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The Trail Boss

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—*to develop an understanding of range ecosystems and of the principles applicable to the management of range resources;*

—*to assist all who work with range resources to keep abreast of new findings and techniques in the science and art of range management;*

—*to improve the effectiveness of range management to obtain from range resources the products and values necessary for man's welfare;*

—*to create a public appreciation of the economic and social benefits to be obtained from the range environment;*

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To ranch or not to ranch: Home on the urban range?

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Abstract

California ranchers in urban Alameda and Contra Costa Counties, and in rural Tehama County, were surveyed to examine effects of increasing development, land use change, and attrition of the ranching community on their commitment to ranching, and to assess land conservation program acceptability. Questions were about practices, reasons for ranching, and what influences ranching's future. Ranchers share much in common. Most enjoy ranching, "feeling close to the earth," living in a "good place for family life," and the camaraderie in the ranching community. They regularly carry out range improvements. Most believe that society is becoming "hostile to ranching." A dislike for outsider intervention and land use control prevails. Urban ranchers cared significantly less about the fate of their ranch if sold, and feared local land use planning much more. Rural ranchers overwhelmingly wanted their ranch to remain a productive ranch even if sold. No new ranchers appeared in the urban sample for the last 10 years. As urbanization proceeds, we suggest that a point is reached where ranchers recognize the social, ecological, and economic landscape as urban and see it as no longer suitable for ranching. Expecting to sell for development, and/or expecting zoning to change to allow it, becomes the rational view. Land conservation efforts, including relatively acceptable though as yet not widespread conservation easement programs, should begin before that happens.

Key Words: land use change, land trusts, rangeland conversion, ranch values

Resumen

Rancheros californianos fueron estudiados, en los condado urbanos de Alameda y Contra Costa y en el rural de Tehama, para conocer los efectos de la urbanización, y de los cambios en el uso del suelo, en relación con el temor de los rancheros a que ello suponga una disminución o pérdida de la comunidad ranchera. También se analizaron sus opiniones acerca del contenido de diversos programas sobre la conservación de los usos posibles del suelo y la tenencia del mismo. El contenido de las preguntas versó sobre las prácticas de los rancheros, las razones que tenían para continuar con su modo de vida y qué aspectos, según ellos, pueden influir en el futuro de su existencia. El sondeo refleja bastante unaimidad en las opiniones de los rancheros. En la mayoría de los casos les gusta ranchear, "sentire que están pisando la tierra", "vivir en en buen lugar para la vida familiar" y disfrutar del compañerismo dentro de la comunidad. Trabajan juntos en el desarrollo de proyectos para la mejora del campo y de los terrenos de pastoreo. Muchos opinan que en la sociedad, en general, existe cierta aversión hacia los rancheros y su modo de vida. Entre los rancheros predomina un sentimiento de decepción hacia los forasteros y con los intentos de intervención exterior para controlar los usos del terreno. Los rancheros urbanos no muestran tanta preocupación sobre las consecuencias de las ventas de sus ranchos, sin embargo temen más que el gobierno les limite los usos de la tierra o la oportunidad de vender sus propiedads. Los rancheros rurales, de manera contundente, desean que sus ranchos continúen siendo productivos, aunque sean vendidos. Ningún ranchero urbano nuevo, perteneciente a los últimos diez años, aparece en el grupo encuestado. Con el proceso de urbanización avanzando, nosotros sugerimos que se llegue a un punto donde los rancheros reconozcan el entorno social ecológico y económico de su rancho dentro de un paisaje urbano y no lo vean como la continuación del rancho. La expectativa de vender su propiedad para el desarrollo, y/o esperar un cambio en las leyes que permita tal desarrollo, es un punto de vista lógico. Los esfuerzos encaminados a la conservación de la tierra,, incluyendo programas que aunque no muy extendidos todavía sean aceptables para muchos rancheros, deberían ser puestos en marcha antes de que el proceso de ventas de parcelas o urbanización del campo ocurra.

Ranchers own most of California's highly productive low elevation annual rangelands, an estimated 8.1 million ha of oak woodland and annual grassland (Ewing et al. 1988). Studies of oak woodlands statewide have shown they are two-thirds owned by livestock producers with holdings larger than 8 ha, and about three-fourths grazed (Huntsinger et al. 1997, Holzman 1993, Bolsinger 1988). Annual rangelands produce an average of 700 kg/ha of biomass each year under conservative stocking, and provide watershed, wildlife habitat, and open space. Although such benefits are now earning broad acknowledgment, rangelands are at growing risk of residential development, or conversion to high value products such as wine grapes. Urban out-growth is becoming more common throughout the West (Wright 1993a).

This paper compares results of a survey of ranchers in a highly urban area of California and a mostly rural, but growing, area. The goal was to examine how increased expectations of development and the attrition of the ranching community that comes with a more urban landscape affects a rancher's commitment to ranching, and to help assess what sorts of land conservation programs

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are most acceptable. Ranchers were asked about their management practices, their reasons for ranching, and what they think is likely to influence the future of ranching.

Rangeland Conversion Patterns

Drawn by open space, affordable housing, and rural lifestyles, a growing population is stimulating conversion of California rangelands to new uses, transforming the landscape through development. A study of Sierran foothill oak woodlands and grasslands found ranchers a shrinking proportion of ownerships. Estate taxes, conflicts between multiple heirs, and lucrative purchase offers encourage ranchers to sell land to developers, and much land is being purchased and held for development by corporate and individual speculators (Johnson 1998). In his economic case study in the Sierra foothills, Hargrave (1993) found ranching unprofitable when the opportunity costs of investment were considered—the only economic justification for ranching was to hold land for increased real estate value. Smethurst (1997) concluded that the Sierra foothills were "being transformed to an absentee-owned landscape, where natural resources such as water, timberland, and recreational assets are owned by those living outside the region. Residential development has increased, while ranching, farming, and hardwood rangeland have declined."

