseyana* Nutt.) and antelope bitterbrush (*Purshia tridentata* (Pursh) DC) prior to burning. Common graminoids included bluebunch wheatgrass (*Agropyron spicatum* (Pursh.) Scribn. & Smith), king spikefescue (*Leucopoa kingii* (Wats.)

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Table 1. Site and preburn vegetative conditions, date, and weather during burning on 6 burned areas in southcentral Wyoming.

Burn	Type[1]	Aspect	Elev	Veg. type[2]	Size	Date	Weather Temp.	RH[3]	Wind
			(m)		(ha)		(C)	(%)	(kph)
Douglas Cr.	W	E-SE	2,450	MS/AB	10	6/85	26	24	16-20
Encamp. NE	W	E-NE	2,400	MS/AB/SS	100	9/85	17	33	13-20
Encamp. SW	W	SW	2,350	WS/TMM	100	9/85	17	33	13-20
Prospect Mtn.	P	E-SE	2,380	MS/AB/SS	13	4/87	11	17	5-7
West Enc. 1988	P	E-SE	2,400	MS/AB	41	4/88	na[4]	na	na
West Enc. 1989	P	E-SE	2,400	MS/AB	31	4/89	na	na	na

[1] W = wildfire; P = prescribed fire.
[2] Pre-burn vegetation community dominants: MS = mountain big sagebrush; WS = Wyoming big sagebrush; AB = antelope bitterbrush; SS = Saskatoon serviceberry; TMM = true mountain mahogany.
[3] Relative humidity.

Weber), needle-and-thread (*Stipa comata* Trin. & Rupr.), and Ross sedge (*Carex rossii* Boott). The Encampment SW site supported Wyoming big sagebrush (*A. t. wyomingensis* Nutt.) and true mountain mahogany (*Cercocarpus montanus* Raf.), with bluebunch wheatgrass and cheatgrass (*Bromus tectorum* L.) common in the understory. Plant names follow Dorn (1988).

Regional climate is semi-arid. Annual precipitation and temperature at Encampment average 38 cm and 5° C, respectively (NOAA 1988). Average annual precipitation is probably greater on the study sites, because all were 150-250 m higher in elevation than the Encampment weather station. Aspen (*Populus tremuloides* Michx.) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) communities occurred in mosaics around the burned sites, indicating the high precipitation regime on the study sites. Soils are lithic, having developed from weathering of fine-grained igneous and metamorphic bedrock (Haas 1979). Burned sites are located within steep V-shaped canyons used seasonally by elk (*Cervus elaphus*) and pronghorn (*Antilocapra americana*), and yearlong by mule deer (*Odocoileus hemionus*) and Rocky Mountain bighorn sheep (*Ovis canadensis*). Cattle occupied these sites during summer but were excluded after burning except at Douglas Creek.

Treatment and Response Variables

The effects of fire on current annual production of herbs and shrubs was assessed at Douglas Creek, Encampment NE and SW, and Prospect Mountain. Data were collected on each burned site and an adjacent unburned control. Aspect, slope, and elevation of controls were similar to burned sites, and we assumed that vegetative differences between controls and burns were the result of fire (fire lines, snow drifts, and forest stringers in drainages prevented spread of fire from burned areas to controls).

We randomly selected sampling areas (n = 15 at Prospect Mountain and Encampment NE and n = 10 at Encampment SW and Douglas Creek) to estimate herb and shrub productivity. Herbivore exclosure cages were placed at each sampling area prior to the growing season. These cages, which measured 1.3 x 1.3 m, were too small to cover shrubs, so herbivores were excluded only from herbaceous plants. We assumed that herbivory on shrubs on burned and unburned sites were equal; subsequent field observations, however, suggested that herbivores preferred shrubs on burns vs. controls, so our estimates of shrub production on the burns likely were low. Cages were moved uphill 2 m after clipping each year to avoid sampling the same plants in successive years. We clipped the current year's herbaceous production at ground level in 1.2-m^2 circular plots in the exclosure cages. The harvested biomass was separated into 5 classes: bluebunch wheatgrass, other perennial grasses including sedges, annual grasses, perennial forbs, and annual forbs. We harvested all current year's twig growth from individual plants of serviceberry (*Amelanchier alnifolia* (Nutt.) Nutt. ex Roem.), bitterbrush, and true mountain mahogany. The 2 shrubs of each species nearest to the exclosure cage were sampled each year (data from each were averaged). No shrubs were reclipped among years. Herb and shrub samples were oven-dried at 65° C for 24 hours and weighed.

Densities of live and dead serviceberry, bitterbrush, and true mountain mahogany were estimated in permanent 1- x 20-m belt transects. Transects were located parallel to slope contours 5 m from each exclosure cage. In each transect, numbers of sprouting shrubs and fire-killed plants, identified by bark characteristics of burned stumps (Bunting et al. 1984), were counted, and survival rates were estimated by dividing the sum of sprouting plants by the number of sprouting and fire-killed plants. We did not monitor mortality of shrubs on the control areas, so fire's effect on shrub mortality may be slightly overestimated.

We calculated current annual twig production (g/m^2) on the burned sites by multiplying density of live shrubs by average twig production per plant. Twig production on the controls was calculated by multiplying total (live and dead) shrub density on the burns by average twig production per plant on the controls. These estimates of twig biomass per unit area are calculated projections rather than estimates directly derived from rigorous sampling.

Crude protein was estimated for herbs in 1986 and 1987 at Douglas Creek and in 1989 at the 2 West Encampment sites. In 1986 at Douglas Creek, we conducted protein analyses on the perennial herb samples (i.e., bluebunch wheatgrass, perennial grasses, and perennial forbs) collected in August for production estimates. In 1987 at Douglas Creek, samples of bluebunch wheatgrass, perennial grasses, and perennial forbs were collected in May, late July or early August, and early October from randomly-located plots on the burn and control sites. Twenty samples of each forage class were collected over the season. At the 2 West Encampment sites and control, herbaceous vegetation in 8, 0.5-m^2 circular plots randomly-located on the control, 1, and 2 year-old burned sites were clipped each month from late May through early November. All current-year's growth clipped in each plot was composited for nutritional analyses.

Samples used for nutritional assessments were oven-dried at 65° C for 24 hours and ground in a Wiley Mill to pass through a 1-mm sieve. Crude protein was estimated by a macro Kjeldahl technique (Horwitz 1980). Laboratory analyses were conducted by the Wyoming Dep. of Agriculture, Analytical Services Laboratory.

Data Analysis

Statistical differences in herb and shrub productivity between the burns and controls were identified with multivariate repeated measures ANOVA using the General Linear Models procedure of SAS (1985). Year and treatment (burned vs. control) were included as main effects. When F-statistics of either treatment or year x treatment interaction effects were significant, we used Duncan's New Multiple Range test to identify significant treatment effects within years.

Multivariate repeated measures analysis was used also to identify significant declines in live shrub density over time after burning. Year was included as the main effect. Orthogonal contrasts were used to identify differences between adjacent years when the year effect was significant.

Significant differences in crude protein content between samples collected from the control and burned sites during August 1986 at Douglas Creek were identified with t-tests. For samples collected in 1987 at Douglas Creek, simple linear regressions of protein and day of the year of sample collection were calculated for each within-treatment and within-forage class combination. Between-treatment differences in protein-calender day regression lines were determined with a test of homogeneity of slopes and intercepts using the General Linear Models Procedure of SAS (1985). The effect of burning on nutrient content at West Encampment also was evaluated using tests of homogeneity of slopes and intercepts, and Duncan's New Multiple Range test was used to identify significant differences between the control, 1, and 2 year-old burn sites.

Statistical significance was established at $P \leq 0.05$ in all tests.

Results

Herbaceous Response

Total herbaceous current year's production averaged 2.2 times higher on the burns compared to controls, pooling data across all 4 sites. There was significant interaction between burning and year at Douglas Creek, Encampment NE, and Prospect Mountain, and the burn effect was significant at Encampment SW. The significant interaction at Douglas Creek and Encampment NE suggests burning depressed production the first year after fire, but significant increases occurred thereafter (Fig. 1). First-year depression in production was not apparent at Prospect Mountain and Encampment SW.

Production of bluebunch wheatgrass averaged 3.9 times higher on

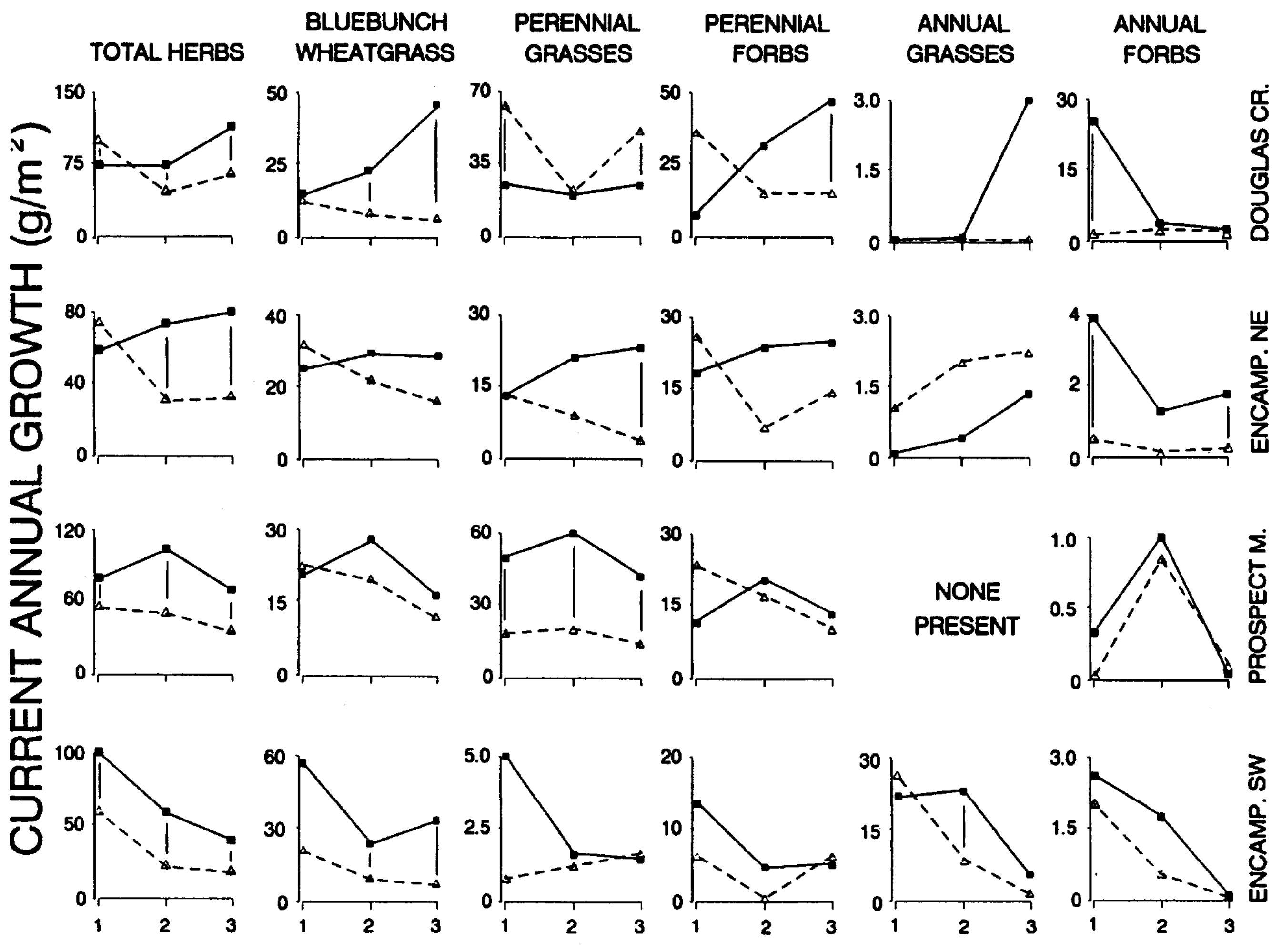

Fig. 1. Current annual growth of all herbaceous vegetation, bluebunch wheatgrass, other perennial grasses, perennial forbs, annual grasses, and annual forbs on 4 burned (solid squares, solid lines) and unburned control sites (open triangles, dashed lines) in southcentral Wyoming. Vertical bars indicate significant differences (P<0.05) between treatments in a given year.

Table 2. Survival (% of preburn abundance ± 95% confidence intervals) of serviceberry, bitterbrush, and true mountain mahogany after burning at Encampment and Prospect Mountain, 1986-89. All bitterbrush plants died after burning at Douglas Creek.

	Serviceberry			Bitterbrush			True mtn. mahogany		
	1[1]	2	3	1	2	3	1	2	3
Encamp. NE	88±12	85±15	85±15	47±10	35±9	34±9	-	-	-
Prosp. Mtn.	99±2	98±2	98±2	66±12	56±12	56±12	-	-	-
Encamp. SW	-	-	-	-	-	-	82±18	78±16	76±16

[1] Years after burning.

burns by the third year, pooling data across all sites. The burn x year interaction was significant at Douglas Creek, and the burn effect was significant at Encampment SW. Significant increases in production of bluebunch wheatgrass did not occur until the second year after burning at both of these areas (Fig. 1). Burning did not have significant effects on bluebunch wheatgrass production at Encampment NE and Prospect Mountain.

The year x burn interaction effect on production of other perennial grasses was significant at Douglas Creek and Encampment NE. At Encampment NE, 3 years were required for significant increases to occur, whereas at Douglas Creek, production of perennial grasses was significantly lower the first and third years post-burn (Fig. 1). Main effects of burning and year were significant at Prospect Mountain; production on this burn was higher each year of the study. Burning did not affect production of perennial grasses at Encampment SW.

Burning generally had insignificant effects on perennial forbs (Fig. 1). Neither burn nor year effects were significant for perennial forbs on any site, and the burn x year interaction was significant only at Douglas Creek. Here, production of perennial forbs was significantly higher on the burn by the third year.

The effect of burning on production of annual herbs was generally insignificant particularly by the third year post-fire (Fig. 1). The burn x year interaction for annual grasses was significant only at Encampment SW; significant increases occurred the second year post-burn. Burning did not significantly affect production of annual grasses at the other sites. The burn x year interaction for annual forbs was significant at Douglas Creek, where production was elevated only the first year post-fire. Burning significantly increased production of annual forbs at Encampment NE the first and third years post-fire (Fig. 1).

Shrub Response

Shrub survival varied among species and burns (Table 2). At Encampment NE, stems of bitterbrush declined significantly to 50% of preburn levels the first year after fire, declined significantly to 35% of preburn levels the second year after fire before mortality ceased. At Prospect Mountain, 66% and 56% of the bitterbrush plants survived through the first and second years, respectively, with significant declines occurring during the first 2 years. Fire eliminated bitterbrush at Douglas Creek. Serviceberry mortality was inconsequential at Prospect Mountain, but declined significantly to 88% of preburn levels the first year after fire. Eighteen and 22% of true mountain mahogany plants died by the first and second years post-fire, respectively, at Encampment SW.

The effects of burning on twig production of individual shrubs varied among species and burns as well (Fig. 2). The burn x year interaction was significant for bitterbrush at Encampment NE and the burn and year effects were significant for this species at Prospect Mountain. Significant increases occurred only the third year and second year at Encampment NE and Prospect Mountain, respectively. The burn effect was significant for serviceberry twig production on both burned areas where it was present. Burning did not significantly affect twig production of true mountain mahogany (Fig. 2). Projections of twig production per unit area for these 3 species generally indicate increased productivity of shrubs compensated for reductions in live shrub densities (Fig. 2).

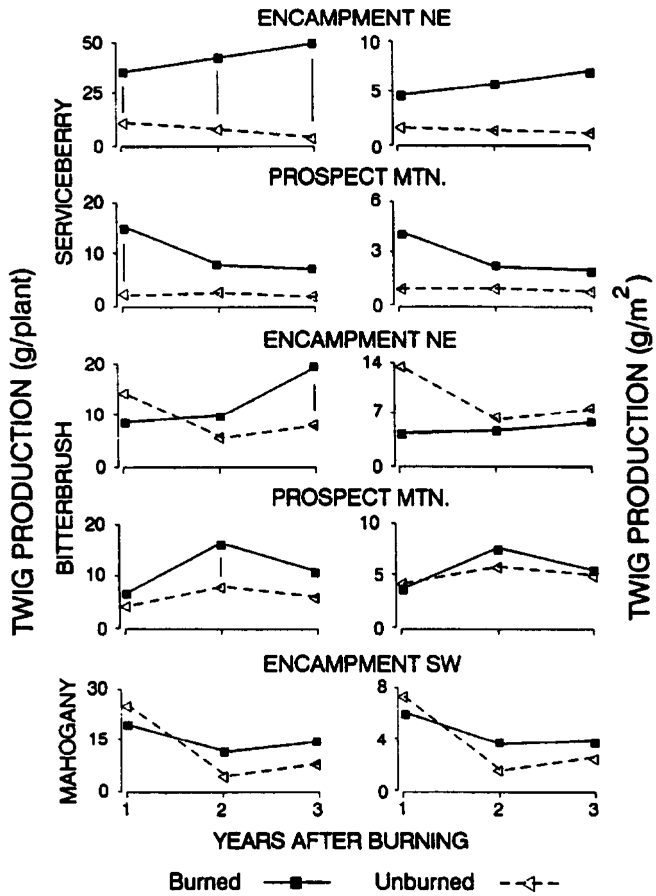

Fig 2. Current annual production of serviceberry, bitterbrush, and true mountain mahogany twigs, expressed as g/plant and g/m2, on 3 burned and unburned control sites in southcentral Wyoming. For graphs depicting g/plant, vertical bars indicate significant differences ($P < 0.05$) between treatments within years.