In 1965, in response to loss of agricultural land, the California Land Conservation Act was passed, commonly referred to as the Williamson Act. Participant landowners, including more than half of California's rangeland owners (Huntsinger et al. 1997, McClaran et al. 1985), enroll in a 10-year rolling land conservation contract with their county in exchange for tax relief. However, McClaran et al. (1985) found this effective only in areas where development pressure was not yet high.

Accessibility and distance from a desired destination, such as a city center or airport, are commonly held to explain patterns of urban growth and development (Furuseth and Pierce 1982). Land conversion pressure does appear greatest on the urban fringe (Hart 1991a, McClaran et al. 1985), but the decision process for land conversion includes political, institutional and behavioral factors in addition to proximity (Furuseth and Pierce 1982). The public generally assumes that government-instituted land use regulations at local and regional levels control rangeland conversion. Researchers have recently pointed out that urban growth limits and sprawl controls are a neglected key to rural conservation in the United States (Alterman 1997, Gale 1992). However decisions of private landowners in fact play a pivotal role in determining future land use (Platt 1991, Johnston and Bryant 1987). Principal factors influencing the sequence and form of development have been summarized by Kaiser and Weiss (1970) as: (1) contextual factors—socio-economic characteristics, including land policies dealing with municipal infrastructure and services and land use regulations; (2) property factors—such as location and physical characteristics of the property; and (3) decision agent factors—the players in the development process and their goals, expectations, and motivations. Obviously, these factors are hardly independent, but this research focuses on the third factor, the decision agent or landowner. According to Furuseth and Pierce (1982), "if one wishes to influence successfully the location and pattern of land conversion, then one must understand the principal decision-makers and the linkages that exist among them."

Rancher Decisionmaking

The importance of rancher decisionmaking has been noted by a number of researchers (Hart 1991a, 1991b, 1976; Berry and Plaut 1978), and is best summed by Johnson (1998): "a single ranch-owner's decision may spell the fate of many thousands of acres. Landowner decisions affect more than their own property, as nearby properties are also influenced through the fragmentation of land use, weakening of the agricultural infrastructure, changing land values, and the creation of new growth nodes in previously undeveloped areas."

Numerous studies note that social factors, values, and attitudes, and not just profits strongly affect the decisions of range livestock producers. In a 1995 survey, the majority of California oak woodland ranchers reported that "living near natural beauty" was an important reason to ranch (Huntsinger et al. 1997). Similar results have been found elsewhere in the western U.S. (Smith and Martin 1972). "Ranch fundamentalism," an idealization of the independent ranching lifestyle, and the benefits of ranching to family life, have been described by economists and others as motivating decisions to keep ranching despite the low profits characteristic of the industry at the producer level (Bartlett et al. 1989, Smith and Martin 1972, Martin and Jefferies 1966). Smith and Martin (1972) reported that Arizona ranchers resisted selling ranches at market prices far exceeding their value as livestock operations for reasons that included "love of the land," and "love of rural values." Hargrave (1993) found that Sierran ranchers persist despite economic hardship and development pressure because they enjoy the tradition and way of life, and want their children to ranch if they so choose. Based on similar findings, ranches have been described as units of consumption rather than production (Grigsby 1980, 1976).

Comparison of urban and rural ranchers allows identification of "transitional effects" that influence rancher decisions, such as rising land speculation, an increase in conflicts with community and neighbors, and loss of the "critical mass" of ranchers necessary to maintain agricultural support services and markets (Huntsinger and Hopkinson 1996, Hart 1991a, 1991b, Heimlich and Anderson 1987, Lisansky and Clark 1987, Berry and Plaut 1978). Rising land speculation can create an environment that encourages a feeling of impermanence; landowners expect to sell out for non-agricultural uses (Berry and Plaut 1978). The term "impermanence syndrome" describes the reduced land and property management, and accompanying lack of investment in farming or ranching that may result when returns anticipated from development far outweigh the returns possible from agriculture (Heimlich and Anderson 1987). If sometimes unrealistic, price expectations can reduce landowner participation in conservation efforts such as the Williamson Act (McClaran et al. 1985). Some researchers have argued that reduced dependence on income from agricultural production will also contribute to a lack of investment and management activity by the landowner (Fortmann and Huntsinger 1989).

Conflicts over odors, noise, stray livestock, human trespass, vandalism, and pet predation may result in formal litigation or restriction of agricultural activities through ordinances or zoning (Lisansky and Clark 1987, Conklin and Lesher 1977). Ranchers, used to resolving disputes through peer relations (Ellickson 1991), face an influx of newcomers with different, often litigious, ideas about recourse, multiplying misunderstanding and cementing conflict. Mutual cooperation or reciprocity and resolution of conflicts through peer relations, are common and successful traits among pastoralists world-wide (Roe et al. 1998, Sandford 1983). Ranching has traditionally relied on the cooperation and participation of neighbors in rounding up herds, brandings, and other activities requiring many people for a short period of time (Starrs 1998). Helping neighbors who help you has social and practical benefits that cement a cohesive ranching community. The transition from a rural to urban landscape fractures the social, economic, and ecological structure of the ranching community, contributing to rancher decisions to sell land for development.

Rangeland Conservation Options

In popular "environmentalist" writings, ranching is often constructed as an exploitative, environmentally destructive activity motivated by greedy and neglectful livestock operators (Jacobs 1991, Wuerthner 1990). In recent years, ranching has been reconceived by elements in the conservation movement as an apt way of conserving open space and wildlife habitat, particularly through the establishment of land trusts and conservation easements (Huntsinger and Hopkinson 1996, Wright 1993a, 1993b, 1994). Diverse groups including the California Cattlemen's Association, the Nature Conservancy, the National Park Service, the Bureau of Land Management, and a variety of local organizations have supported such programs. Determining the best strategies and the acceptability of various programs requires knowledge of rancher values and motives.