Forage Quality

Burning significantly increased crude protein of herbs in all years and sites sampled. In August 1986 at Douglas Creek, protein averaged 30% higher in herb samples collected from the burn (Fig. 3). In 1987 at Douglas Creek, protein content of the 3 herbaceous classes collected on the burn averaged as much as about 60% higher than on the control (Fig. 4). The rate of seasonal decline in protein content of perennial forbs and bluebunch wheatgrass collected from the Douglas Creek burn and control were similar, but differed signifi-

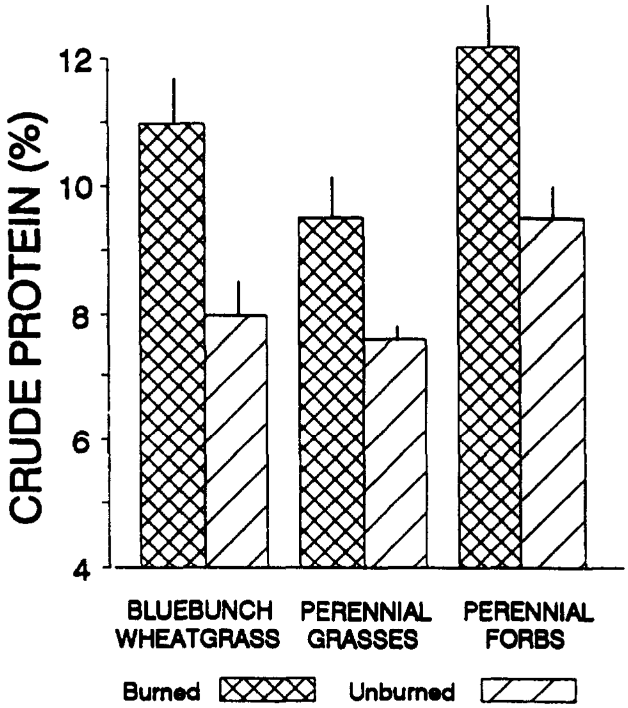

Fig 3. Crude protein of herbs collected during August 1986 on the Douglas Creek burn and control. Vertical bars denote SEM.

cantly for perennial grasses.

On the West Encampment sites, crude protein of herbs averaged 12.3%, 10.9%, and 8.9% on the 1 year-old burn, 2 year-old burn, and controls, respectively, (Fig. 5). Forage quality was significantly higher on the 1 year-old burn than the 2 year-old burn, and was higher on both burns than on the control. The increase in forage quality in August coincided with above-normal precipitation (112% of normal) that followed an April-July drought in which precipitation was 42% of normal (NOAA 1989).

Discussion

Burning increased productivity of perennial herbs by the second year post-burn, while generally inducing only short-term increases in annual herbs. With only 1 exception (perennial grasses at Douglas Creek), there was no significant reduction in production of any perennial herbaceous class on any burn after the first year post-burn. These positive responses occurred even on the June burn (Douglas Creek) and even though drought conditions prevailed during the sampling period (precipitation averaged 77% of normal from January 1986 through July 1989 [NOAA 1986-89]). The significant decrease in perennial grasses at Douglas Creek likely was due to the abundance of needle-and-thread and Ross sedge, 2 dense bunch-formers typically harmed by fire (Wright 1985). King spikefescue, a rhizomatous species, and sandberg bluegrass (*Poa secunda* Presl.), both of which often respond well to burning (Wright 1985), comprised most of the perennial grass foliage on the other burns.

Such consistently positive responses in production contrast variously with findings of others. For example, Countryman and Cornelius (1957), Young and Evans (1978), and Merrill et al. (1980) reported increases in cheatgrass with concurrent decreases of peren-

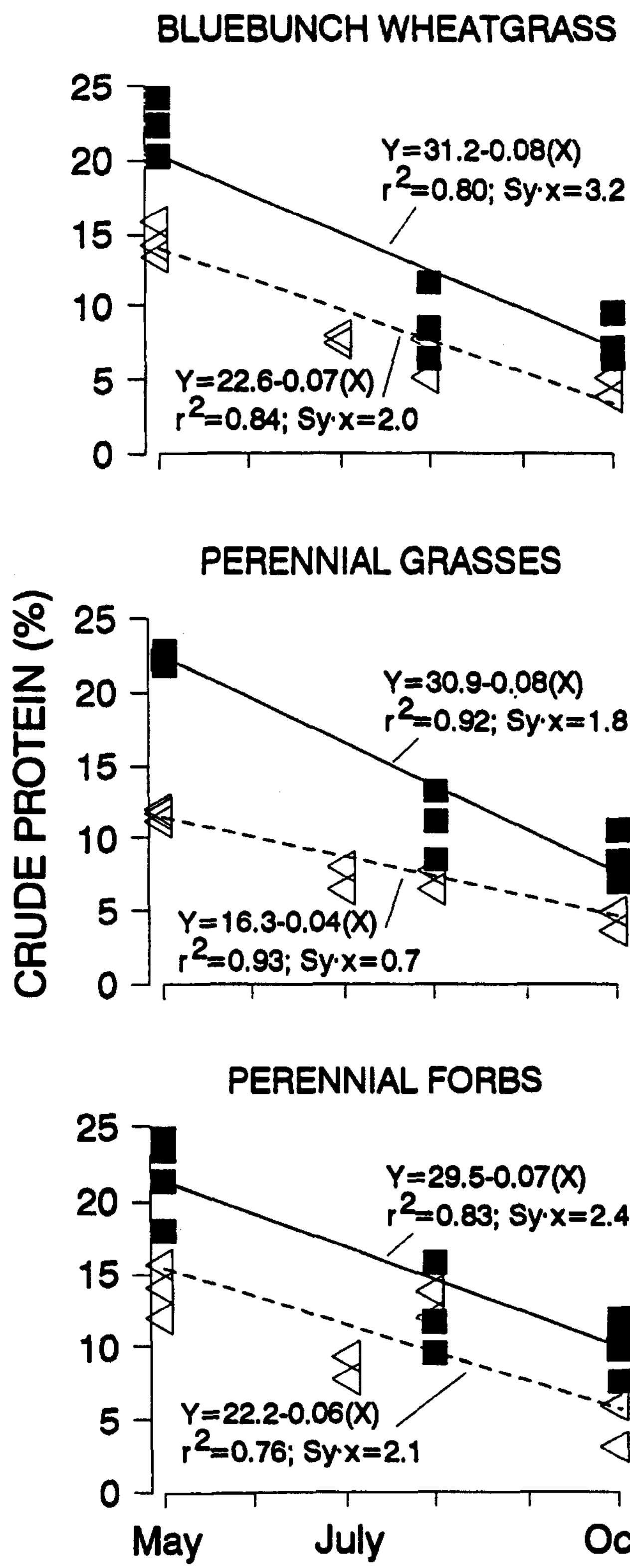

Fig. 4. Crude protein of herbs collected from May through October 1987 on the Douglas Creek burn (solid squares) and control (open triangles).

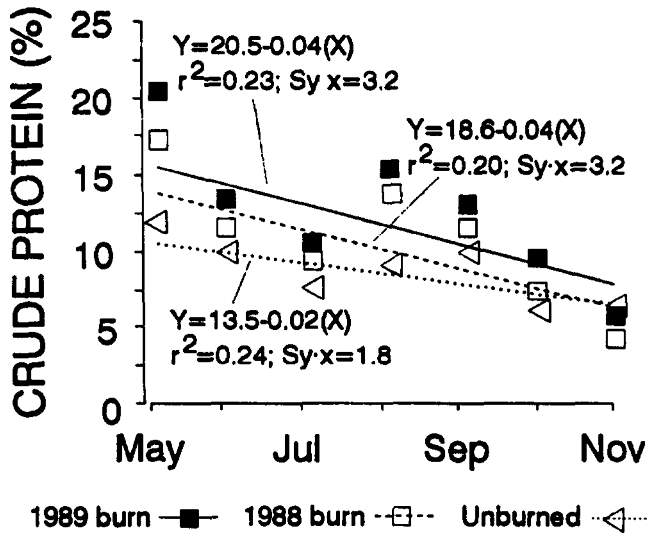

Fig. 5. Crude protein of forage collected from May through November 1989 on the West Encampment 1988 and 1989 burns and control. Each data point represents the mean of 8 samples collected each month. SE of each mean is <1.0.

nial herbs. Launchbaugh (1964), Towne and Owensby (1984), and Jourdonnais and Bedunah (1990) reported either post-fire declines or no changes in production of perennial herbs, with no significant increases in annuals. Engle and Bultsma (1984) and Towne and Owensby (1984) reported significant effects of season of burning. Bailey and Anderson (1978), Merrill et al. (1980), Uresk et al. (1980), and Wright (1985) reported variable responses among perennial herbaceous classes and species to burning.

Similarly, the substantial increases in crude protein of herbs after burning in all years and sites where examined contrast with the results of many other studies. Merrill et al. (1980), Meneely and Schemnitz (1981), Hobbs and Spowart (1984), Wood (1988), and Jourdonnais and Bedunah (1990) reported either minor or insignificant effects of burning on forage quality, and Lay (1957), Peek et al. (1979), Hobbs and Spowart (1984) contend that increases in forage quality, if they occur, are short-lived (≤2 years).

We speculate that the consistent increases in plant productivity and nutrient concentration found in our study are a result of the mesic conditions and plant competitive characteristics that may be unique in high elevation big sagebrush communities. On burns occurring on easterly aspects, shrubs in the pre-burn plant communities were dense and total canopy cover was high (e.g., 2.5 shrubs/m² and canopy cover of 60 to 70%, J. Cook, unpubl. data). Burning removed ≥60% of shrubs, mostly big sagebrush, probably increasing the availability of soil water (Sturgis 1977), soil nutrients, and radiant energy flux to the surviving plants. These changes may account for increased nutrient content by facilitating earlier growth, increased rates of growth, and delayed senescence. Enhanced growth generally improves forage quality by increasing readily digestible cell solubles relative to cell wall constituents (Wilms et al. 1981, Minson 1990). An inverse relationship between forage quality and plant density in many ecosystems has been recognized (Daubenmire 1968, Hobbs and Swift 1985).

We postulate that high elevation plant communities with dense big sagebrush and without aggressive introduced annual herbs such as cheatgrass will respond well to prescribed burning. Reductions in shrub density and associated evapotranspiration losses (Sturgis 1977) should increase growth rates and extend the growing season, thereby enhancing vegetative productivity and quality. The length of time these enhancements persist will likely depend on rate of successional advance. In rangeland plant communities where (1) burning does not substantially alter plant composition, such as mountain grasslands, (2) burning results in rapid increases in competitive annual herbs, or (3) plant growth is restricted by severely limited precipitation, the effects of burning on vegetative productivity and nutrient content may be inconsistent and short-lived.

Serviceberry plants survived burning well, and increases in browse production more than compensated for decreases in plant density. Similar positive production responses of serviceberry have been reported by Leege (1969), Merrill et al. (1982), and Demarchi and Lofts (1985). Moderate losses (25%) and insignificant increases in twig production of true mountain mahogany indicate few benefits of burning this species, at least in the short-term. Even so, our data demonstrate this species tolerates fire relatively well, and based on serviceberry and bitterbrush responses, we suspect losses could be reduced by spring-burning. We are unaware of other studies documenting the response of mountain mahogany to fire; more data is needed to reliably predict response and prescribe appropriate burning strategies for this species.

Survival of bitterbrush varied from 34-56%, but increases in twig production generally compensated for reduced plant density. Survival on the spring burn (56%) is similar to that reported by Blaisdell and Mueggler (1956), Bunting et al. (1984), Britton and Clark (1985) for the decumbant, multi-stemmed ecotype. Spring-burning appears most suitable for this species (Rice 1983, Britton and Clark 1985), perhaps because carbohydrate reserves in bitterbrush roots are high at this time (McConnell and Garrison 1966). Complete elimination of bitterbrush at Douglas Creek suggests summer burning is highly detrimental, as noted by others (Britton and Clark 1985).

Increased nutrient concentration, reduced structural and dead biomass, and increased productivity underscore the potential for burning to provide nutritional benefits to wild ungulates. Moreover, the relationships among diet quality, milk yields, and juvenile growth in wild ungulates (Peart 1968, Loudon et al. 1984), and summer weight gains in cattle (Skovlin 1962, Vavra 1983) identify the importance of dietary quality during summer. In our study, crude protein fell below requirements of a domestic ewe nursing a single lamb (National Research Council 1985) by early July on the controls, but generally exceeded requirements through early fall on the burns. Although large-scale removal of big sagebrush may reduce forage availability and dietary quality during winter, elimination of sagebrush from burned mosaics in mountain shrub communities should have little impact on ungulate diets during summer in southcentral Wyoming (Haas 1979, Cook 1990).

Managers who contemplate burning to improve habitats for ungulates should consider short- and long-term effects of fire on dietary and habitat needs of ungulates. Foliage of deciduous shrubs is an important component of ungulate diets during summer on mountain-shrub ranges in southcentral Wyoming (Haas 1979, Cook 1990). We believe that repeated burning at frequent intervals (e.g., 5 years) likely will maintain high forage quality and herbaceous productivity for herbivores (Peek et al. 1979), but the long-term effects on deciduous shrubs in particular and ecosystem productivity in general are unknown. More information on shrub survival (Leege 1979, Martin and Driver 1983), seedling establishment (Martin and Driver 1983, Bunting et al. 1984), and soil fertility (Hobbs and Schimel 1984) is required to make informed management decisions on frequency of burning. If managers desire to enhance plant productivity and retain deciduous browse in burned habitats, we recommend creating a mosaic of different-aged burned and unburned habitats where a treatment unit is burned once every 15-25 years.

Finally, our data suggest burning in spring minimizes damage to shrubs and perennial herbs and minimizes first-year increases in weedy annual species. Positive effects of spring burning reported here are consistent with findings of others in the Intermountain West (Smith and Busby 1981, Wright 1985, Britton and Clark 1985). But spring-burning may not be most suitable for all management objectives (Peek 1989). Greater plant mortality and exposure of mineral soil resulting from hotter burns in other seasons may enhance seedling establishment of deciduous shrubs (Martin and Driver 1983) and may prolong increases in forage quality. Effects of season of burning on community succession and forage quality and quantity needs further assessment as well.

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Protein supplementation of stocker cattle in the Northern Great Plains

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Abstract

A comparison of the response of varying classes of growing beef cattle to protein supplementation was conducted on Northern Great Plains rangeland during the summer and early fall. Response was evaluated in 2 experiments, conducted in 1988 and 1989, by measuring organic matter intake and body weight gain in 13-month-old (spring-born steers) and 7-month-old steers (fall-born steers), which received either a 26% crude protein supplement or no supplement. Weight gain was also monitored in 7-month old heifers (fall-born heifers). In experiment 1, spring-born steers were fed 1.28 kg and fall-born steers and heifers 1.64 kg of protein supplement every other day. During experiment 2, spring-born steers were fed supplement at a rate of 1 kg and fall-born steers and heifers at 1.8 kg every other day. Intake of forage organic matter for steers was not affected ($P > 0.10$) by supplementation in either experiment. In experiment 1, total organic matter intake tended to be increased by protein supplementation in June but not in August (date x supplementation level interaction, $P = 0.08$). Forage organic matter digestibility was greater ($P < 0.01$) in June than in August during experiment 1 and in August than September in experiment 2. In experiment 1, this difference was greater for fall-born steers than spring-born steers. In experiment 1, supplementation increased ($P < 0.01$) average daily gain of cattle from 0.63 to 0.78 kg/day. In experiment 2, daily gain of cattle was increased ($P < 0.01$) from 0.62 to 0.82 kg/day with protein supplementation. Also, in experiment 2, cattle receiving supplement were 18 kg heavier ($P < 0.05$) at the end of the grazing season than unsupplemented controls. Protein supplementation increased weight gains of growing cattle in the late summer in the Northern Great Plains. The advantage was most consistent for fall-born steers with higher relative protein requirements.

Key Words: forage quality, intake, rangeland, supplements

Past research has shown that range forage in eastern Montana may become deficient in protein for growing cattle during late summer (Adams and Short 1988). Unsupplemented steers grazing native range in late August and early September have been shown to cease gaining or even to lose weight (Currie et al. 1989). Protein supplementation may alleviate this depression in weight gain by supplying a limiting nutrient. In addition, protein supplementation may improve nutrient intake and utilization through an increase in forage intake and digestibility (Caton et al 1988; DelCurto 1990a,b; Sanson et al. 1990). However, the effect of protein supplementation on forage intake is not consistent (Kartchner 1980). Protein requirements for growth differ by sex and body weight (NRC 1984). As cattle grow, protein requirements, per unit of body weight and per unit of gain, decrease. In addition, heifers require less protein at high rates of gain than steers. Due to differences in requirements and growth rates, response to supplemental protein may vary with age and sex of grazing cattle. The objectives of this study were to evaluate the effects of protein supplementation on intake and weight gain of cattle in different stages of growth, grazing Northern Great Plains rangelands.

Materials and Methods

Experiments were conducted in a single 176 ha pasture of native range at the Fort Keogh Livestock and Range Research Laboratory, Miles City, Mont. (46° 22' N 105° 5' W). Dominant forages were western wheatgrass (*Pascopyrum smithii*, [Rydb.] Love); Japanese brome (*Bromus japonicus* Thunb.), blue grama (*Bouteloua gracilis*, [H.B.K.] Lag. ex. Griffiths) and needle-and-thread (*Stipa comata*, Trin. and Rupr.). Precipitation was 134 mm in 1988 and 383 mm in 1989 compared to a 92-year average of 338 mm (Fig. 1).

In the first study (1988), the pasture was stocked with twenty-four 13-month-old steers (spring-born steers), eleven 7-month-old fall-born steers and 13 fall-born heifers. Protein supplementation was provided to 13 spring-born steers and 12 fall-born calves (6 steers, 6 heifers) at rates of 1.28 and 1.64 kg of supplement (335 and 429 g crude protein) every other day, respectively. Supplementation was by group feeding of each animal type. This level of supplement was expected to meet the needs of cattle (NRC 1984) gaining about 0.8 to 1.0 kg/day, assuming a daily dry matter intake of 2% of body weight of a forage containing 6 to 6.5% crude protein (Adams et al. 1987; Ward et al. 1990a). In study 2 (1989), the same pasture was stocked with 24 spring-born steers (12 control, 12 supplemented), 24 fall-born steers (12 control, 12 supplemented) and 11 fall-born heifers (6 control, 5 supplemented). Spring-born steers were fed 1.0 kg (274 g crude protein) and fall-born calves 1.8 kg (493 g crude protein) of the supplement every other day. Differences in the amount of supplement fed in the 2 years were because of different initial weights of cattle. Cattle were group fed by animal type, except during the fecal

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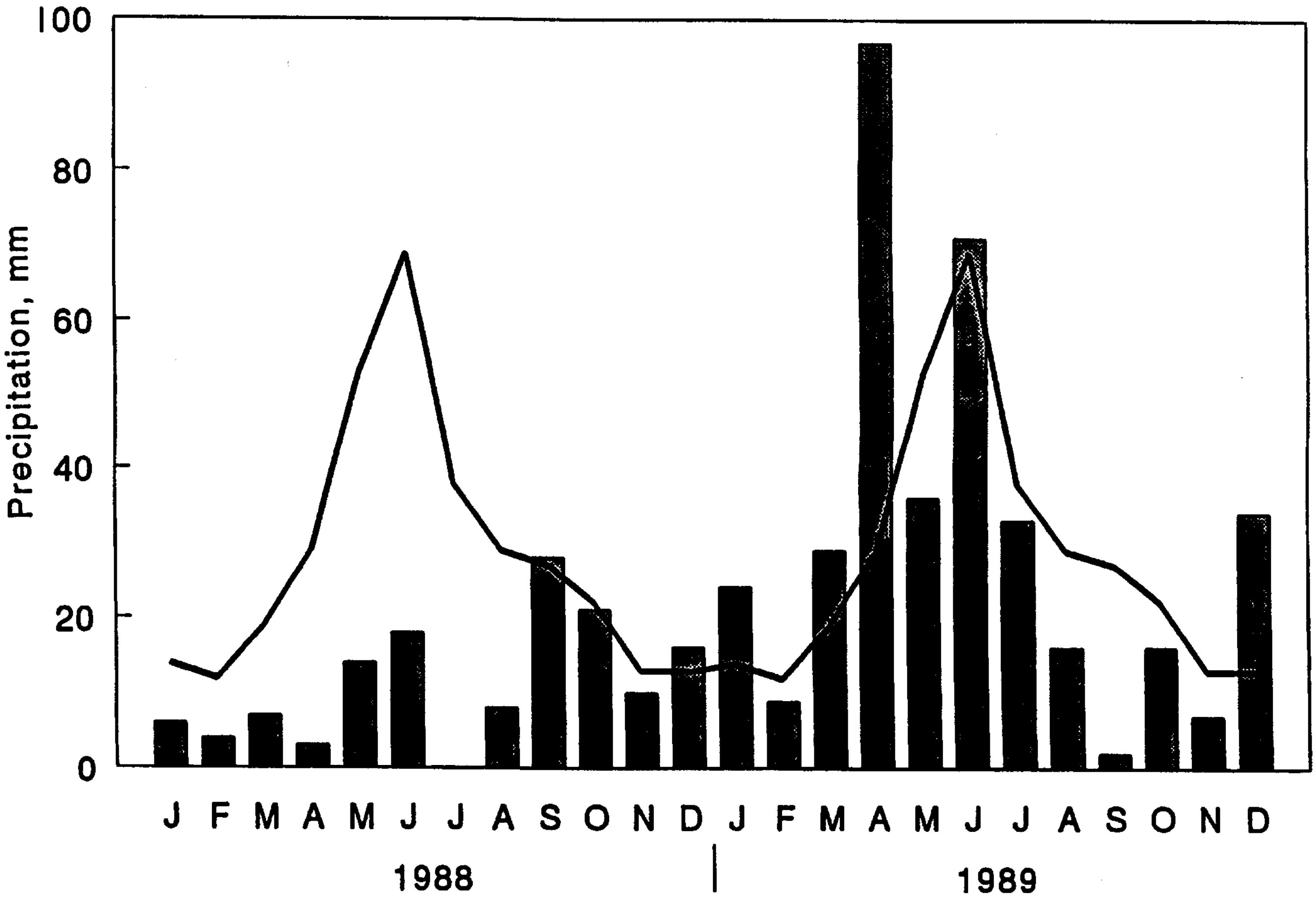

Fig. 1. Monthly precipitation during the 2 years the studies were conducted (1988 and 1989). Bars represent actual precipitation while the line represents a 92-year average.

collection period, when cattle were individually fed. The supplemental protein was provided as a pelleted 50% soybean meal, 25% barley, 25% wheat cake. Chemical composition of the supplement is shown in Table 1. Animals were allowed access to minerals and water at all times.

Preweaning weight gains of fall-born calves were 0.76 kg/day in 1988 and 0.62 kg/day in 1989. Winter weight gain of spring-born cattle in 1989 averaged 0.77 kg/day. One-half of the spring-born cattle used in 1987 were purchased prior to the study and previous winter weight gain was unknown for these animals.

Forage intakes were estimated for steers only. In experiment 1, 10 fall- and 10 spring-born steers were fitted with fecal collection bags during 5-day periods in June (20 - 24 June) and August (15 - 19 August). Fecal bags were emptied each morning and a subsample collected and dried at 60° C. A 5-day composite was then made using

Table 1. Chemical composition (% of dry matter) of protein supplements fed to growing cattle in Experiments 1 and 2.

Item	Experiment 1	Experiment 2
	(%)	
Organic matter	95.3	87.7
Crude protein	26.2	27.4
Neutral detergent fiber	18.4	13.9
Acid detergent fiber	7.3	8.0
Acid detergent lignin	1.1	1.4

0.1% of the daily fecal dry matter. Forage organic matter indigestibility was estimated by marker ratio techniques using indigestible neutral detergent fiber (Cochran et al. 1986). In experiment 2, 24 steers were given a sustained release bolus containing chromic sesquioxide[1] with a daily Cr release rate of 1123 mg. Rectal grab samples of feces were collected once daily over two 5-day periods (31 July - 4 August, 11 - 15 September), dried at 60° C, and composited on an equal dry weight basis for each animal. Fecal samples from both experiments were ground to pass a 1-mm screen in a Wiley mill and analyzed for dry matter, organic matter (AOAC 1989), and indigestible neutral detergent fiber. Fecal samples from experiment 2 were also analyzed for Cr by atomic absorption spectrophotometry (Williams et al. 1962). Fecal organic matter output was estimated by dividing Cr released by the sustained release bolus by the concentration of Cr in the feces. Fecal output attributed to supplement was subtracted from total fecal output to estimate fecal output attributed to forage intake. For both experiments, forage organic matter intake was estimated by dividing fecal organic matter output from forage by forage organic matter indigestibility. Estimates of fecal output using the sustained release bolus have been reported to be within 10% of total fecal collections for steers on similar forage (Adams et al. 1991).

Five mature (3-4 years old) steers, fitted with esophageal cannulae, grazed with the other cattle during the week of fecal collections.

[1]Captec Chrome, Nufarm, Auckland, New Zealand

Table 2. Chemical composition of diets consumed by esophageally-fistulated steers at the time of intake trials.

	Experiment 1 (1988)		Experiment 2 (1989)	
	21 Jun.	21 Aug.	1 Aug.	13 Sep.
	(% of dry matter)			
Organic matter	89.8	89.6	90.7	88.2
	(% of organic matter)			
Crude protein	8.1	6.2	8.8	9.4
Neutral detergent fiber	77.0	77.4	74.8	75.4
Acid detergent fiber	49.1	53.9	51.9	59.0
Acid detergent lignin	6.1	5.2	7.0	16.2
Acid detergent insoluble nitrogen	0.29	0.28	0.36	0.77

Esophageal collections were made once during each intake trial. Steers were penned at 1600 with water but no feed available. Collections were made the following morning at 0700. Collection periods lasted from 20 to 30 min. Esophageal masticate samples were oven dried at 55°C, ground through a Wiley mill, and analyzed for dry matter, organic matter, and acid detergent fiber by AOAC (1989) procedures, acid detergent lignin and neutral detergent fiber by the procedures of Goering and Van Soest (1970), indigestible neutral detergent fiber, and crude protein (Hach 1987).

Steers were weighed on a non-shrunk basis and average daily gain was calculated as final weight minus initial weight divided by the number of days of the study. Experiment 1 was terminated after 64 days (9 June to 11 August) because of low forage availability associated with low precipitation (Fig. 1). Experiment 2 was conducted over an 80-day period (30 June to 18 September).

Data were analyzed as 2 separate experiments because sample dates and techniques for intake measurement varied between years. Intake and digestibility data were analyzed using the general linear models procedure of SAS (1989) with a model that included steer age, supplementation level, steer age x supplementation level, steer within age by supplementation level, date, steer age x date, supplementation level x date, and steer age x supplementation level x date. Steer age, supplementation level and the interaction were tested using steer within age by supplementation level (16 df, experiment 1; 20 df, experiment 2) as the error term. Animal growth data were analyzed with a 2 x 3 (supplementation level x animal type) arrangement of treatments. The residual error was used to test effects. When a significant F value was obtained, individual (1 df) orthogonal contrasts were used to test control vs supplemented cattle within animal type (spring-born steer, fall-born steer, and fall-born heifer).

Results and Discussion

Diet Quality

In experiment 1, dietary crude protein concentrations (Table 2) were less than expected for the summer months for this area (Adams and Short 1988). Low precipitation (Fig. 1) during the year apparently reduced both quality and quantity of forage. In experiment 2, diet quality appeared to be greater than in experiment 1. Based on estimated intakes, about 80% of the NRC (1984) requirement for crude protein of steers was met through forage consumption. Addition of the protein supplement increased crude protein intake to 85% of requirement in experiment 1 and 98% of requirement in experiment 2.

Intake and Digestibility

In experiment 1, intake of forage organic matter (g/kg BW) and forage organic matter digestibility (%) were not affected by supplementation, but total organic matter intake was greater ($P < 0.01$) in June for steers fed supplement than for non-supplemented controls (Table 3). Total organic matter intake was not affected by supplementation in August. Organic matter intake (forage and total) was greater ($P < 0.01$) in August than June (Table 4). There was an effect of steer age ($P < 0.01$), with fall-born steers consuming more organic matter per unit body weight than spring-born steers. Digestibility of forage organic matter was greater ($P < 0.01$) in June than August, which may be associated with the higher diet quality in June. There was a greater difference in digestibility between June and August for fall-born steers than for spring-born steers (type x date interaction, $P < 0.05$).

In the second experiment, intakes of forage and total organic matter (g/kg BW) and forage organic matter digestibility for steers were not affected ($P > 0.10$) by supplementation. Fall-born steers consumed more ($P < 0.01$) organic matter on a body weight basis than did spring-born steers and forage digestibility was 1.5% lower ($P < 0.05$) in fall-born steers (Table 4). Differences ($P < 0.01$) were observed between July and September trials for forage and total organic matter intake and organic matter digestibility. Diet digestibility averaged 19.5% less in September than in August. This may be related to the large difference in dietary acid detergent lignin

Table 3. Least squares means of organic matter (OM) intake (g/kg BW) of steers, Experiments 1.

	Spring-born				Fall-born				
	Control		Supplemented		Control		Supplemented		
Item	Date 1[a]	Date 2	Date 1	Date 2	Date 1	Date 2	Date 1	Date 2	SEM
Experiment 1									
No. of animals	5		5		5		5		
Total OM intake[bcde]	14.1*	18.7	17.8*	20.4	16.9*	23.4	20.3*	24.2	0.5

[a]Dates for intake trials were 20 - 24 Jun. and 15 - 19 Aug. 1988.
[b]There was a significant effect of date in the model ($P < 0.01$).
[c]There was a significant effect of steer age in the model ($P < 0.05$).
*Means comparing control and supplemented cattle within age and date differ at $P < 0.05$.
[d]There was a tendency toward an effect of supplementation level ($P = 0.06$).
[e]There was a tendency toward a date x supplementation level interaction ($P = 0.08$).

Table 4. Least squares means of organic matter (OM) intake (g/kg BW) and digestibility in steers, Experiments 1 and 2.

Item	Spring-born		Fall-born		
	Date 1[a]	Date 2	Date 1	Date 2	SEM
Experiment 1					
No. of animals	10		10		
Forage OM					
Intake[bc]	15.1	18.7	16.9	22.3	0.3
Digestibility, %[be]	65.9	64.0*	66.9	61.7*	0.3
Experiment 2					
No. of Animals	11		13		
Forage OM					
Intake[bd]	15.6	14.0	22.8	19.1	0.4
Digestibility, %[bc]	68.7	50.0	68.0	48.3	0.3
Total OM intake[bd]	16.2	14.6	24.4	20.5	0.4

[a]Dates for intake trials were 20 - 24 Jun. and 15 - 19 Aug. 1988 for experiment 1 and 31 Jul. - 3 Aug. and 11 - 15 Sep. 1989 for experiment 2.
[b]There was a significant effect of date in the model ($P < 0.01$).
[c,d]There was a significant effect of steer age in the model at $P < 0.05$ and $P < 0.01$, respectively.
[e]There was a significant steer age x date interaction ($P < 0.05$).

observed between the 2 intake periods in experiment 2. There was no difference in lignin content between dates in experiment 1 and this may partially explain the smaller differences in organic matter digestibility observed in experiment 1 compared to experiment 2.

Goestch et al. (1990, 1991) has suggested that fall-born calves would have lower capacity than yearlings for consumption of low-quality forages. This was not found to be the case for steers grazing Northern Great Plains rangelands during the summer months. Across both experiments, fall-born steers consumed 39% more forage on a body weight basis than did spring-born steers. Coleman and Evans (1986) found no difference in intake on a metabolic body weight basis between fall- and spring-born calves fed alfalfa pellets. Differences in intake between animals of different age and liveweight may be dependent on forage quality.

Differences in organic matter intake over time varied between years. In experiment 1, steers consumed more forage in the second intake trial than in the first with the opposite occurring in experiment 2. Differences between experiments may be related to the difference in timing of intake studies. In contrast, we previously observed no effect of advancing maturity of eastern Montana native range vegetation on organic matter intake in yearling steers from early May to late October (Adams et al. 1987).

Intake response to protein supplementation on rangeland has been varied. No response (Krysl et al. 1989) or positive responses have been observed (Caton, et al. 1988; DelCurto 1990a,b; Sanson et al. 1990). Differences in response have been suggested to be related to forage quality (Caton et al. 1988) and environmental conditions (Kartchner, 1980). Ward et al. (1990b) found no effect of protein supplementation on forage or total organic matter intake by steers grazing southeastern Montana rangeland in winter. In the current study, total organic matter intake was increased due to supplementation in June during experiment 1, indicating that steers were not substituting supplement for forage at this time.

Animal Performance

Average daily gains were increased ($P<0.01$) by protein supplementation in the first experiment. Final weights were increased by supplementation ($P<0.01$) for fall-born steers but not for spring-born steers or fall-born heifers (Table 5).