Land use planning and zoning may reduce rangeland conversion, but are subject to fluid political and economic objectives. They have proven useful for temporarily slowing development until more permanent conservation strategies can be employed, such as conservation easements (Hart 1991b). Property rights include a variety of rights, such as mineral rights, grazing rights, rights to develop, and rights to sell, each of which can be sold or contracted separately (Raymond 1997, Huntsinger and Hopkinson 1996, Daniels 1991). Property owners can sell or donate the right to develop land in perpetuity as part of creating a conservation easement. Easement sales can compensate for loss of land value or buy out heirs; donation or sale of easements can reduce taxes. Other rights, including the right to sell, are retained as defined in the easement agreement, and the land remains private and in production. Voluntary, incentive-based programs such as conservation easements and land trusts depend on willing landowner cooperation, and according to Wright (1994), work best in areas where people are committed to conserving a way of life. But in regions of rapid growth and rising land values, does this commitment wane?

Methods

Range livestock producers in 2 areas, Tehama County, and Alameda/Contra Costa Counties, were surveyed by mail. Samples were randomly selected from a compilation of U.C. Extension's Farm Advisor list, Natural Resource Conservation Service (NRCS) list, and an emergency feed program list. The questionnaire was edited and pretested working with natural resource management professionals, and ranchers not selected for sampling, within and outside the study areas.

Study Areas

Tehama County and the combined Alameda and Contra Costa Counties (ACC) are similar in resources, with livestock forage mostly of Mediterranean-type annual grasses. Both study areas have strong agricultural components in their county General Plans and participate in the Williamson Act.

Tehama County is 764,000 ha in the upper reaches of California's Sacramento Valley, about 200 km north and inland of the San Francisco Bay counties of Alameda and Contra Costa (Fig. 1)(Table 1). Hilly chaparral, oak woodland, and annual grass rangelands make up most of Tehama, bordered on the west by the coast range, and on the east by Sierra Nevadan lava rock ranges and coniferous forests. A predominately agricultural county, croplands and much of the irrigated grazing land follow the Sacramento River flowing north to south through the valley floor. The urban areas of Red Bluff and Corning contain around 37% of the county's 52,000 people, and lie within the Interstate 5 (I-5) corridor paralleling the river. Average population density for the county was .07 per ha in 1994 (Table 1). Tehama County planners consider agriculture of prime importance, though industrial, commercial and residential development is encouraged along the I-5 corridor on land unsuitable for crops. Ranching is considered by county planners to be flexible and suitable for marginal lands (Tehama

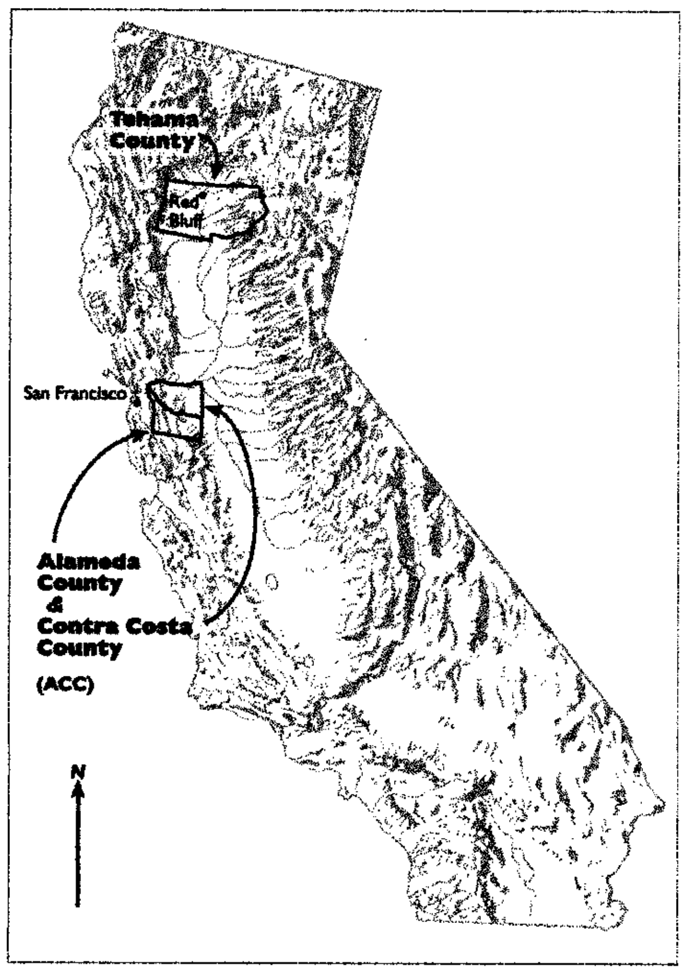

Fig. 1. Tehama, Alameda, and Contra Costa Counties, Calif.

Table 1. Characteristics of Tehama and Alameda–Contra Costa Counties, California.

	Tehama	Percent Tehama study area	Alameda-Contra Costa	Percent ACC study area
Total land area (ha)	764,000	100.0	378,000	100.0
BLM (ha)	21,000	2.7	800	.2
USFS (ha)	158,000	20.6	0	0.0
Other public (ha)	23,000	3.01	31,500	8.3
All public (ha)	202,000	26.2	32,300	8.5
1993 irrigated range (ha)	9,106	1.2	1,939	.5
1993 non–irrigated range (ha)	376,371	49.3	155,587	41.2
Population in 1994	51,903		2,148,157	
Population density	0.07/ha		5.70/ha	
Value ag products in 1993	$100,365,200		$125,533,750	
Value beef cattle/calves in 1993	$11,682,000		$11,478,000.00	
Production $ per ha in 1993 (Irrigated)	$191.50		$220.00	
Production $ per ha in 1993 (Dry)	$17.30		$37.00	

Sources: Contra Costa Department of Agriculture 1993, Tehama County Department of Agriculture 1993, U.S. Dept. of Commerce 1992 and 1994, Ewing et al. 1988.