In experiment 2, average daily gain of fall-born steers was again increased ($P<0.01$) by protein supplementation (Table 5). Final weights were also increased ($P<0.05$) by supplementation. Spring-born steers and fall-born steers and heifers fed supplement were 18, 20, and 15 kg heavier, respectively, at the end of the grazing period than their nonsupplemented counterparts.

The decreased response of final weight to supplementation observed in the first experiment compared to the second was due to the shorter period that the cattle were fed supplement in experiment 1 (60 days versus 80 days in experiment 2). Although standing crop was not measured, cattle were removed from pastures in August of 1988 due to limited forage during severe drought.

Table 5. Least squares means for weight and average daily gains of steers and heifers in 2 years.

Item	Spring-born steers		Fall-born steers		Fall-born heifers		
	Control	Supplemented	Control	Supplemented	Control	Supplemented	SEM
Experiment 1							
No. of animals	11	13	5	6	7	6	
Initial weight, kg[a]	334	327	205	226	215	212	3
Final weight, kg[abc]	376	380	237**	277**	261	259	3
ADG, kg/day[d]	0.66	0.83	0.50	0.78	0.72	0.74	0.02
Experiment 2							
No. of animals	12	12	12	12	6	5	
Initial weight, kg[a]	383	389	184	183	185	182	3
Final weight, kg[ac]	422	442	241	260	236	251	3
ADG, kg/day[ad]	0.52	0.65	0.71	0.95	0.63	0.85	0.02

[a]There was an effect of animal type ($P < 0.01$).
[b]There was an animal type X supplementation level interaction ($P = 0.05$).
[c,d]There were effects of supplementation level in the model at $P < 0.05$ and $P < 0.01$, respectively.
**Means within animal type differ ($P < 0.01$).

The results of this study show that protein supplementation may be beneficial to growing cattle grazing Northern Great Plains rangelands in late summer and fall. The increase in weight gain can occur without an associated increase in forage intake. Response may be limited, however, if forage availability or quality is decreased due to drought. Younger (fall-born) cattle respond to protein supplementation more consistently than do older (previous year's spring-born) cattle. The decision to supplement should be made based upon expected response coupled with economic and management considerations.

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Preferences of mule deer for 16 grasses found on Intermountain winter ranges

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Abstract

In rangeland revegetation, selection of forages palatable to the primary grazer is crucial. Five tame mule deer were used in the spring and fall to determine forage preferences for 16 grasses commonly found on seeded foothill rangelands. Trials were conducted within a planted enclosure. Cheatgrass (*Bromus tectorum* L.) was the most preferred species in spring, and also preferred in fall. Other preferred species included 'Paiute' orchardgrass (*Dactylis glomerata* L.), 'Luna' pubescent wheatgrass (*Agropyron trichophorum* link.), and fairway wheatgrass (*Agropyron cristatum* [L.] Gaertn). The least preferred grasses were three species of wildrye, 'Vinall' and 'Boisoisky' Russian wildrye (*Psathyrostachys juncea* Fisch.) and 'Magnar' basin wildrye (*Elymus cinereus* Scrib. and Merr.). Results showed a wide range of preferences for grasses.

Key Words: mule deer, seeding, grasses, diet, forage preferences, winter range

The grass component in the year-long diet of mule deer is generally small compared to the amount of forbs and browse consumed (Kufeld et al. 1973). Consumption of grasses is primarily limited to early spring, before ample forbs become available, and fall if late summer precipitation stimulates regrowth (Austin and Urness 1983, Willms and McLean 1978). Availability of nutritious new growth in the fall improves body condition, delays utilization of fat and reduces subsequent winter mortality (Urness et al. 1983, Wallmo et al. 1977). The timing of spring green-up is important to ending overwinter mortality and rapid physical recovery, particularly for lactating does (Moen 1978).

The values of improving depleted or burned big game winter ranges through revegetation are evident, and the selection of species used in planting is critical to success in terms of plant establishment and persistence, erosion control, and increased forage availability and quality (Plummer et al. 1968). The objective of this study was to determine preferences of mule deer for various grasses used for revegetation of big game winter ranges.

Materials and Methods

A combination of species and accessions of grasses (n=16) were selected for evaluation. Grass selections are listed in Table 1. Four replicated macroplots were established in a linear rectangular design with 2 m between macroplots. Each macroplot contained 16 randomly assigned microplots, one for each selection, arranged in a 4 x 4 square. Microplots were separated by 2 m. Within each microplot 16 plants of a selection were established also in a 4 x 4 square on 1 m centers. The only exception was cheatgrass (*Bromus tectorum* L.) which was direct seeded throughout the microplot in fall 1990. All other selections were established as transplants in spring 1990.

The center of each microplot was marked with an identifying color-coded and numbered wooden stake. Plants were watered and weeds were removed during the initial summer (1990) of establishment. Weeds were removed the following spring prior to sampling with deer and again in fall. To investigate differences between deer preferences for irrigated and non-irrigated plants in fall, 2 of the 4 replications were irrigated.

To determine production and nutritive values of selections, before sampling for dietary preferences, 2 plants, ocularly estimated as the mean in size within each microplot, were selected. One-half of each plant was clipped. For cheatgrass, 2 samples were selected to each represent 1/32 of the available biomass on each replication. Thus 1/16 of all plant biomass was removed from each accession. Samples were air-dried, weighed, and subjected to near infrared reflectance spectroscopy (NRI) for nutritional analyses at the Utah State University Soils, Plant and Water Analysis Laboratory.

Sampling for dietary preferences using 5 tame mule deer was completed during spring (5 April to 11 May) and fall (12 to 25 September), 1991. During both periods, deer were transported to a holding pen and maintained for 3 days before the first sampling trial. Samples of all grasses were available within the holding pen to facilitate acclimatization to the selections.

Diets were determined by bite counts (Neff 1974) with individual deer used as replications in the diet analyses. Total bite counts for all trials were converted to dry-weight consumption using air-dry weight of 25 simulated bites for each species. Simulated bites were collected mid-way through the sampling periods. During each trial, morning or evening, all deer were released into the research pasture. A pre-determined sampling schedule for deer was followed with a primary and a secondary deer designated for observation. That is, when the primary deer was feeding, it was observed and bites were counted; observations shifted to the secondary deer when the primary deer was not feeding. When neither the primary nor secondary deer were feeding, observations were shifted to a third deer selected at random. Bites were recorded with hand-held tally registers, and number of bites recorded when the observed deer changed grass selection. A rejection was recorded when the observed deer walked through a selection and failed to take a bite, but began foraging on the next selection encoun -

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Table 1. Production, estimated use, and mule deer diet preferences and nutritional parameters for selected grasses in central Utah during spring and fall, 1991.

	Spring							
	Production		Estimated Use[2]	Diet				
Grass accessions	$\bar{x}$	SE		Consumption	$\bar{x}$	SE	$\bar{x}$	SE
	g/plant[1]			(%)	(Bites/deer)		Rejections/deer	
Cheatgrass *Bromus tectorum L.*	12.3^{bef}	6.0	H	49.6^{a}	3,386	909	0.2^{a}	0.4
Paiute Orchardgrass *Dactylis glomerata L.*	14.0^{be}	5.9	H	17.3^{b}	1,124	489	2.0^{abc}	1.6
Luna Pubescent Wheatgrass *Agropyron trichophorum* (Link.)	14.7^{bcd}	9.5	H	13.2^{b}	820	603	1.4^{ab}	1.3
Kentucky Bluegrass *Poa pratensis* L.	4.9^{hi}	2.3	H	5.2^{c}	823	776	0.8^{a}	1.1
Fairway Wheatgrass *Agropyron cristatum* (L.) Gaertn.	15.8^{abc}	4.5	M	3.4^{c}	277	103	2.8^{ad}	2.7
Crested Wheatgrass *Agropyron desertorum* (Fisch.) Schult	16.8^{ab}	5.7	M	2.5^{c}	248	84	5.0^{df}	5.3
Crested Wheatgrass (wideleaf) *Agropyron desertorum* (Fisch.) Schult	9.2^{egi}	3.3	M	1.5^{c}	174	75	2.4^{ad}	1.7
Mountain Rye *Secale montanum* Guss.	14.9^{bc}	3.2	M	1.5^{c}	177	93	4.6^{cde}	3.4
Hycrest Crested Wheatgrass *Agropyron cristatum* (L.) Gaertn.*A. desertorum* (Fisch.) Schult	20.8^{a}	4.7	L	1.4^{c}	152	37	6.2^{efh}	3.1
Regar Meadow Brome *Bromus erectus* Hudson	10.4^{ceg}	3.7	M	1.1^{c}	190	179	4.0^{bde}	2.1
Smooth Brome *Bromu inermis* Leyss	17.1^{ab}	10.3	L	1.0^{c}	148	80	7.6^{fh}	4.9
Ephraim Fairway Wheatgrass *Agropyron cristatum* (L.) Gaerth	9.5^{degh}	5.0	M	0.9^{c}	153	71	8.2^{hi}	3.1
Vinall Goldar Western Wheatgrass[3] *Agropyron spicatum* (Push) Schibn. and Smith	6.8^{gi}	2.4	M	0.9^{c}	174	146	4.2^{bde}	2.8
Russian Wildrye *Psathyrostachys juncea* (Fisch.)	10.4^{ceg}	3.8	L	0.3^{c}	41	46	11.4^{j}	3.6
Boisoisky Russian Wildrye *Psathyrostachys juncea* (Fisch.)	8.3^{fgi}	6.5	L	0.1^{c}	11	13	11.6^{j}	4.0
Magnar Basin Wildrye[3] *Elymus cinereus* (Scrib. and Merr.)	3.7^{i}	2.7	L	0.1^{c}	12	6	10.8^{ij}	1.9

Fall											
Production		Estimated Use	Diet					Nutritional Parameters			
								Protein		Digestible Dry Matter	
x	SE		Consumption	$\bar{x}$	SE	$\bar{x}$	SE	Spring	Fall	Spring	Fall
(g/plant)			(%)	(Bites/deer)		Rejections/deer		----- (%) -----			
26.7^{f}	16.4	H	15.4^{a}	587	120	3.2^{bc}	1.0	21.2	9.0	72.2	55.4
63.9^{bde}	47.0	H	15.6^{a}	762	434	0.6^{a}	0.5	24.3	12.3	69.8	59.2
28.7^{ef}	11.8	H	16.8^{a}	627	162	3.8^{c}	1.3	27.4	11.1	71.7	56.6
27.7^{ef}	9.3	M	4.3^{bc}	233	206	4.2^{c}	1.9	24.5	14.3	71.4	62.3
59.4^{bf}	49.0	H	8.7^{b}	521	305	0.4^{a}	0.5	28.4	15.3	72.0	60.3
66.2^{bd}	48.4	H	7.0^{bc}	364	203	0.8^{a}	1.1	28.3	14.2	72.8	59.6
41.4^{cdf}	28.7	H	6.2^{bc}	289	208	0.0^{a}	—	27.6	13.5	73.2	58.7
114.9^{a}	111.6	H	6.4^{bc}	308	109	0.6^{a}	0.5	25.0	16.6	70.6	63.6
58.5^{bf}	45.1	H	6.4^{bc}	294	168	1.8^{ab}	1.5	27.1	18.3	71.3	63.9
70.4^{bc}	65.4	M	3.2^{c}	152	279	3.6^{bc}	2.6	27.2	16.8	70.8	61.0
112.6^{a}	86.4	M	2.5^{c}	131	169	3.0^{bc}	1.9	27.5	19.8	72.0	63.6
36.5^{cdf}	26.9	H	5.0^{bc}	389	217	1.8^{ab}	1.3	29.0	16.9	71.3	60.7
50.7^{bf}	40.0	H	1.8^{c}	99	51	6.6^{d}	1.5	26.0	13.6	72.3	59.9

Continued on page 310

Table 1. Continued

Fall											
Production			Diet					Nutritional Parameters			
		Estimated Use						Protein		Digestible Dry Matter	
x	SE		Consumption	$\bar{x}$	SE	$\bar{x}$	SE	Spring	Fall	Spring	Fall
(g/plant)			(%)	(Bites/deer)		Rejections/deer		----- (%) -----			
85.9^{ab}	77.4	L	0.4^{c}	19	28	7.2^{de}	2.8	30.1	20.5	73.2	63.6
56.2^{bf}	58.7	L	0.5^{c}	34	44	7.8^{de}	2.0	29.0	18.8	72.3	62.3
57.8^{bf}	38.1	L	0.1^{c}	8	14	9.0^{e}	1.7	28.7	9.4	71.1	55.5

[1]Within columns, means with the same letter are not significantly different P>.0.05.
[2]Categories of use by %: Light 0-5, Moderate 6-25, Heavy 26+.
[3]Native species.

tered.

Twenty trials were completed in spring, with deer having simultaneous access to all 4 replications. Sixteen trials were completed in fall, with 6 trials on non-irrigated and 10 on irrigated replications. Irrigated and non-irrigated replications were separated by a temporary fence. Trials lasted 2 to 3 hours, and ended when all deer finished foraging.

At the end of spring and fall trials, percent utilization of grass biomass was ocularly estimated for each selection in each replication, by 4 independent observers. Plant use was categorically placed into 3 levels of utilization using the means from the observers: light 0-5%, moderate 6-25%, heavy 26+%.

Data sets from spring and fall were analyzed separately. In spring, because of the extremely high variability between trials in total bites and in dietary choice of bites/deer/selection, all 20 trials were combined. In fall, because diets were not different between irrigated and non-irrigated macroplots ($P > 0.75$), all 16 trials were also combined. To determine differences in dietary preferences and rejections among selections, and the variability among deer, 2-way analyses of variance using the repeated measures design (Neter and Wasserman, 1974, Sokal and Rohlf 1981) were used. That is, grass selections were considered treatments (N=16) and deer were replications (N=5). Contrast comparisons were used to separate differences between treatments. Because conclusions from the statistical analyses for both spring and fall diets were the same for bite count and bite counts converted to consumption, only the statistics using the consumptive values are presented.

To determine differences in biomass production between selections for both spring and fall a repeated measures, 2-way analysis of variance was used. Selections were considered treatments (N=16) and clipped plants were replications (N=8). To relate dietary consumption with selection production and nutritional parameters, coefficients of determination (r^2) were obtained.

Results

Analyses revealed dietary differences among grasses were significant for both spring and fall ($P < 0.001$). A total of 39,557 bites was recorded during spring dietary preference trials and 24,089 in fall.

In spring, cheatgrass was the most preferred selection comprising 49.6% of the diet (Table 1). Paiute orchardgrass (*Dactylis glomerata* L.) and Luna pubescent wheatgrass (*Agropyron trichophorum* Link.) were also preferred. These 3 preferred species comprised 80% of the diet. The 3 selections of wildrye (*Elymus cinereus* Scrib. and Merr. and *Psathyrostachys juncea* Fisch.) received the lowest use and comprised less than 1% of the diet. Variability among deer was not significant ($P > 0.25$).

Dietary choice of selections was similar in fall. The same 3 preferred selections comprised 48% of the diet, and the 3 least preferred selections comprised only 1%. Fairway wheatgrass (*Agropyron cristatum* [L.] Gaertn.) was also selected in preference to several selections (Table 1). Variability among deer was significant ($P < 0.02$).

Analyses also showed rejection differences among grasses were significant for both spring and fall ($P < 0.001$). A total of 416 and 272 rejections of grass selections were recorded in spring and fall, respectively. The number of rejections were inversely related to selection preferences. In spring and fall combined, the 3 selections of wildrye each contributed about 14% of all rejections. 'Regar' meadow brome (*Bromus erectus* Hudson), 'Hycrest' crested wheatgrass (*Agropyron cristatum* X *desertorum* [Fisch.] Schult), 'Ephraim' fairway wheatgrass (*Agropyron cristatum*), smooth brome (*Bromus inermis* Leyss), and 'Goldar' western wheatgrass (*Agropyron spicatum* [Push] Scribn. and Smith) each comprised 5-8% of all rejections. The 8 other selections, including the 3 preferred, each contributed less than 5%.

Differences in dry-weight production among grass selections (Table 1) were significant in both spring and fall ($P < 0.001$). Differences among replications were not significant in spring ($P > 0.50$), but were significant in fall ($P < 0.001$) probably due to differences between irrigated and non-irrigated treatments. In spring, mean production ranged from 3.7 to 17.1 g/plant and in fall from 26.7 to 114.9 g/plant. The coefficients of determination relating percent consumption and plant production showed no significant ($P > 0.50$) relationships ($r^2 = 0.01, 0.16$) for spring or fall.

Utilization estimates mirrored dietary consumption. Use was heavy for the 3 preferred selections, mostly moderate to heavy for the 10 intermediate selections, and light for the 3 wildryes. The highest levels of use occurred on Kentucky bluegrass (*Poa pratensis* L.) at 47% in spring, and 64% for Paiute orchardgrass in fall.

Nutritional parameters among grass selections showed mostly low variability (Table 1) for both spring production and fall regrowth. Except for percent neutral detergent fiber in fall the coefficients of determination (r^2) relating dietary consumption and nutritional parameters were all zero or negative. Most correlations were low ($r^2 < 0.30$). The highest negative correlations between consumption and nutritional parameters were percent protein ($r^2 = -0.59$) and percent total digestible nutrients ($r^2 = -0.50$), both in spring.

Discussion and Conclusions

Deer showed large differential preferences for the available forages. Dietary preferences were confirmed directly by post-trial estimates of forage utilization, and inversely by observations of forage rejections. Results suggest choice of grasses used in revegetation of mule deer winter range may have considerable influence on the degree of grass utilization by deer. Furthermore, in consideration of alternative foraging areas, the choice of seeded selections may influence movement patterns as well as deer numbers. Consequently, revegetation using selections of wildrye might displace deer. Thus, private landowners or highway departments may choose grasses of lower deer preference rankings where perceived competition with livestock for forage or where incidents of deer-vehicle collisions are high. Conversely, managers of wildlife management areas favoring deer should choose grasses preferred by deer.

Even though plant production varied greatly among selections, differences in biomass were not related to deer choices for forages. This was probably due to all forages being adequately abundant, and completion of foraging trials before availability became limiting on any selection.

The nutritional levels of all 16 grass selections in spring and fall were high. Most grasses exceeded 16% protein (dry matter basis), generally regarded as the level where maximum needs of deer are met (Verme and Ullrey 1972, Urness 1973). Digestible dry matter estimates exceeded 60% in most grasses, and all other parameters were high in comparison with other deer forages (Dietz et al. 1962, Tueller 1979), and exceeded nutritive requirements where known (Short 1981). Consequently, even though deer in this study preferred grasses with comparatively lower nutritional level was relatively high.

For seeding rangelands with grasses where use by mule deer in spring or fall is desirable, plantings of Paiute orchardgrass, Luna pubescent wheatgrass, and fairway wheatgrass would be preferred. These grasses would complement seeded browse species, native forbs and ubiquitous cheatgrass. For seeding rangelands with grasses where use by mule deer is not desired, Russian or basin wildrye may decrease use.

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Technical Note: Influence of duration of exposure to field conditions on viability of fecal samples for NIRS analysis

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Abstract

This experiment was conducted to address the issue of spectral integrity of pelleted feces exposed to environmental conditions at different times of the year in near infrared reflectance spectroscopy analysis, using goats as the representative herbivore. Both dietary crude protein and digestible organic matter were predicted. Results indicated that fecal samples collected with up to 7 days of exposure provided similar estimates of diet crude protein and digestible organic matter from samples collected immediately after defecation. Goat feces response to environmental conditions provided useful information as to how collection of many wild herbivores' fecal material could be efficiently sampled for future near infrared reflectance spectroscopy analyses.

Key Words: near infrared reflectance spectroscopy, goats, nutrition, crude protein, digestible organic matter

Recent studies have indicated that near infrared reflectance spectroscopy can be a viable tool to predict dietary crude protein concentration and digestibility via fecal profiling for both cattle and goats (Coleman et al. 1989, Leite et al. 1992, Lyons and Stuth 1992, Stuth 1992). Pearce et al. (1993) indicated that spectral integrity of fresh cattle feces can remain useful up to 9 days post-collection when samples were stored in insulated styrofoam containers with freeze packs and allowed to warm up to room temperature.

Goat fecal deposition and physical characteristics show both differences and similarities when compared to other herbivore species. For example, goat defecation patterns across landscapes are much more dispersed than those of cattle. In addition, moisture content in goat feces is much lower than in cattle feces, being 49-54% and 75-82% (Putman 1985), respectively. On the other hand, goat feces is similar to the characteristic "pellets" of many wild ruminant herbivores (Putman 1985). Given the success of near infrared reflectance spectroscopy fecal profiling technology, it appears feasible to develop these equations for wildlife species as well (Brooks et al. 1984). However, with the widely dispersed nature of goats and wild herbivore populations, freshly defecated samples may be difficult to obtain in a timely manner.

Therefore, the question emerges as to the spectral stability of fecal pellets from small ruminants when exposed to field conditions for extended periods. The current experiment was conducted to address the issue of near infrared reflectance spectroscopy spectral integrity of pelleted feces exposed to environmental conditions at different times of the year, using goats as the representative herbivore.

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Study Area and Treatments

Field Area

The study was conducted at the Native Plant and Animal Conservancy area, near Texas A&M University campus, in College Station (30.37 N, 96.21 W). The area is representative of the Post Oak (*Quercus stellata* Wang.) Savannah region of Texas (Gould 1975). Herbaceous vegetation in the study area was dominated by little bluestem (*Schizachyrium scoparium* var. virile (Shinners) Gould). Other important graminoids present were brownseed paspalum (*Paspalum plicatulum* Michx.), thin paspalum (*Paspalum setaceum* Michx.), and broomsedge bluestem (*Andropogon virginicus* L.). Important forbs occupying the site were Texas croton (*Croton texensis* (Klotzch) Muell. Arg.), redseed plantago (*Plantago rhodosperma* Dene.), and oxalis (*Oxalis dillenii* Jacq.). Yaupon (*Ilex vomitoria* Soland. in Ait.), post oak and common persimmon (*Diospyros virginiana* L.) were dominant woody plants in the area.

Field Methods

The experiment was conducted in 3 trials (February, April, and July, 1992) to study the effect of time of exposure in 3 seasonal conditions (winter, spring, and summer, respectively). Ambient temperature during the trials ranged from 2 to 24° C in February, 3 to 29° C in April, and 23 to 36° C in July. Precipitation events during sampling periods occurred only in February (6.5 mm) and April (5.1 mm).

In each trial, 3, free-ranging Spanish goats (*Capra hircus*) were fitted with fecal collection bags and fresh fecal samples were collected after 4 hours. The same individual goats were used in all trials. These samples were composited and mixed, and 3 fresh subsamples of about 10 grams were collected for immediate near infrared reflectance spectroscopy processing. The remaining fecal material was placed on the soil surface, simulating normal fecal excretion. To prevent trampling damage and mixing with pellets of free-ranging goats, the pellets were deposited in a grazing exclosure and sampled at 12, 24, 48, 72, 96, 120, 144, and 168 hours after deposition. Three, 10-g subsamples were collected at each sampling period.

Laboratory Procedures

All fecal samples were dried at 60° C in a forced air convection oven for 48 hours and then ground in a Udy mill to pass a 1-mm screen. Samples were again placed in the oven for 12 hours to stabilize moisture before scanning (Lyons and Stuth 1992). After removal from the oven, samples were placed in a desiccator for 1 hour to cool to ambient temperature (Lyons and Stuth 1992). Samples were then packed in sample cups with quartz windows, and scanned with a Pacific Scientific near infrared reflectance Scanner 4250 and the spectra generated were stored in a micro-computer linked to the scanner equipment (Williams and Norris 1987). Dietary crude protein (%) and digestible organic matter (%) were determined using fecal near infrared reflectance spectroscopy equations described in a previous study (Leite et al. 1992).

The calibration equation used in this study for crude protein analyses consisted of 163 samples. Five wavelengths resulted in an R^2 of 0.94 with a standard error of 1.12. The validation analysis for crude protein resulted in an R^2 of 0.94 with a standard error of 1.28, a slope of 1.18 and a bias of 0.16. The laboratory standard error for crude protein was 0.91. The calibration equation for digestible organic matter analyses consisted of 86 samples. Four wavelengths resulted in an R^2 of 0.93 with a standard error of 2.02. The validation analysis for digestible organic matter resulted in an R^2 of 0.92 with a standard error of 2.12, a slope of 0.91 and a bias of 0.18. The laboratory standard error for digestible organic matter was 1.98.

Statistical Analyses

The possible seasonal influence on sample stabilization was studied with the analysis of each individual trial through a completely random design method (Freund and Littell 1981, Lentener and Bishop 1986). The periods (hours) of collection after defecation were assigned as treatments. Tukey's Studentized Range Test at 95% level of probability was used to separate differences among treatments (Freund and Littell 1981).

Results and Discussion

Mean near infrared reflectance spectroscopy analyses of crude protein and digestible organic matter content of predicted diets from feces collected throughout 168 hours (7 days) post defecation were not affected (P>0.05) by duration of exposure, regardless of season (Figs. 1 and 2). Standard errors were 0.218, 0.232 and 0.215 for crude protein and 0.354, 0.511 and 0.576 for digestible organic matter, for winter, spring, and summer trials, respectively. Consequently, the slight fluctuations in crude protein and digestible organic matter contents within each season studied could be attributed to random variations in samples collected.

In a study conducted to detect chemical and physical changes over time in fecal pats on the ground, Hinnant and Kothmann (1988) reported that cattle feces collected after 48 and 72 hours of exposure were decimated by insect activity during the summer trial. Researchers in Oklahoma indicated that concentrations of fecal nitrogen, neutral detergent fiber, and acid detergent fiber in deer pellets collected during the fall, remained constant until 24 days after defecation (Jenks et al. 1990). In the present study, fecal sample usefulness for near infrared reflectance spectroscopy analysis did not appear to be affected by the biotic and abiotic factors occurring during the observed trials. In contrast to cattle feces, goat pellets have a low moisture content (Putman 1985), and their fast drying characteristics may be a factor to act against damage caused by insects. Therefore, the small fluctuations in crude protein and digestible organic matter contents throughout the sampling periods may be attributed to the random effects associated with the process of collection, a possible slight variation in botanical composition of the subsamples within each trial, and inherent variations of the near infrared reflectance spectroscopy equation.

Although precipitation can be an important factor affecting degradation rate of fecal pellets (Harestad and Bunnell 1987), this experiment was not designed to examine the effect of precipitation on fecal nutrients concentrations. It was assumed that samples exposed to pre-

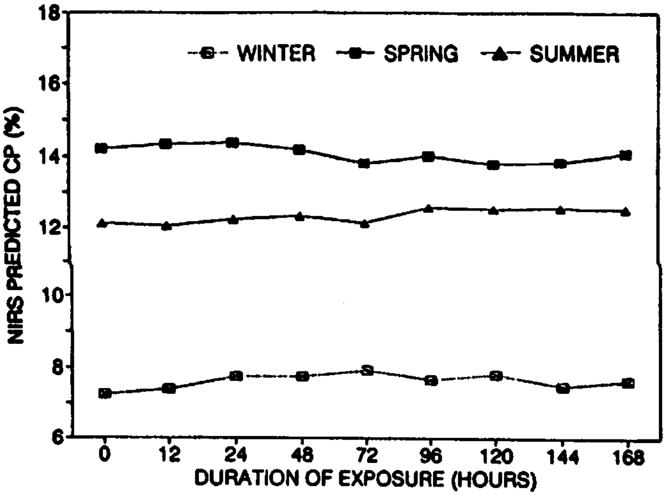

Fig. 1. NIRS predicted crude protein (CP) from fecal material subjected to varying durations of exposure in winter, spring, and summer 1992, in College Station Texas. Means within a season did not differ (P>0.05) among the 9 exposure durations.

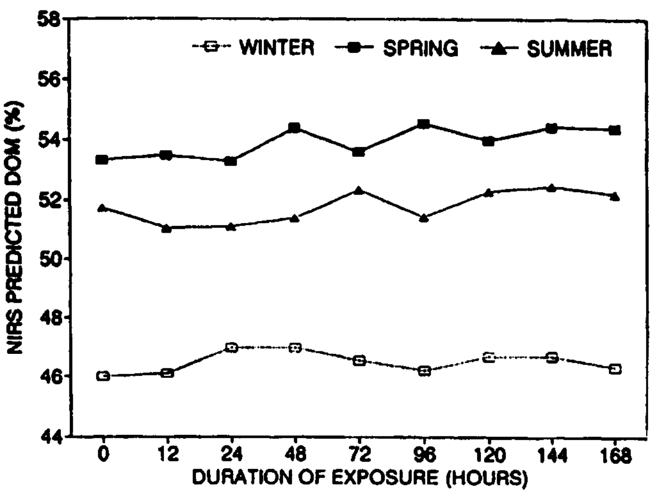

Fig. 2.NIRS predicted digestible organic matter (DOM) from fecal material subjected to varying durations of exposure in winter, spring and summer, 1992, in College Station, Texas. Means within a season did not differ (P>0.05) among the nine exposure durations.

cipitation were unsuitable for near infrared reflectance spectroscopy analysis. Thus, to evaluate time of exposure on pellet groups, the samples were covered during the precipitation events. However, feces exposed to ambient conditions in the field, experienced extreme fluctuations in temperature, sunlight, humidity, and wind within season. Results of the present study indicate that pellet samples from goats exposed to environmental conditions, for periods no longer than 7 days, can be used to predict dietary crude protein and digestible organic matter with similar levels of precision to fecal samples collected at the time of defecation.

Conclusions

Age of goat fecal pellets should not constrain remote sampling strategies for fecal near infrared reflectance spectroscopy monitoring within the sampling period (< 8 days) reported in this research. However, it is recommended that samples be collected as soon as possible after defecation, to avoid possible effects of precipitation, trampling, insect loss or addition, crusting, and the risks of collecting samples with longer periods of exposure than those suitable for near infrared reflectance spectroscopy and chemical analysis.

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Book Reviews

Building Soils for Better Crops. Organic Matter Management. By Fred Magdoff. 1992. University of Nebraska Press, Lincoln. 176 p. $US22.95 cloth. ISBN 0-8032-3160-1.

This short work examines the importance of organic matter in the sustainable agricultural management of soils. According to the author, it was written for farmers, gardeners, extension agents, and students. The technical level of the book is somewhat lower than that of an article in *Scientific American*, to which it is comparable in length.

The text is arranged into three parts. Part 1 consists of four chapters covering the essentials of soil organic matter. The eight chapters of Part 2 examine the management of organic matter in agricultural soils and include such topics as animal manures, cover crops, reduced tillage, crop rotations, composts, and integrated management. Part 3 is slightly more technical, and presents elementary concepts of organic matter dynamics, nutrient availability, and soil chemistry, all in two short chapters. A glossary, a list of recommended readings, and an index follow. Soil management under agricultural practices in East and Midwest are emphasized, but most of the principles, and some of the practices in East and Midwest are emphasized, but most of the principles, and some of the practices discussed are applicable to Western range and agricultural lands. The book contains a few figures, a few tables, but no photographs, in an objective treatment of the subject of soil organic matter, written in a utilitarian style. Any reader looking for fast-paced excitement in a book about humus and compost piles will likely by disappointed.

The audience for this book will be from the groups targeted by the author as stated above. The book would certainly be appropriate for good students in high school agriculture classes. It is actually too elementary for students who have had an introductory soils class at a university. For those who know little about soil organic matter, it is an objective, understandable treatment. —*David L. Scarnecchia*, Washington State University, Pullman, Washington.

Essentials of Conservation Biology. By Richard B. Primack, 1993. Sinauer Associates, Sunderland, Mass. 564 p. US$28.95 hardbound. ISBN 0-87893-722-6.

Conservation biology is one of the most exciting and rapidly growing fields in the natural sciences. Combining scientific interdisciplinary understanding with advocacy, conservation biology has developed to answer the need to confront the growing global loss of biological diversity and of entire ecosystems. Until now there has been no unified overview of the subject that was both accessible and comprehensive. With the publication of *Essentials of Conservation Biology* there is finally a text that can be enjoyed by both academics and non-academics.

Designed as an introductory textbook for undergraduate college students, it would also be valuable reading for anyone involved in conservation issues today. It would be of interest to professionals in natural resource management, journalists who want to write with intelligence about environmental issues, and staff members of natural resource or conservation organizations. In fact, it should be read by business and political leaders as well.

The textbook contains an excellent overview of basic biological concepts including island biogeography, minimum viable population, and other elements fundamental to the understanding of the current situation. It goes well beyond basic biology, discussing the history of conservation, the ethical values associated with species preservation, the economics of conservation biology, conservation strategies, and legal aspects applicable to ecosystem and species conservation both nationally and internationally. Sample chapters include: *What is Biological Diversity?; Habitat Destruction, Fragmentation, and Degradation; Population Biology of Endangered Species; Designing Protected Areas; and Working with People and Restoring the Environment.*

Essentials of Conservation Biology is easy to read because it has a minimum of technical jargon. When jargon is used, terms are defined so that anyone with a basic interest in the topic will not be overwhelmed. Nearly every concept is illustrated with real life situations or examples. There is an abundance of illustrations including maps, charts, and photos that are understandable. Sidebars highlight current controversies such as *owls vs. jobs, giant panda, decline of fungi in forests*, and other relevant topics. The bibliography has over 1000 references covering the latest literature and concepts.

Read this book and you will come away with a firm understanding of the biodiversity crisis as well as the multitude of issues, ideas and strategies swirling around the discipline today. —*George Wuerthner*, Livingston, Montana.

The Grass Genera of the World. By Leslie Watson and Michael J. Dallwitz. 1992. CAB International, Wallingford, UK. Available in the US from University of Arizona Press, Tucson, AZ. 1038 p. $US $142.50 hardbound. ISBN 0-85198-802-4.