County Planning Dept. 1990, G. Robson, Planning Director, Tehama Co., pers. comm. 1995). Between 1984 and 1994, urban acreage increased by 522 ha in Tehama (FMMP 1996).

Alameda and Contra Costa Counties are adjacent and stretch from the eastern shore of San Francisco Bay to the western edge of the Sacramento Valley. Their combined 377,634 ha (Table 1) incorporates densely populated, urbanized development and less populated agricultural area, where a marine influence and mild winters support some of the most productive annual grass rangeland in the State (Forero et al. 1992). With about half the rangeland of Tehama, Alameda and Contra Costa produce about the same value of beef cattle and calves (Table 1). The average population density of 5.7 per ha (Table 1) is spatially concentrated in the western and north central sections of the counties (Landis et al. 1993). But the coast range oak woodlands and grasslands that comprise the eastern agricultural area are undergoing intense development pressures and skyrocketing land values (Forero et al. 1992). The General Plan of Alameda County has an Urban Growth Boundary, and Contra Costa County has a designated Urban Limit Line (ULL), that delimit areas suitable for urban development versus areas suitable for long-term protection of natural resources, agriculture, and open space (ACPD 1994, CCCCDD 1991). Between 1984 and 1994, urban acreage increased by 10,222 ha in Alameda and Contra Costa counties (FMMP 1996).

Rancher Survey

In the winter of 1993/94, ranchers were surveyed by mail using the questionnaire style and 4-wave mailing technique designed by Dillman (1978) to achieve a high response rate. Eligible survey respondents had to meet 2 specific criteria: they grazed livestock on rangeland or pasture in the study areas and they were the main decision-maker. Eligible and usable questionnaires were returned by 132 out of 178 Tehama County respondents for a response rate of 74%, and by 113 out of 204 Alameda-Contra Costa County respondents for a response rate of 55%.

The questionnaire was 19 pages long in booklet format, with 48 questions and groups of questions. Grouped questions were focused on a topic area, including reasons to quit or to stay in ranching, threats to ranching, characteristics of the ranching operation, management practices, management goals, and standard demographic characteristics. In general, responses were measured on Likert-type scales, with the respondent circling the number from 1 to 5 that represented how important an item was to the rancher in his or her decisions about ranching, or how frequently a practice was used. For example, respondents were asked to rate how important several "reasons to keep ranching" were to them. In response to the question of how important "feeling close to the earth" is as a reason to keep ranching, the respondent could circle 1 of the following responses: (1) *not at all important*, (2) *not very important*, (3) *fairly important*, (4) *very important*, or (5) *does not apply.* The Chi-square (X^2) statistic was used to test for significant differences in categorical responses between ranchers in the 2 study areas, while Student's t-test was used to compare grouped continuous variables such as respondent age or how many years the ranch was owned (Spicer 1972). Differences of $P < .1$ are discussed as significant.

Results

Respondents in the 2 study areas were similar demographically: the majority were owner-operators, male, of mean age 50, with some college education, and third or more generation rancher (Table 2). Most had a family or individual cow-calf operation, sometimes in combination with stocker production. Only a few ranchers had only sheep or a combination of cattle and sheep, with significantly less sheep ranchers in Alameda-Contra Costa (ACC) than in Tehama (Table 2).

There were more Tehama than ACC ranchers in the lower income brackets, and ACC ranchers had more often obtained college degrees (Table 2). American per capita personal income figures (1993 dollars) show a mean of $25,433 for ACC and $14,276 for Tehama, a 56% difference between the study sites (Calif. Dept. of Finance 1996). Significantly more Tehama ranchers earned 75% or more of their income from ranching, while significantly more ACC ranchers earned less than 25% of their income from ranching (Table 2).

Alameda and Contra Costa County ranchers had owned their land significantly longer. More than two-thirds of all respondents had owned their land for 25 or more years, but close to half of ACC families had owned their land for at least 50 years, and more than a quarter for 100 years plus. None of the ACC sample had owned their land for less than 10 years (Table 2). Two-thirds of all respondents had land enrolled in the Williamson Act, and 4% had land in a conservation easement. In ACC, ranches were in significantly closer proximity to current or planned development (Table 2).

Overwhelmingly, ranchers found other ranchers, and University of California Cooperative Extension, to be useful information sources. Other common sources were pharmaceutical companies and veterinarians, the local Farm Bureau, and the National Cattleman's Association (Table 2).

Most rangeland grazing in both sites took place on private rather than public land. Tehama ranchers grazed larger properties than ACC ranchers. About a third of Tehama ranchers had livestock graze part of the year outside the county, compared to less than a quarter of ACC ranchers (Table 2).

Goals, Practices, and Management

Improving livestock quality and increasing production, as well as improving the quality and quantity of forage, and improving soil stability and wildlife habi-

Table 2. Demographics and ranch ownership in Tehama and Alameda–Contra Costa Counties, California, 1994.

	Tehama Ranchers (n=132)[1]	Alameda/Contra Costa Ranchers (n=113)	$P(X^2)$
	--------------(%)--------------		
Some college or higher	75	61	.02
3rd + generation rancher	60	60	.99
Gross income:			
less than $25,000	18	6	.01
25,000 – 74,999	61	56	.54
more than $75,000	21	38	.01
Percent income from ranch:			
75% – 100%	33	23	.07
25% or less	30	52	.00
Mean years owned land:	39	63	.00
Owned land < 10 yrs	13	0	.00
Type of ranch operation:			
cow–calf only	45	35	.10
cow–calf and stocker	21	25	.46
sheep only	11	5	.08
sheep and cattle	11	4	.04
Raises food crops	41	32	.20
Raises horses	28	39	.08
Goes hunting or fishing on ranch	52	29	.00
Uses own irrigated pasture or meadow	84	35	.00
Grazes in more than one county	32	18	.02
Grazes some public land	30	35	.40
Enrolled in Williamson Act	67	69	.71
Land in conservation easement	4	4	.92
Grazes more than 809 ha of own property	22	10	.02
Grazes 1–20 ha of own property	25	30	.40
Distance from development			
ranch is part of one	0	4	.00
8 km or less	58	81	.00
UC Cooperative Extension is a useful source of information	92	81	.02
Other ranchers are a good source of information	97	95	.51

[1]n varies slightly by question.