This work provides alphabetically arranged descriptions of 778 genera of the grass (*Poaceae*) family from a computer-generated data bank of taxonomic characters. Over the past twenty years, the authors developed a computer software system DELTA for detailed representation and convenient manipulation of taxonomic descriptions. This book is the first hard-copy version of that data bank, automatically typeset without additional editing.

Organizationally, the book begins with 6-page introduction explaining the history of the project, the development of the DELTA system and its support programs, and a description of shortcomings of the system. Next are 37 pages of a list of 496 characters used to describe each genus in the DELTA system. The characters describe variables of the genera, including their vegetative and flowering morphology, their cytology, physiology, ecology, economic importance, and geographic distribution. Part 3 is a brief chapter on classification, focusing on the division of the *Poaceae* into subfamilies, on the specifics of the *genus* taxon, and generally on the history and development of phylogenetic classification. Section 4 consists of the genus descriptions, and is followed by a list of references and sources of data. An appendix consisting of a list of species sampled for leaf blade anatomy follows. An index of plant names completes the book.

The Grass Genera of the World will have great value exclusively as a reference book primarily for agrostologists and other taxonomists. The genus characteristics described include variables relevant to management (e.g., economic importance, geographic distribution), but taxonomic characters dominate the descriptions. Special-levels taxonomy tends to be more important in management anyway, so the generic description, however thorough, are inherently limited in their value for management. The book succeeds in condensing voluminous information into, in the authors words, a "tolerably readable form." Characteristics of a flora, the text is a terse unsyntactic phraseology, in this case unembellished by any photographs, drawings, or graphics of any kind. It is tolerably readable. The technical taxonomic terms come unhindered by wasted words, so a glossary of terms, not provided by the book, would be indispensible to all but the taxonomic specialist. — *David L. Scarnecchia*, Washington State University, Pullman, Washington.

Sagebrush Country. A Wildflower Sanctuary. By Ronald J. Taylor. 1992. Mountain Press Publishing Company, Missoula, Montana. 221 p. US$12.00 paper. ISBN 0-87842-280-3.

Sagebrush Country is a colorful, ecological field guide to the plants, especially the wildflowers, of the Intermountain sagebrush steppe. Beyond that, its striking color photographs showcase the undeniable beauty of the sagebrush steppe, not just of its species individually, but of its plant communities and their geographical setting.

Three-fourths of the book consists of popularized scientific descriptions and good color photographs of the most important species of major plant families arranged alphabetically by family common name. Scientific names of the families are provided. Plant descriptions are variable in content, and may include characteristics of morphology, value as indicators of site characteristics, poisonous effects on humans or livestock, grazing value to wildlife or livestock, reproductive characteristics, soil preferences, and numerous others. Seldom are all of these characteristics discussed for a single species. Notable curiosities of species are usually mentioned. The concept of plant communities is used throughout the descriptions, and the roles of species within communities and generally within the sagebrush steppe are emphasized.

The book has a good introduction consisting of short sections on vegetative zones, plant adaptations, origins of plant names, pollination strategies, and animals of the sagebrush steppe. Here again, the color photographs are fine. One page of instruction on how to use the book follows the introduction and precedes the plant species. Following the plants is a non-technical dichotomous key to only the families of plants represented in the book. Appendix II is a list of scientific names of species according to the vegetative zone within the sagebrush steppe that they most frequently inhabit. Following the appendices, some simple morphological drawings of flowers, inflorescences, and leaves, a brief glossary of morphological terms, a cross-reference of scientific and common names, and indexes of scientific and common names, all aid in using the book.

Sagebrush Country is a well-designed field guide which could be useful to anyone interested in learning about the Intermountain sagebrush steppe. Even those long familiar with the region will appreciate the book's fine photographs and clear, readable text. —*David L. Scarnecchia*, Washington State University, Pullman, Washington.

Wildlife-Habitat Relationships: Concepts and Applications. By Michael L. Morrison, Bruce G. Marcot, and R. William Manna. 1992. The University of Wisconsin Press, Madison, Wisconsin. 343 p. US$26.95 cloth. ISBN 0-299-13200-5.

The authors reveal that this text was conceived during discussions at the 1984 symposium--Wildlife 2000: Modeling Wildlife Habitat Relationships of Terrestrial Vertebrates. The book assumes the reader's competence in basic principles of inventory and monitoring wildlife and their habitats. Many of the most noteworthy and familiar introductory wildlife management texts are cited in the preface; but this book begins its journey where these other texts have made port. Its message speaks best to graduate students and professionals in ecology and various disciplines of natural resource management, but can be called upon to test the metal of advanced undergraduates. The theoretical concepts and applied aspects of wildlife habitat relationships are covered in greater depth than by any previous stories in this arena. An emphasis is placed on critical evaluation of both methodologies and their application by the biologist. Both classic studies and the most recent advances in wildlife habitat relations are presented. Literature on amphibians, reptiles, birds and mammals of temperate latitudes is called upon with a refreshing, but not exclusive, non-game flavor.

The text is organized into seven chapters with black and white photographs and numerous figures and tables for clarification and referral. Chapter 1 presents an historical view of studies in natural history and ecology, and legislation that prompted study, preservation, and management of wildlife habitat. Chapter 2 discusses why a population of animals is found in a particular area. Its distribution and abundance are mediated both by existing factors and through adjustments to previous factors (climatic, evolutionary, geologic, and competitive history) which may now be absent or declining in influence. The concept of habitat selection is treated with a review of classic papers on the subject. Chapter 3 defines landscape ecology, the dynamics of patches, and provides guidelines for management fragmented environments and planning for human presence in the landscape. Fragmentation is shown to affect species richness, population trends, and biological diversity either favorably or unfavorably, and the previous hailing of "creating edge wherever possible" is brought under closer scrutiny. Chapter 4 reviews five major aspects of analyzing habitat - who, what, when, where and how to measure it. Chapter 5 deals with the theory, measurement and analysis of foraging behavior, in essence the study of how an animal perceives its environment. The final two chapters review models to predict habitat relationships (i.e., HEP, HSI, PATREC, habitat preference, optimum foraging), their inherent uncertainty, and their validation. Multivariate statistical techniques (ordination, cluster analyses, multiple regression, discriminant analyses) are reviewed to conceptualize habitat relationships.

The strengths of this book are its depth and level of coverage, its blending of classic and cutting edge literature, and its courage to discuss statistics with biologists. I encourage researchers and managers in natural resource sciences and college instructors of graduate level courses in wildlife habitat concepts to review this book and come to their own conclusions. —*Bruce B. Davitt*, Wildlife Habitat Lab, Dept. Natural Resource Sciences, Washington State University, Pullman, Washington.

The Grass Genera of the World. By Leslie Watson and Michael J. Dallwitz. 1992. CAB International, Wallingford, UK. Available in the US from University of Arizona Press, Tucson, AZ. 1038 p. $US $142.50 hardbound. ISBN 0-85198-802-4.

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(Handbook and Style Manual for the *Journal of Range Management*

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1 July 1994

Third Edition, First Printing

Preface

This *Handbook and Style Manual* is not intended as an exhaustive presentation of manuscript preparation. Points of style, however, must be followed by all authors. Manuscripts not conforming to *JRM* style as designated here will be returned to authors for correction before being sent out for review. The inside back cover of the *Journal of Range Management* will carry brief instructions for authors and will advise them of style changes or a new edition of the style manual.

Introduction

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The *Journal of Range Management* is a publication for reporting and documenting results of original research. Previously published papers are unacceptable and will not be considered for publication. Exceptions to this criterion are selected invitational papers and research results that were originally published as Departmental Research Summaries, Field Station Reports, Abstracts of Presentations, and other obscure, non-technical handout publications. Manuscripts submitted to the *JRM* are the property of the *Journal* until published or returned to the author(s). Manuscripts may not be submitted elsewhere while they are being considered for this journal. Papers not accepted for publication are automatically released to the authors.

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Address contributions to the Editor, *Journal of Range Management.* Prepare manuscripts according to the instructions in this handbook. The *JRM* Editor must be notified if the manuscript is to be one of a series. Four quality copies of the complete manuscript, typed double spaced on paper with numbered lines, are required. Also included in the submission are the completed Manuscript Submission Form and the Copyright Release Form signed by all authors (See Appendix). Authors should retain original figures until the paper is accepted. Good quality photocopies are required for the review process. Manuscripts that do not follow the directives and style in this handbook will be returned to the authors. Upon receipt of the manuscript in the appropriate format, a manuscript number and submission date will be assigned by the *JRM* Editor Authors are informed about subsequent steps in review, approval or release, and publication.

Manuscript Review

Manuscript reviews are conducted by an Associate Editor, who obtains 2 or more anonymous reviews. These reviews are a critical evaluation to assess the scientific and literary merits of the manuscript. Where reviewers disagree, the Associate Editor, at their discretion, may obtain additional reviews before accepting or rejecting a manuscript.

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Manuscripts found inappropriate for the *JRM* are released to the author by the Associate Editor. Authors who believe that their manuscript has not received a satisfactory review may file an appeal, including copies of all correspondence relative to the review of the manuscript, with the *JRM* Editor. The Editor will then determine the validity of the complaint and decide if a second review is warranted. If the appeal is sustained, a new review of the manuscript by another Associate Editor may be implemented at the discretion of the Editor.

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Every paper should be written clearly, and concisely. It should lead the reader from a clear statement of previous work, objective, materials and methods, results, and discussion to significance of results. The data should be reported in coherent sequence, with a sufficient number of tables and figures to clarify the text. The narrative discussion is the minimum necessary to explain the study and results. Tables, figures, and narrative should not duplicate each other.

Manuscripts should be critically reviewed by appropriate colleagues before submission to *JRM*. Peer review before submission will speed *JRM* review processes. It is not the task of the Associate Editors or *Journal* reviewers to edit poorly prepared papers or to correct readily detectable errors. Papers not properly prepared will be returned to the author.

Organization of the Manuscript

Title Page

Each manuscript shall have a single page "Title Page" set in the format shown in the Appendix. Titles are the first introduction to a manuscript. A good title briefly identifies the subject, indicates the purpose of the study, and contains key words. Titles should not exceed 10 words.

Common names of chemicals, plants, and animals will be used in titles. If a species has no common name, then the genus and species will be used.

Additional Key Index Words

Index words amplifying the title are placed on the Title Page. Four to 6 additional phrases and words for indexing and abstracting services are listed.

Abstract

The abstract is the first section of the manuscript and constitutes page 1. The word *Abstract* shall be centered at the beginning of the page. The abstract must be a completely self-explanatory paragraph. The abstract is a short literary adjunct to the scientific report. A person reading the abstract should be able to determine quickly the value of the report. The abstract should state the problem investigated, indicate the methods used, summarize the major findings, and indicate the significance of the results.

The abstract includes the justification, objectives, methods, and conclusions of the researcher. It should call attention to new items, observations, and numerical data. Names of plants, animals, insects and pathogens must be shown in both common and scientific form the first time they are mentioned. Further mention may be by common name only. Expressions such as "is discussed" and "is described" should be avoided. Specific rather than general statements must be used, especially in the methods and results sections of the abstract. For example, do not say, "2 rates of P," but instead, "rates of 40 and 80 kg ha^{-1} P." Instead of saying, "The P content of the plant was increased," say, "A x µg g^{-1} increase in P was obtained." References are not cited in the abstract. The length of the abstract should not exceed 250 words for full length papers and 75 words for notes and brief articles. The abstract should be written last, to insure that it reflects accurately the content of the paper.

Introduction

The introduction section is the beginning of the manuscript text. The word *Introduction* shall be centered at the top of the second page; the text starts immediately below it. Introductions should be kept short, usually not more than 200 words, but still include: (1) a brief statement of the problem or hypothesis being tested; (2) a brief literature review, including the findings of others that will be challenged or developed; and (3) an explanation of the general approach and objectives. The third part may indicate the means by which the question was examined, especially if the methods are new. References should be **limited** to that information which is essential to the reader's orientation. Both common and scientific names of plants, animals, insects, and pathogens must be used the first time they appear in the text, even if they occurred in the abstract. Further mention should be by common name only.

Materials and Methods

This section contains details about the study area, materials, techniques, experimental design, and environment. Sufficient detail must be provided to permit the reader to repeat the experiments. Standard methods or techniques should be referenced. Modifications of standard methods should be fully outlined. The methods section may be arranged in a chronological pattern, succession of techniques, or any manner which will effectively assist the reader in studying the paper.

Results

Use tables, graphs, diagrams, and photographs to provide a clear understanding of the results. Data included in illustrations and tables should be discussed briefly in the text, and significant findings emphasized. Show how the objectives have been achieved. A common fault is to repeat in prose what is already clear from an examination of the graphics Well-designed tables and figures expose both results and experimental design. Text discussion is limited to make the object of each experiment clear; to point out special features, such as one quantity being greater than the other, one result is linear over a range, or what the optimum value is. Finally, results should be linked together This may be accomplished by combining the results section with the discussion section.

Discussion and Conclusions

The discussion section is used to assess the meaning of the results in terms of the problem or hypothesis outlined in the introduction. Results are compared to previous work. Conclusions and discussion from data should be clearly stated. The significance and implications of the work is indicated as well as probable future developments. Speculation or conjecture that is not clearly supported by data is acceptable but must be identified, reasonable, and firmly founded in observation. Controversial issues should be discussed clearly and fairly. Where results differ from previous results, the differences should be explained.

The conclusions may be a part of the discussion section. For long and complex manuscripts, it may be helpful to present the conclusions in a separate section. This should not be a separate summary. This section includes any significant conclusions that have been drawn from the research. These statements should be carefully worded so there is no misunderstanding on the part of the reader.

Literature Cited

The literature cited list must be double spaced and include all **published** works referred to in the text. There must be a text citation for each reference in the Literature Cited section and vice versa. **Each reference to a periodical publication** must include, in order, the name(s) of the author(s), year of publication, full title of the article, the publication in which it appears, and the volume and inclusive page numbers. **Reference to a book or bulletin** must give the author(s), the year, title, edition, if other than the first, publisher, city of publication, and number of the volume (if two or more). **For symposium proceedings,** the editor, date and place of the symposium, publisher, and city of publication must be included. Except for proper names that occur in the titles of articles, bulletins, or books, **capitalize only** the first word in a title.

Authors should be cited as follows: Jones, A.H.; or Smith, A.H., and J.H. Doe. Initials and names should be listed as found in the referenced article. **Arrange the list alphabetically** by the names of the first authors and then by the second and third authors, as necessary. Two or more articles by the same author (or authors) are listed chronologically; 2 or more in the same year are indicated by the letters a,b,c, etc.

Abbreviate names of federal agencies when such abbreviations are commonly used and clearly understood (USDA, ARS, SCS).

Abbreviate state names using the dictionary abbreviations for states, not the 2-letter postal abbreviation. (See Common Abbreviations).

Periodical titles are abbreviated from the list of abbreviations prepared by the American National Standards Institute. (See Appendix). Consult the CBE Style Manual for examples of the various types of literature citations. A few of the more common types are shown below.

Examples

Transactions

Bower, C.A. 1960. Sodium electrode and its use for salinity investigations. Int. Congr. Soil Sci. Trans. 7th (Madison, Wis.) 11:16-21.

Bulletin

Bryand, M.S. 1951. Bibliographic style. USDA Bibliogr. Bull. 16. Washington. D.C.

Monograph series

Childs, E.C. 1957. The physics of land drainage. *In:* J.N. Luthin (ed.) Drainage of agricultural land. Agron. 7:1-78. Amer. Soc. Agron. Madison, Wis.

Technical or other report

Cloyna, E.F., E.F. Herman, and W.R. Dryman. 1955. Oxidation ponds-waste treatment studies, radio isotope uptake and algae concentration. Univ. Texas Dep. Civil Eng. Tech. Rep. 2 (Also AECU-3113). Austin, Tex.

Foreign language periodicals

Gavrilov, K.A and T.S. Perel. 1958. Earthworms and other invertebrates in the soil under forest in Vologda region. (In Russian). Pochovovedeniyc 1958(8):133-140.

Advances in Agronomy series

Heinrichs, D.H. 1963. Creeping alfalfas. Adv. Agron. 15:317-337.

Chapter in book

Severson, Kieth E. 1981. Plains habitats, p. 459-485. *In:* Olof C. Wallmo (ed.), Mule and black-tailed deer of North America. Univ. Nebraska Press, Lincoln, Neb.

Journal Article
Scifres, C.J., J.R. Scifres, and M.M. Kothmann. 1983. Differential grazing use of herbicide-treated area by cattle. J. Range Manage. 36:65-67.

Dissertation or thesis
Rafferty, N.S. 1958. A study of the relationship between the pronephros and the haploid syndrome in frog larvae. Ph.D. Thesis, Univ. Illinois. Chicago, Ill.

Book
Heady, Harold F. 1975. Rangeland management. McGraw-Hill Book Co., New York, N.Y..