[2]t–test is used on continuous data.

Table 3. Ranching goals and practices, Tehama and Alameda–Contra Costa Counties, California, 1994.

The following are important goals for my ranch:	Tehama Ranchers (n=132)[1]	Alameda/Contra Costa Ranchers (n=113)	$P(X^2)$
	----------(%)--------------		
Improving wildlife habitat	78	69	.12
Increasing forage	95	97	.66
Improving soil stability	94	90	.23
Increasing livestock production	89	91	.44
Protect scenic values	78	67	.05
Diversify operation	41	37	.52
Reduce need for pesticides and herbicides	79	68	.05
Improve livestock quality	99	98	.91
Have carried out the following practices in last 5 years:			
Prescribed or controlled burn	34	25	.12
Herbicides	35	36	.82
Chaining or thinning	32	28	.43
Browsing by goats or others	18	18	.90
Controlled grazing	65	73	.20
Deferred or rest rotation	53	37	.02
Continuous year–round grazing	12	40	.00
Seeding rangeland	40	43	.60
Fencing riparian areas	23	15	.06
Commercial fertilizers	44	24	.01
Manure application	39	26	.09
Mulching with ungrazed forage	65	57	.17
Electric fencing	38	39	.87
Developed springs	24	64	.00
Put in water tanks or troughs	70	90	.00
Laid water pipe	46	71	.00
Stabilized streambanks	40	30	.13
Overall satisfied with range condition	87	86	.96
Used volunteer labor by neighbors	85	87	.50

[1]n varies slightly by question.

tat, were important management goals for most ranchers (Table 3). More than two-thirds of all ranchers described reducing the need for insecticides and herbicides and protecting or improving scenic values as important goals, but Tehama respondents rated the importance significantly higher. Diversifying their operation to produce non-livestock products was not an important goal for most (Table 3).

Over a five-year period 90% or more of all ranchers carried out at least 1 range improvement practice, including seeding, thinning or chaining woody vegetation, prescribed burning, stabilizing streambanks, developing springs, building ponds, putting erosion control structures in streams, and/or using fertilizers (Table 3). Tehama ranchers were significantly more likely to use fertilizer, and to fence and manage riparian areas separately. There were more springs developed, water pipes laid, and tanks or troughs placed by ACC ranchers. More than 80% of all respondents at least occasionally used neighbor volunteer labor, and around half of those reported that neighbors help regularly.

Just over a third of the ACC respondents used deferred or rest rotation grazing systems, while 40% grazed year-round (Table 3). In Tehama, however, half of the respondents used deferred or rest rotation systems, and only 12% grazed year-round on Tehama's hot summer grasslands where seasonal use is the norm. Of Tehama ranchers grazing year-round, all used irrigated pasture except 2 who had thousands of ha of rangeland with water improvements. There was no significant difference in the use of mulch management, the practice of leaving specified levels of dry grass/residue behind. Regardless of the grazing system used, most respondents were satisfied with ranch range condition (Table 3).

Half of Tehama and ACC ranchers found people trespassing 2 to 10 times over a 2-year period of time. And, in ACC, almost a third found people trespassing more than 10 times, significantly more often than in Tehama (Table 4). Trespassing was felt by more than two-thirds of all respondents to be a threat to ranching, though significantly more so in Tehama (Table 6). More than half of respondents reported finding other people's cattle on their property at least twice within two years. Almost all would respond by rounding the livestock up and returning them to their owner or, by calling or talking to the owner about it (Table 4).

Ranchers agreed public lands grazing is important for U.S. livestock production and local economies. Most believed private lands are better managed, particularly in Tehama where most public ownership is federal. Most did not agree that low public fees penalize private land ranchers (Table 4).

Motives for Ranching

An overwhelming 90% or more of respondents in both study sites indicated

Table 4. Management issues, Tehama and Alameda–Contra Costa Counties, California, 1994.

What they would do if found someone else's livestock on property:	Tehama Ranchers (n=132)[1]	Alameda/Contra Costa Ranchers (n=113)	$P(X^2)$
	----------(%)--------------		
Shoot the animals	2	0	
Call the Brand Inspector	2	0	
Round them up and return them	39	39	
Call or talk to the owner by phone	56	53	.58
Report them to the sheriff	2	0	
Do nothing	0	0	
Found people trespassing or stray cattle on their land in last 2 years:			
People trespassing:			
2 – 10 times	55	51	.57
more than 10 times	23	31	.05
Stray cattle:			
2 – 10 times	58	53	.39
more than 10 times	17	22	.30
Agrees with the following about grazing on public lands:			
Is important for U.S. sheep and cattle production	93	94	.64
Is degrading the land	11	3	.02
Low fees penalize ranchers on private lands	39	45	.33
Is important to local economies	89	84	.33
Private lands are better managed	82	68	.02

[1]n varies slightly by question.

that "feeling close to the earth" and having "a good place to raise a family" are important reasons to continue ranching. But Tehama ranchers placed significantly greater importance on working and visiting with friends and neighbors as a motivation to ranch (Table 5).

Commonly held reasons to quit ranching included 'being over-regulated,' ranked important by over 80% of all respondents, 'society's hostility towards ranching,' also denoted important by two-thirds of ACC and Tehama ranchers, and leaving to 'improve current investment returns,' indicated important by over half of all respondents. However, significantly more Tehama respondents considered 'the next generation not wanting to ranch' an important reason to stop ranching, and said that one reason they keep ranching is because of the 'chance to work and visit with friends, neighbors and/or relatives.' Significantly more Tehama respondents also agreed that a reason to keep ranching is that it is hard to find another job, and that finding another job is a good reason to quit (Table 5).