Miscellaneous publication
Van Dersal, W.R. 1938. Native woody plants of the United States, their erosion-control and wildlife values. USDA Misc. Pub. 303. Washington, D.C.
Chojnacky, D.C. 1986. Pinyon-juniper site quality and volume growth equations for Nevada. USDA For. Serv. Res. Paper INT-372.Washington, D.C.

Proceedings paper
Squires, V.R. 1978. Distance trailed to water and livestock response, p. 431-434. *In:* D.N. Hyder (ed.), Proc. 1st Int. Rangeland Congress Soc. Range Manage. Denver, Colo.

Society
American Phytopathological Society, Committee on Standardization of Pungledal Tests. 1948. Definitions of fungicide terms.

State
Wisconsin Agricultural Experiment Station. 1950. What's new in farm sciences; 65th annual report 1948/49. Part I. Wisconsin Agr. Exp. Sta. Bull. 491. Madison, Wis.

Federal
U.S. Salinity Laboratory Staff. 1954. Quality of irrigation water. p. 75-81. *In:* L.A. Richards (ed.) Diagnosis and improvement of saline and alkaline soils. Agr. Handb. USDA, U.S. Government Printing Office, Washington, D.C.

Do not put an unpublished work in the Literature Cited list unless it has been approved and a date set for its publication. Unpublished results, other source material, unpublished references such as personal communication, mimeo reports, etc., are cited in parentheses immediately following the area where they appear in the text, for example (Unpublished data, Scifres et al.).

Manuscript Preparation

Statistical Methods

Data must be analyzed and summarized by statistical methods appropriate to the design of the experiment or survey. The design should be briefly and clearly described. The data population should be discussed and the experimental unit identified.

Statistical methods commonly used in the biological sciences do not require presentation of mathematical formulas. Those infrequently used need not be described in detail, but adequate references should be given for them.

Standard designs are adequately described by name and size; for example, "a 6 X 6 Latin square." For a factorial set of treatments, an adequate description might be:

> Tryptophan at 0.05 or 0.01% of the diet and niacin at 5, 10, or 20 mg kg^{-1} of diet were fed in a 2 X 3 factorial combination arranged in a 6 X 6 Latin square with 6 animals per experimental unit.

For the report of a study having a completely randomized design, the following description of the design might suffice:

> Ten varieties were each assigned to 4 replications in a completely randomized design.

Emphasize the science, not the statistics. A simple statement of the results of statistical analysis should justify the interpretations and conclusions. Do not report a number of similar experiments separately. When a standard deviation or standard error is given, the number of degrees of freedom on which it rests should be stated. Give only meaningful digits. A practical rule in statistics is to round so that the change caused by rounding is less than one-tenth of the standard error. Such rounding increases the variance of the reported statistic by <1%, sacrificing <1% of the relevant information the data contain.

Conversion Rules

1) To convert means from one scale to another, the standard error of the means, the L.S.D., or similar measure used to evaluate or compare means is converted by the factor used for the conversion of the means.

2) In regression studies each regression coefficient is converted by the product of the factor used to convert the Y variable and the reciprocal of the factor used to convert the corresponding X variable.

3) Certain measures require no conversion because the computation involves the ratio of 2 values that both require the same conversion factor. The *F* value, Student *t*, the correlation coefficient, chi-square and the coefficient of variation are in this category.

4) The factor for converting the variance of the mean square of a variable (or some subdivision of the of the mean square, such as a variance component estimate) is obtained by squaring the factor used to convert the variable itself; e.g., if a variable measured in lb $acre^{-1}$ is converted to kg ha^{-1}, the conversion factor for the variance would be $(1.12)^2$.

5) The factor for converting the covariance between 2 variables is the product of the factors used to convert each variable.

Computer printout of data and pertinent statistical analyses may be used with approval of the Editor as manuscript or typesetter's copy, if properly planned, and of high quality for photographic reproduction and printing. Useful references on statistics include Cochran and Cox 1957, Snedecor and Cochran 1967, and Steel and Torrie 1980.

Treatment Comparisons

Multiple comparison procedures are frequently used inappropriately. Such misuse may result in incorrect scientific conclusions. For example, loss of power results from the use of a multiple range test when single degree of freedom contrasts or other logical comparisons are appropriate. Multiple range tests should be used only when the treatment structure is not well understood (e.g., studies to compare cultivars). The following instances are considered misuses of multiple comparison procedures:

1. Use of multiple range tests or other pairwise procedures when treatments have an obvious structure and/or when planned single degree of freedom contrasts were built into the experiment;
2. Use of a multiple range test or other pairwise procedure to compare means from quantitative treatments such as rates of fertilizer, plant density, seeding rate, or time;
3. Comparing factorial treatment combinations by multiple range tests without consideration of the estimation of main effects and interactions.

Whenever possible, treatment comparisons that are logical from a scientific standpoint should be made as single degree of freedom contrasts as part of the analysis of variance. The analysis of variance table is needed when it helps to interpret interactions.

Validation of Field Results

Experiments, such as field studies of above-ground biomass, that are sensitive to environmental interactions and the environment is not rigidly controlled or monitored, **should** be repeated (over time and/or space). Two or more environments may be necessary to obtain meaningful results. Repeatability must be established. There are cases where replication is difficult to achieve because of the availability of study areas, problem of scale, or other reasons. In these instances the methods should clearly state the absence of replication and describe the problem it presents in interpretation. Descriptive statistics should be used to analysis unreplicated research.

Presentation of Statistical Material

Errors in transcription of equations and formulas is a potential source of typesetting error. The author may elect to prepare equations to be stripped into the typeset page or as a plate containing all equations. Such presentations must be professional in appearance and subject to approval of the Editor.

Avoid vertical fractions within the text. Most typesetting equipment has fonts with Greek alphabet and common mathematical symbols, but accents and characters from some foreign languages may present difficulties.

Symbols and Abbreviations to be Used

Population parameters	Sample statistics	Explanation
	n, **N**	Total number of individuals or variates
μ		Mean of population
	$\bar{x}$	Arithmetic mean of the sample
σ^2		Variance of population
σ		Standard deviation of the population
	s^2	Sample variance
	sx, **SE**	Standard error of mean sample
	C.V.	Coefficient of variation
	t	Statistical datum derived in Student's t test
	X^2	Statistical datum derived in the chi-square test
	p, **P**	Probability of rejecting null hypothesis when indeed it is true (significance level)
ß		Regression coefficient of the population
	b	Regression coefficient of the sample
p		Population coefficient of linear correlation
	r	Sample coefficient of linear correlation
	F	Variance ratio

Units of Measurement

The International System of Units (SI), including derived units, will be used. The base units (with abbreviations) of SI are meter (m) for length, kilogram (kg) for mass, second (s) for time. Acceptable deviations from SI are:

Area-Hectare (ha) in lieu of square meters,
Energy-Calorie (cal) in lieu of Joules,
Temperature-Celsius (C) in lieu of Kelvin (K)
Time-Min, hour, day in lieu of seconds, and
Volume-Liter in lieu of dm^3.

Appropriate prefixes (i.e., kilo, milli) can be used to reduce the use of insignificant digits and decimals. A prefix preferably should be chosen so that the numerical value is between 0.1 and 1000. Usually, the prefixes hecto and deka should be avoided, but they are acceptable.

Reporting Time and Dates

Time. The 24-hour time system is preferred. Time is indicated by 4 digits-the first 2 for hours, and the last 2 for minutes. In this system, the day begins at midnight, 0000, and the last minute is 2359. Thus, 2400 of 10 June 1975 is the same as 0000 of 11 June 1975.

Dates. Use the following style with the day of the month first, then the month, followed by the year. 18 Dec. 1975; 4 July 1976, 18 May.

Tables

Tables are for presenting extensive numerical data in an organized manner. They should be self-explanatory. Data presented in tables should not be duplicated in figures nor discussed extensively in the text. Table captions should be brief, but sufficiently explanatory of the data included, and should include the units of measurement. Number the tables consecutively and refer to them in the text as Table 1, Table 2, etc.

Use no more digits than the accuracy of the method justifies. Do not include columns of data that can be calculated easily from other columns. In general, only horizontal rules are used: a double rule at the top, a single rule below the boxhead, and a single rule at the bottom, just above the footnotes. Additional horizontal rules may be needed under spanner heads and subheads.

Two types of footnotes are used with tables: those to show statistical significance and those to give supplementary information. If tables present information on means, some statistical indication of variability is required. The * and ** are always used in this order to show statistical significance at the 0.05 and 0.01 levels, respectively, and cannot be used for other footnotes. The designation *** may be used, with explanation, for significance at the 0.0001 level. Supplementary notes are given by superscript numbers, i.e., [1,2].

Numbers with the same unit and or equal length should be centered in the column. If they are unequal, center the longest one and align the rest on the decimal point. If a column contains various units, like units should be aligned, but different units may be centered differently. Indicate italics by underlining if italic lettering is not available on the typewriter used. Tables should be double spaced. Type each table with its heading on a separate sheet with headings included. Tables with more than 15 columns cannot be accepted (see example table in appendix).

		Spanner head (if applicable to all Columns)		
		Subspanner head		
Sub head[2]	Column head	Column head[3]	Column head[4]	Column head[5]
	(units)	(units)	(units)	(units)
	Independent line			
Main entry line				
Sub entry line			536**	
Subsubentry line		203		
Subentry line	105*			
	Independent line			
Main entry line				
Subentry line				

*, ** Significant at the 0.05 and 0.01 levels respectively.

[1,2,3,4,5,6] Supplementary notes.

Figures (Illustrations)

Figures are another means for presenting scientific data. They are expensive to publish and should be easily interpreted. Figures must not duplicate material given in tables or text. Figure drawings and photographs must be of good quality. The Editor or Associate Editors have the authority to reject inappropriate drawings or photos.

A figure caption is a brief explanation of the data, and must stand alone. Appropriate statistics must be included in the figure or caption. Identification of the curves or other parts is generally included in the figure itself. Refer to figures as Fig. 1, Fig. 2, etc., in the captions and in parentheses in the text (Fig. 1.). Otherwise, use Figure; for example, "as is shown in Figure 1." Type all captions together on a separate sheet. Draw or mount each figure on a separate 21.6 X 28-cm (8 1/2 X 11-inch) paper.

Preparing the Drawing

Size: Drawings are to be submitted in the size they are to be when printed. Acceptable widths are 3 1/2 (single column) or 7 1/8 inches (double column). Figure heights should not exceed 8 1/2 inches (see acceptable figure sizes in appendix).

Materials: Use white drawing paper or tracing vellum and black ink. If computer-generated figures are used, they must have sharp, dark lines. Pencil drawing or typewriter lettering are not acceptable for publication. Copy machine reproductions of figures are adequate for the review process. Original drawings or are required for publication.

Consistency: Figures in a paper should have a consistent format of style. Overbold drawings interspersed with delicate drawings and a mixture of lettering styles are unacceptable.

Sending Drawings: Drawings sent through the mail should be supported by cardboard. Loss of materials in transit is always a possibility. The original or a good-quality reproduction should be kept on file.

Photographs (Shaded Material)

A photograph should be used only if it shows something essential for the point being made. Authors should examine their photographs carefully and determine whether each one shows something unique, interesting, and clearly identifiable.

Photographs should provide a point of reference for the reader. A ruler or other length indicator is a simple point of reference in a photograph. Indicate the magnification of photomicrographs in the legend and or include a bar indicating scale.

Provide glossy prints of approximately 20 X 25 cm; if possible, small photomicrographs should be mounted. Slides are unacceptable. Letters or numbers on the photographs must be large enough to withstand reduction. Letters and numbers in a series of prints should all be of uniform height and density, clear, and legible. Equally important, especially on photomicrographs, is the necessity of contrast between written material added to the picture and its background.

Protect one-of-a-kind photographs. The publication process takes several months, and you may need duplicates for other purposes.

Black-and-white photographs are preferred. For certain studies, color maybe essential to show contrast. The cost of publishing color photographs may be prohibitive for a single paper. Group papers requiring color may be combined in a single issue so that several authors can bear the cost Authors interested in such a procedure should contact the *JRM* Editor.

When 2 or more photographs or drawings are to be combined into a single figure, the parts should be mounted together on paper or lightweight cardboard. It is the author's responsibility to prepare the composite figure. Collections of drawings or photos to be composited will be returned to the author. Be certain that each part of the copy is trimmed square and that all photos lie flat and fit snugly together without excess paste or other mounting material around the margins. Each part of a composite figure must be clearly identified on the figure and the caption by letters, e.g., A, B,...

Writing on the back of a photograph should be done with a china-marker pencil, *not* ball point pen. Name of author, short title of the article, and figure number are required. Provide all figure captions, typed, double-spaced, on a separate sheet of paper.

If a named person or named product is shown in a photo, written permission must be obtained by the author from the person or the manufacturer of the product for use of the photo. The Society is not responsible for any claims that may result.

Common Abbreviations

1) Abbreviate metric units used with numerals, except metric tons and liters.

2) State names are spelled out when used alone and are to be dictionary abbreviated when used with city or county.. (See Appendix)

3) Use the % sign with numerals; otherwise, spell out percent or percentage.

4) Names of months in text are spelled out. In footnotes, tables, and references, always abbreviate the month. Accepted abbreviations are as follows:

Jan.	Apr.	Jul.	Oct.
Feb.	May	Aug.	Nov.
Mar.	Jun.	Sep.	Dec.

5) In a series of measurements, give the unit at the end; i.e., 2 to 10 km; 3,6, and 8 cm.

6) Do not begin a sentence with an abbreviation. If a number is spelled out at the beginning of a sentence, and it is followed by an abbreviation, spell out both the number and the abbreviation; i.e., Ten milliliters, not Ten ml.

7) Spell out short units of measure, such as hour, day and liter. Milliliter is abbreviated ml.

8) United States is abbreviated U.S. when it is modified or used as a modifier, i.e., U.S. Government. Well-known government units may be abbreviated, i.e., USDA-ARS, etc., without spelling them out the first time in footnotes and references. Certain abbreviations, such as the 2 preceding, are commonly written without periods.

9) Coefficient of variation or coefficient of variability is abbreviated C.V. Do not abbreviate mean, mode, or median in text except as follows: x may be used in tables to represent the mean and as follows in the text example: "Yield was greater ($P<0.05$) in July($x=60$ g m^{-2}) than in June ($x=30$ g m^{-2})."

10) For a single species, such as one that has already been cited, use sp.; for example, if *Avena sativa* L. was cited, the author may later call it *Avena* sp. However, spp. is used to denote more than one species of the same genus; the author may mention several *Avena* species in the paper and then use *Avena* spp. to indicate they mean all of them.

11) Use the abbreviation "Lat" and "Long" in expressions such 30°10'5"N Lat or 20°50'15"W Long. When used together, an abbreviation is not needed: 30°10'5"N 20°50'15'W.

12) Limit the use of acronyms to commonly known words. Most people do not read a paper from front to back. Acronyms tend to make a paper difficult to read for someone not familiar with the subject.

Abbreviations Used

animal unit month	AUM
atmosphere	atm
average	avg
Celsius	C
coefficient	coef
concentration	conc
degrees of freedom	df
diameter	diam
dry weight	dry wt
grams	g
kilogram	kg
hectare	ha
least significant difference	L.S.D.
meter	m
micron	µm
milliequivalent	meq
milliliter	ml
minute	min
molar (moles per liter)	M
normal (concentration)	N
nitrogen	N
number	N
not significant	NS
parts per million	ppm
percent	%
plant-introduction (number)	PI
standard deviation	SD
standard error	SE
standard error of mean	SEM
versus	vs

Capitalization and Punctuation

Italics: Use italics (underline in manuscript) for isolated foreign language wording likely to be unfamiliar to readers. Familiar words and scholarly abbreviations such as en masse, in vitro, in vivo, in situ, et al., e.g., i.e., or ca. are set in roman type, and should not be underlined.

Capitals: Follow common rules for capitalization (proper names, first word in sentence, etc.). Also use initial capitals for:

1) Regions, sections, or groups of states commonly associated together, e.g., Corn Belt, North Atlantic States, the South, the West, Midwest; but not "southern states," "northern" Iowa, etc.;

2) First letter of genera, family, order, etc., but not species;

3) Trademarked names, but not adjectives derived from them;

4) First word after a colon if it begins a clause not logically dependent on the preceding clause;

5) Any title immediately preceding a name. President Ford, Chairman Stelly, etc. There are some exceptions such as Vice-presidential candidate Smith.

6) Chemical symbols, e.g., Fe, Cu.

Do not capitalize words derived from proper names but now in common usage, e.g., paris green, bunsen burner, petri dish, microkjeldahl, plexiglass. Do not capitalize names of grasses, e.g., bermudagrass, sudangrass, or seasons of the year, e.g., spring, summer, fall, and winter. Do not capitalize titles such as associate professor, conservationist, etc., unless preceding a proper name.

Compound Words and Derivatives

1) Derivatives are usually written solid, e.g., nonadditives, nonsignificant, preemergent, spoonful, clockwise. Hyphens are used with prefixes to words that begin with a capital letter and in a few awkward combinations, that bring two vowels together, e.g., un-American, pro-British, semi-independent, anti-inflation.