Reported by most ranchers as serious or extreme "threats to ranching" in general were state or federal wilderness designations, statewide or regional planning, the Endangered Species Act, animal rights, closure of open range, efforts to increase recreational access to public lands, "environmentalism," trespassing, efforts to raise grazing fees on public lands, and urbanization of California. Overwhelmingly more ACC respondents rated local land use planning a serious threat, while significantly more Tehama ranchers found vandalism or theft, trespassing, and state and federal water quality standards seriously threatening to ranching (Table 6).

Attitudes Toward Land Use Change

Significant differences between study sites were found in the response to the question, "If you should decide to sell your ranch, how desirable, if at all, would it be to you to see the following happen as a result of your choice of buyer?" More than three-quarters of Tehama ranchers wanted the ranch to remain private and used for livestock grazing, while over a third of ACC respondents indicated that it didn't matter to them (Table 7). Half of ACC respondents indicated that it is desirable to have the ranch developed for residential use or that it makes no difference, whereas more than two-thirds of Tehama respondents declared this an undesirable outcome. Finally, a quarter of ACC respondents were indifferent to whether their ranch is sold to a public owner or to a non-profit organization, while most Tehama respondents found these 2 options undesirable (Table 7).

Discussion and Conclusions

Ranchers in predominately agricultural Tehama County and in rapidly developing Alameda and Contra Costa Counties were more alike than dissimilar in attributes, values and motives, land management practices, and attitudes toward land use change. However, significant differences between the 2 study sites illustrate urbanization's effects on ranching.

Ranches in both sites were mostly family-oriented, privately-owned livestock operations run by third or greater generation ranchers with at least some college education. Although gender roles are out-

Table 5. Rancher motivations, Tehama and Alameda–Contra Costa Counties, California, 1994.

Agrees the following is a good reason to ***keep*** *ranching:*	Tehama Ranchers (n=132)[1]	Alameda/Contra Costa Ranchers (n=113)	$P(X^2)$
	----------(%)--------------		
Selling the ranch is hard	17	39	.00
Like working with friends, relatives	66	47	.00
Getting another job is hard	25	12	.00
It allows me to feel close to the earth	92	90	.41
A ranch is a good place for family life	98	94	.50
Ranching is profitable	62	57	.46
I want my children to ranch	54	46	.24
Ranching is what I have always done	55	51	.51
Keeping the ranch is a good investment	47	53	.36
Agrees the following is a good reason to ***quit*** *ranching:*			
To find another job	34	19	.02
My kids don't want to ranch	39	26	.04
Over–regulation	91	83	.07
Society is hostile to ranching	73	65	.18
To improve investment returns	58	50	.27
To sell or lease ranch in a better market	35	40	.50
I don't want my children to ranch	19	20	.90
My kids have moved away	20	18	.74
To move closer to services	18	16	.55
My friends have moved away	11	14	.56

[1]n varies slightly by question.

Table 6. Threats to ranching, Tehama and Alameda–Contra Costa Counties, California, 1994.

Agrees that the following is a threat to ranching:	Tehama Ranchers (n=132)[1]	Alameda/Contra Ranchers (n=113)	$P(X^2)$
	----------(%)--------------		
Animal rights	86	82	.42
State & federal water quality standards	85	63	.00
Endangered Species Act	86	81	.37
Statewide/Regional Planning	79	82	.58
Local land use planning	54	82	.00
Urbanization of California	87	77	.75
Raising grazing fees on public lands	63	71	.18
Vandalism and theft	76	59	.00
Trespassing	78	66	.04
Environmentalism	87	88	.89
State or federal wilderness designations	81	78	.53
Closure of open range	74	73	.96
Recreation access	64	62	.64
Dogs	57	52	.46
Wild predators	57	46	.11

[1]n varies slightly by question.

side the scope of this study, for almost all the ranches, it was a male respondent who described himself as the "main decision-maker." Most participated in land conservation through the Williamson Act, had goals of improving livestock production and wildlife habitat, and found the same information sources useful, preferring most to get information from other ranchers. Using volunteer labor and the work of friends and relatives was common practice; peer relationships were relied on to resolve conflicts, rather than involving outside authority. Ranchers share a love of the land and the camaraderie of the ranching community, and their motivations reflect a long history and identification as stock-raising pastoralists. Almost all found the lifestyle, for themselves and their families, an important reason to continue ranching.

Respondents in both ACC and Tehama reported they felt threatened by vandalism or theft, and trespassing by people, which are conflicts that build as urbanization proceeds. Although two-thirds of ACC respondents found these factors a threat and they were more likely to experience multiple trespass events, significantly more Tehama ranchers felt threatened by these conflicts. One interpretation would be that since Alameda and Contra Costa Counties have been on the urban fringe for decades, some ACC ranchers have adapted to problems of trespass and vandalism.

Another interpretation, bearing on whether the "impermanence syndrome" explains the differences, is that ACC ranchers intend to sell their land, and are not as concerned with the day to day ranching operation. Several answers indicate this: they were less likely to care about the fate of the ranch land if sold, the friendship of their neighbors, the interest of their children in ranching, and water quality regulations, and they were much more threatened by land use regulations that affect ability to sell. Local land use planning was rated a serious or extreme threat to ranching by almost 80% of ACC respondents, nearly 30% more than in Tehama. Ranchers in ACC clearly have strong interest in maintaining the opportunity to develop land.

Ranchers in Alameda and Contra Costa Counties do seem to partially fit the "impermanence syndrome." For the majority of ACC ranchers, selling the ranch for development either was not bad or they simply did not care. Half of ACC respondents, earning a quarter or less of their income from ranching, depended on outside income sources. Tehama ranchers earned a greater portion of their income from the ranch, and indicated dependence on ranching as a job. But the survey did not reveal the expected decrease in management activity in ACC compared with Tehama County, or major differences in goals. Important ACC management goals included improving livestock quality, increasing forage and livestock production, and improving or maintaining soil stability near streams. In fact, more than two-thirds of ACC ranchers made water improvements on their ranches during a 5 year drought that included the year of this study, more so than Tehama ranchers, though water improvements are not as needed in Tehama where range is used less often in summer. Burning, fencing, and fertilization were more common range improvements in Tehama. Water improvements typical in ACC could be seen as stop-gap measures to protect the herd, an asset with no alternative value, rather than an investment in the productivity of land worth more as real estate. However, seeding was done with the same frequency in both study areas. This topic remains an area for future research.