2) A compound adjective is usually hyphenated when used before the word it modifies, but not after the word itself, e.g., winter-hardy plant; it is winter hardy; well-known method; it is well known; warm-season grasses, grasses grown during the warm season.

3) A hyphen is used after a prefix to a unit modifier, e.g., semi-winter-hardy; non-winter-hardy.

4) A hyphen is used in a compound adjective that includes a number, including when the adjective is an abbreviated unit of measure; e.g., 10-year-old field, 5-hour period, 4-mm depth.

5) Noun compounds are usually formed when the term is a unit of measure or has special meaning, or when one of the words has lost its accent, e.g., light-year, northeast, pineapple, germplasm.

6) No hyphen is used after an adverb ending in *ly* as the first part of a two-word modifier, e.g., widely known fact.

7) Use a hyphen for a noun-adjective expressions for clarity. For example, "On a per-gram basis."

Punctuation

Punctuation marks help to show the meanings of words by grouping them into logical units. These marks must be used in the proper number, kind, and manner if the reader is to understand the intended meaning exactly.

Incorrect punctuation as noted by the reviewers or editors, will be changed or called to your attention. The author is responsible for the punctuation used in the submitted manuscript and in the final article.

A few rules that are frequently violated are the following:

1) Failure to use a comma before "and" or "or" in a series of three or more items, e.g., 2, 7, and 10 hours.

2) Using a comma before month and year date, e.g., May 1975.

3) Do not use any punctuation after short items in a list unless it is needed to specify the item or show a meaning; e.g.:

a. Plant per row

b. Plant height (cm)

c. Number of earlets

4) Use commas and semicolons to separate items in text citations as follows: (Gray 1980, 1982), or (Gray 1980, White 1983), or (Gray 1980, 1982; White 1983).

Nomenclature

Names of Organisms

The Latin binomial or trinomial (in italics) and the authority must be shown for plants, animals, insects, and pathogens when the name first appears in the abstract and in the text. When numerous organisms are cited, the scientific name can be cited in a data table and the table referenced from the text. Crop cultivars (varieties, not experimental lines and strains) must be identified by single quotation marks when first mentioned, e.g., 'Ranger' alfalfa (*Medicago sativa* L.) or *Medicago sativa* L. 'Ranger,' *Festuca rubra* var. *commutata* Guad. 'Jamestown.'

The *inclusions of appropriate scientific names of organisms is the author's responsibility*. Manuscripts that reach the editorial office and lack scientific names will be returned to authors requesting insertion of the appropriate name. An exception to this is when organisms mentioned are from a literature citation that does not include both common and/or scientific name.

Chemistry

Full chemical names for elements and organic compounds must be used when they are first mentioned in the abstract and in the text. The names can be carried in tabular form in the text if there are a fairly large number of them in the paper. Thereafter, the common or generic name can be used in the paper, e.g., atrazine; DDT; TCA; 2,4-D; dicidrin; etc. Trade names should be avoided whenever possible. If it is necessary to use a trade name, it should be capitalized and spelled out as specified by the owner in the registration, e.g., Isolan/Vapam/. If a writer coins an abbreviation, it must not be used in the title or abstract and must be exactly defined when first used in the text. Chemical symbols and molecular formulas of common and simple substances should be used when such terms occur repeatedly in a paper.

In the U.S. and Canada, the authority for names of chemical compounds is *Chemical Abstracts* and its indexes. The American Chemical Society's *Handbook for Authors* and the *CBE Style Manual* contain many additional details on nomenclature in chemistry and biochemistry. Publications of the ACS Committee on Nomenclature and the Nomenclature Commissions of the International Union of Pure and Applied Chemistry are available through Chemical Abstracts Service, Columbus, Ohio 43210. The authority for biochemical terminology is the *Handbook of Biochemistry* (Sober 1970).

Pesticides

The accepted reference for herbicides is the list of "Common and Chemical Names of Herbicides" included on the back covers of the journal *Weed Science*, published by the Weed Science Society of America. For insecticides, the *List of Names to be Used in Entomology Research Division Manuscripts*, prepared by the Entomology Research Division, Pesticide Chemicals Research Branch, USDA, Beltsville, Md., is the accepted reference.

Many organic substances used for pesticides contain prefixes, letters, numbers, etc., designating configuration and rotation of the chemical structure. Some general rules are:

1) The most common hyphenated prefixes which should be italicized (underlined) are *o-, m-, p-,s-, cis-c, trans, sec-, tert-, endo-*, and *exo-*. The prefixes bis- and tris- are not italicized;

2) Elements that occur as locants are also italicized: *O-, S-, N-, H-*; and

3) Configurational relationships may be indicated by the italic capital letter prefix R and S. Rotation may be shown with small capital D and L and, in some cases, the italic *d* and *l* are used.

Identification of Soil

The soil used in experiments should be identified at the lowest possible taxonomic level. As a general guideline, soils from the United States should be identified at the series and the family level. For example, the soil was Pullman clay, fine, mixed, thermic Torrertic Paleustolls.

If possible, members of the National Cooperative Soil Survey should be consulted for proper classification. Contributors outside the United States are encouraged to give the classification in *Soil Taxonomy* (USDA-SCS, 1975) in addition to the classification in their national system.

Numerals

Round off decimal numbers where appropriate. Retain no more significant digits than the precision of the experimental methods warrants. (5,126±100, 5.126±.01)

Most rules for the use of numerals are based on readability and typographic appearance. Arabic numbers are preferable to roman numerals. **Numerals must be used for numbers except when the number is the first word of a sentence eg. "there were 4 pastures and 2 herds "; "only 1 treatment showed significant effect." Exceptions would be where 2 sets of numbers occur together: "5, 8-m plots". Where feasible, write out the first number: "five 8-m plots".** Commas must be used to group digits 1,000 and above. In writing a number including many trailing zeros, substitute a word for part of the number: 1.6 million (not 1,600,000) or 23 µg (not 0.00023 g). Use a zero before decimal numbers less than 1.0: 0.1, 0.5.

Miscellaneous Style Points

Abstract—Footnotes may not be used in the abstract.
Data—This word is plural; *datum* is singular.
Hardiness—Use Webster's for this: winterhardiness and winterhardy.
However—Be careful with this word. It is most often used between commas as a transition word, but it may also be used as an adjective, such as "...however great the cost..." Use it rarely at the beginning of a sentence. *Also* is seldom appropriate at the beginning of a sentence.
Normal—Use 6 *N*.
Per—Use superscripts when expressing rates such as km hour^{-1} or kg cow^{-1} day^{-1}.
Ranges—Use -22.9 to 14.9°C. It is not necessary to repeat °C.
Seasons—Use lower case: fall, autumn, winter, etc.
Was, were—Use "a total was" and "none was."
c.f.—Compared with
i.e.—That is
e.g.—For example
Is due to, so long as, as long as,—these phrases should be avoided, and terms such as results from substituted.
Prior to—Use "before"
Approximately—Use "about"
Words ending in ion—change to *ing* to remove wordiness and increase action.

APPENDICES

Abbreviations for Citations

Word	Abbreviation	Word	Abbreviation
Abstract	Abstr.	Genetics	Genet.
Academ-	Acad.	Geochem-	Geochem.
Adminstr-	Admin.	Geolog-	Geol.
Advance	Advan.	Geophys-	Geophys.
Agricult-	Agr.	Grassland	Grassl.
Agronom-	Agron.	Her Majesty's	H.M.
America	Amer.	Histochem-	Histochem.
Anal-	Anal.	Horticult-	Hort
Animal-	Anim.	Husbandry	Husb.
Annal-	Ann.	Hydraul-	Hydraul
Annual	Annu.	Illustration	Illus.
Anual-	Anu.	Institut-	Inst.
Associa-	Assoc.	International	Int.
Atomic	At.	Irrigat-	Irrig.
Australian	Australian	Journal	J.
Bacteriolog-	Bacteriol.	Laborator-	Lab.
Bacterium	Bact.	Livestock	Livestock
Behavior	Behav.	Management	Manage.
Bibliograph-	Bibliogr.	Mathematic	Math.
Biochem-	Biochem.	Meteorolog-	Meteorol.
Biolog-	Biol.	Microbiolog-	Microbiol.
Botany	Bot.	Miscellaneous	Misc.
British	Brit.	Monograph	Monogr.
Bulletin	Bull.	National	Nat.
Bureau	Bur.	Natur-	Natur.
Canad-	Can.	Nutrition	Nutr.
Chemistry	Chem.	Official	Official
Chromatography	Chromatogr.	Pamphlet-	Pam.
Circular	Circ.	Phenolog-	Phenol.
Climatolog-	Climatol.	Physiology	Physiol.
College	Coll.	Plant	Plant
Commission	Comm.	Proceeding	Proc.
Communic-	Commun.	Production	Prod.
Concentrate	Concent.	Publication	Pub.
Conference	Conf.	Publisher	Publ.
Congress	Congr.	Report	Rep.
Conserv-	Conserv.	Reproduction	Reprod.
Council	Counc.	Research	Res.
Current	Curr.	Review	Rev.
Cytolog-	Cytol.	Series	Ser.
Department-	Dep.	Special	Spec.
Dissert-	Diss.	Station	Sta.
Document-	Doc.	Supplement-	Suppl.
Ecolog-	Ecol.	Survey	Surv.
Econom-	Econ.	Taxonom-	Taxonom.
Edition	Ed.	Technical	Tech.
Engineer-	Eng.	Transaction	Trans.
Environment-	Environ.	Veterinary	Vet.
Experiment-	Exp.	Undergraduate	Undergrad.
Extension	Ext.	Universidad-	Univ.
Extermination	Exterm.	Universit-	Univ.
Federal	Fed.	Wildlife	Wildl.
Feeding	Feed.		
Fertility	Fertil.		
Forest-	Forest.		

STATE NAME ABBREVIATIONS

Alabama—Ala.
Alaska—Alaska
Arizona—Ariz.
Arkansas—Ark.
California—Cal. or Calif.
Colorado—Colo.
Connecticut—Conn.
Delaware—Del.
Florida—Fla.
Georgia—Ga.
Hawaii—Hawaii
Idaho—Ida.
Illinois—Ill.
Indiana—Ind.
Iowa-Iowa
Kansas—Kan.or Kans.
Kentucky—Ky.
Louisiana—La.
Maine—Me.
Maryland—Md.
Massachusetts—Mass.
Michigan—Mich.
Minnesota—Minn.
Mississippi—Miss.
Missouri—Mo.
Montana—Mont.
Nebraska—Neb. or Nebr.
Nevada—Nev.
New Hampshire—N.H.
New Jersey—N.J.
New Mexico—N.M.
New York—N.Y.
North Carolina—N.C.
North Dakota—N.D.
Ohio—Ohio
Oklahoma—Okla.
Oregon—Ore. or Oreg.
Pennsylvania—Penn.
Rhode Island—R.I.
South Carolina—S.C.
South Dakota—S. Dak.
Tennessee-Tenn.
Texas—Tex.
Utah—Ut.
Vermont—Vt.
Virginia—Virg.
Washington—Wash.
West Virginia—W. Va.
Wisconsin—Wis. or Wisc.
Wyoming—Wyo.

SAMPLE TITLE PAGE

Effects of Early Season Cattle Grazing
on Riparian Plant Communities

John R. Brown, Jane T. White, and Robert R. Black

Keywords:

Authors are assistant professor, Range Science Department, Ohio State University, Columbus 44082; and habitat biologist and research technician, USDA, Agricultural Research Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo. 80423. At the time of the research, the senior author was research assistant, Range Science Department, Colorado State University, Fort Collins.

Research was funded in part by National Science Foundation Grant 682-59. Authors wish to thank Dr. J. Green for assistance in statistical analyses.

Manuscript received ____________________.
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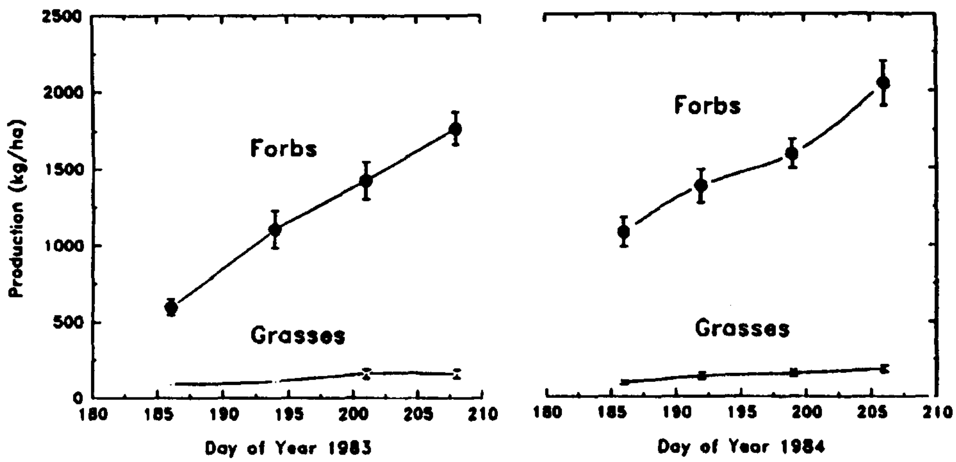

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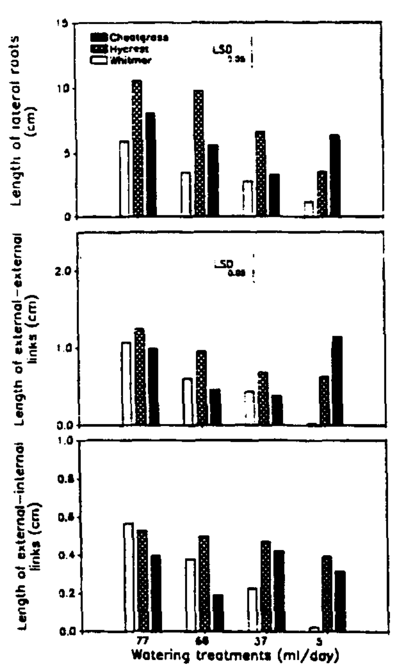

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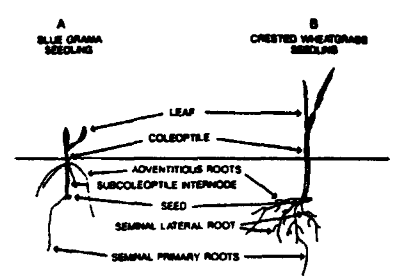

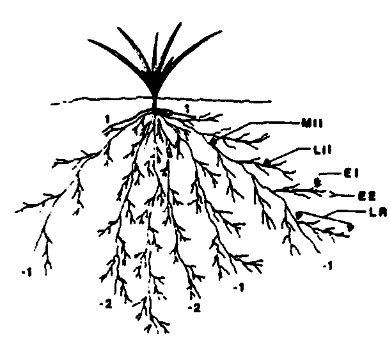

(SAMPLE TABLE 1)

Table 1. Assumed diet composition by season for cattle and antelope grazing in study area.

Plant class	Winter		Spring	
	Antelope	Cattle	Antelope	Cattle
	(%) [1]			
Grass	13	82	22	91
Shrubs	80	14	61	2
Forbs	7	4	13	8

[1]Percentages do not always add to exactly 100%, since they are derived as a composite average from several sources.

(SAMPLE TABLE 2)

Table 2. Site and species mean percent foliar cover and dry matter biomass of resident annual plants in a 25 X 25 cm area.

Species	15 April		20 May	
	Cover (%)	Dry Matter (g)	Cover (%)	Dry Matter (g)
(Site 1)				
Fescue	72.0 ab[1]	3.6 a	59.9 ab	9.0 a
Orchard	37.9 d	1.3 c	41.1 bc	3.1 b
Wheagrass	43.6 cd	1.8 b	27.7 c	4.4 b
Site 1 Average	63.3 A[2]	2.8A	48.2 B	6.0 B
(Site 2)				
Fescue	50.9 b	2.5 b	51.1 b	7.2 b
Orchard	45.2 c	2.3 b	53.4 b	6.3 c
Wheatgrass	62.7 a	4.8 a	69.6 a	10.0 a
Site 2 Average	51.6 B	3.1 A	61.1 A	8.5 A

[1]Within column and site, means with the same lower case letter are not significant at P<0.10.

[2]Within column, site averages with the same upper case letter are not significant at P<0.10.

SAMPLE TABLE 3)

Table 3. Chemical composition of feed components of diets fed to goats.

	Oak		
	Juvenile	Mature	Alfalfa
Dry matter (%)	35.2	44.8	92.2
Cell wall (%)	36.2	43.8	38.0
Lignin (%)	7.8	11.8	5.8
Nitrogen (%)	2.1	1.9	2.5
Gross energy (Kcal/g)	4.6	4.3	4.6
Tannin (mg/mg)[1]	0.231	0.176	----
Tannin (mg/g)[2]	40.4	34.7	----

[1]Martin and Martin (1983) mg prot. precp/mg).

[2]Hagerman and Butler (1978) assay (mg tannic acid equiv./g).

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