Several interviewed ACC ranchers indicated that they want to continue ranching, but plan to use ACC land sale profits to buy a larger ranch in a rural community welcoming of ranching, and with lower land prices. Two interviewed ACC ranchers were buying ranches in Tehama County.

Moving elsewhere to start anew can be difficult. All surveyed ACC respondents

Table 7. Desired outcomes of ranch sale, Tehama and Alameda–Contra Costa Counties, Calif. 1994.

Would be a good outcome of ranch sale:	Tehama Ranchers (n=132)[1]	Alameda/Contra Costa Ranchers (n=113)	$P(X^2)$
	----------(%)--------------		
Stays a ranch used for livestock grazing	76	48	.00
The above makes no difference to me	20	36	.00
Is developed for housing	6	23	.00
The above makes no difference to me	16	26	.00
The ranch stays private	81	55	.00
The above makes no difference to me	17	38	.00
Goes to a public agency	2	3	.73
The above makes no difference to me	11	25	.00
Goes to a non–profit	4	13	.00
The above makes no difference to me	16	31	.00
Is designated open space	16	22	.32
The above makes no difference to me	21	19	.62
Has no livestock grazing	3	3	.87
The above makes no difference to me	16	23	.20
Hunting takes place on it	19	14	.28
The above makes no difference to me	38	38	.95

[1]n varies slightly by question.

had owned their land for at least 10 years, with a mean of over 60 years, a significantly longer period of time than Tehama ranchers. An ACC ranch real estate specialist indicated that this lack of movement out of ranching and no recruitment of new ranchers was due to several factors:

1. Within areas zoned for development, it can still take years to sell grazing land because a myriad of interest groups impose conditions on the sale.
2. Ranches located outside development boundaries and zoned for agriculture, recreation, or open space, are still close to high value real estate within the designated urban boundary. The possibility of zoning changes inflates ranch prices. This may also lead ranchers to have unrealistic land price expectations, higher than the market will pay.
3. The very factors that motivate ranchers to leave ACC, such as tight restrictions, increasing frustrations in conducting daily operations, and anti-grazing sentiments, drive away prospective ranchers.

Land Use Planning and Conservation Incentives

Ranchers not only obtain social fulfillment and livelihood from their land, they also see it as an insurance policy and retirement fund (Daniels 1991, Gobster and Dickhut 1988). A decrease in land value or an inability to sell some or all of their property undermines this security. In the more urbanized setting with higher land prices and more conflicts, ranchers were even less inclined to favor land use control.

Compensatory incentives such as landowner-negotiated conservation easements that protect ranching as a land use are voluntary and even offer a source of funds. Yet less than 5 percent of ranchers had land in conservation easements. The main land conservation policy tool widely accepted by ranchers in both study sites is the tax relief of the Williamson Act. Since ranchers can pull out of the program after a 10 year period, they feel they are not relinquishing future options.

Policy Approaches

Retaining ranching, whether for open space, historic preservation, or food and fiber production, takes policies and actions that work in concert, if at different scales. This research offers some insight to approaches needed at 3 different scales: national/international, landscape/community, and local/neighbor to neighbor. At the national or international level, policies that improve prices to rangeland producers, consider the fate of ranch land under tax regimes, and encourage agencies to use an ecosystem management approach that considers the surrounding landscape could be considered.

At the landscape level, an important goal is to manage the pattern and direction of growth to maintain rural landscape character and a ranching community critical mass to support markets and facilities (Huntsinger and Hopkinson 1996, Hart 1991b). Conservation easements and land use planning are common landscape level approaches, but a stronger commitment to urban planning would be of great benefit. About a third of the ranchers in this study used some public lands, and the need for continued access to public grazing lands makes relations with public land agencies crucial. Collaborative management programs and mutual consultation and trust with agencies may be critical to establishing a sustainable ranching landscape.

At the local or community level, where ranch and suburban or urban lands meet, policy and regulatory arrangements should minimize and control unwanted impacts. These include policies to control "nuisances," "right to farm" ordinances, and regulation of water and air quality. Just as landscape level policies give local conflicts their character and magnitude, the effectiveness and equity of policy for mitigating unwanted impacts ultimately shapes very local, person to person, landowner to landowner interactions. Local level problems with urban neighbors sometimes arise out of misunderstanding, lack of knowledge and information, and plain disagreement about land management. Emphasis on mutual education, collaborative alliances, and other "ground up" paths to mitigating conflicts are needed. In Marin County, California, as an example, environmentalists supported county aid for needed water quality improvements on local dairy ranches, and this helped build a collaborative land conservation strategy for the county (Huntsinger and Hopkinson 1996). When feasible, development of local markets for ranch products may help (Hart 1991b).

This study supports earlier research that found lifestyle a major motivation for ranching despite urbanization's effects, and despite the generally dismal profits to livestock producers in recent decades. Ranchers have strong environmental values, but dislike outside control, including environmental regulations. As landscapes become more urban, increasing difficulties with ranching combine with growing expectations of lucrative land sales, and the ranching community becomes more hostile to land use control. Escalating land prices make the costs of incentive-based land conservation programs rise, and attrition of the ranching community threatens the economic and social viability of ranching. Ideally, rangeland conservation programs should begin early, so that a viable ranching community, and its attendant infrastructure, can be maintained.

For some relationships, a "tipping point," or threshold model may be a better fit than a linear or curvilinear correlation. Future research might examine the possibility that the relationship between urbanization and the rancher's inclination to continue ranching might be best described with a threshold model. Ranchers persist and adapt for a time as rural lands succumb to urban outgrowth and subdivision. But consciously or otherwise, ranchers recognize the importance of the social and environmental landscape connections that enable ranching. There comes a point when the landscape begins to be widely recognized as "urban" in character, rather than rural. At this threshold, ranchers shift from thinking about ranching as a long term part of the landscape to a phenomenon moribund in their locale. Committed to ranching as a lifeway, they look elsewhere to continue it, less concerned with the future of the functionally compromised land they now occupy, and more concerned for the short haul with maintaining their opportunity to liquidate.

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Investigation of herbaceous species adapted to snowfence areas

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Abstract

Decreases in biomass and cover, as well as changes in species composition have occurred on rangelands affected by snowdrifts behind 3.8 meter tall "Wyoming" type snowfences along Interstate 80 in southeast Wyoming. Within the state of Wyoming, government agencies are responsible for the mitigation of any adverse effects associated with snowfences. These agencies need information which may aid mitigation efforts. In this study, 13 grass species and 2 tillage treatments (till and no-till) were evaluated in the field on both drift and non-drift areas, to determine the potential of each for the revegetation of snowfence sites. Evaluation was based on foliar cover at the end of the first growing season and aboveground biomass production after the second growing season. The project included plantings on 2 different soil depth sites (<50 cm and >50 cm) that were treated as 2 separate experiments. Results indicate that pubescent wheatgrass 'Luna' (*Elytrigia intermedia*[Host]Nevski), thick-spike wheatgrass 'Critana' (*Elymus lanceolatus* [Scribn. & J.G. Smith] Gould), and 2 varieties of slender wheatgrass 'Pryor' and 'San Luis'(*Elymus trachycaulus* [Link] Gould ex Shinners), were superior in cover and aboveground biomass production when planted in combination with tilled plots. Tufted hairgrass (*Deschampsia caespitosa* [L.] Beauv.) exhibited the least potential for cover and aboveground biomass production.

Key Words: species performance, reclamation

Resumen

Las disminuciones de la biomasa y la tapa, tanto como los cambios de la composición de las especies, han ocurrido en las praderas afectadas por la nieve acumulada detrás de las cercas del tipo "Wyoming" de 3.8 metros de altura a lo largo de la autopista 80 en el sudoeste de Wyoming. Dentro del estado de Wyoming, agencias del gobierno están responsables para la mitigación de cualquier efecto adverso asociado con las cercas de nieve. Estas agencias necesitan información que tal vez apoyará los esfuerzos de la mitigación. En este estudio, trece especies del pasto y dos tratamientos de labranza (cultivo y no cultivo) fueron evaluados en el campo en dos áreas, la con ventisquero y la sin ventisquero, para determinar el potencial de cada una para la revegezación alrededor de las cercas de nieve. La evaluación fue basada en la tapa del follaje al fin de la primera temporada del crecimiento y la producción de la biomasa sobre la tierra después de la segunda temporada del crecimiento. El proyecto incluyó el plantar en dos sitios diferentes de espesos diferentes (<50 cm y >50 cm) que fueron tratados como dos experimentos diferentes. Los resultados indican que el pasto de trigo pubescente 'Luna' (*Elytrigia intermedia* [Host] Nevski), el pasto de trigo espinagruesa 'Critana' (*Elymus lanceolatus* [Scribn. & J.G. Smith] Gould), y dos variedades del pasto de trigo delgado 'Pryor' y 'San Luis' (*Elymus trachycaulus* [Link] Gould ex Shinners), eran superior en la tapa y la producción de la biomasa sobre la tierra cuando fueron plantados en combinación de los lotes cultivados. El pasto de pelo copeludo (*Deschampsia caespitosa* [L.] Beauv.) exhibió el potencial menor para la tapa y la producción de la biomasa sobre la tierra.

The construction of Interstate Highway 80 across Wyoming during the early 1970s brought attention to the impact of blowing snow on travelers and the transportation system. A snowfence system was designed and installed to mitigate these impacts (Tabler 1973). The economic benefits that accrued from the snowfence system included a 70% decease in accidents due to ground blizzards, a 27% decrease in wind only caused accidents, and a 33% reduction of snow removal costs. Snowfences in this system are designed for a lifespan of 25 years and construction costs can be amortized over a 10 year period (Talder and Furnish 1982).

Between 1971 and 1979, approximately 53 kilometers of snowfence were constructed between Laramie and Walcott, Wyoming (Tabler and Furnish 1982). Most of these fences are of the 3.8 m high "Wyoming" type described by Tabler (1974).

The snowfence system along Interstate Highway 80 is designed to trap as much snow as possible. This results in very large fence-induced snowdrifts. At maximum capacity, snow depth at the deepest part of the drift is approximately 4.3 m. Drifts begin to form late in the fall and persist into late spring or early summer, sharply reducing the length of the growing season on these sites. Weaver and Collins (1977) found that community composition as well as cover and productivity could change as a result of shortened growing seasons on late melting natural snowdrift areas. They also discovered higher mean growing season temperatures resulting from the absence of a cool spring on the same sites. Pope (1985) demonstrated that lower cation exchange capacities, lower pHs, and decreased phosphorous availability all occur on snowfence sites when compared to adjacent non-drifted sites in southeast Wyoming. It is logical to assume that plants will respond to these altered climatic and soil characteristics.

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In July of 1989, the Albany County Weed and Pest District conducted a survey of the vegetation occurring on snowfence sites located along Interstate Highway 80 in Albany county, Wyo. (Pomeroy 1990). The results of the survey indicated that 3.8 m high snowfence systems had negatively impacted the native rangeland vegetation by altering species composition, and decreasing cover and aboveground biomass production. The primary reason for these shifts was a reduction in the native cool season grass component and an increase in annual and perennial forbs. Guernsey (1996) also documented similar shifts in species composition and standing crop at snowfence sites along Halleck Ridge in southcentral Wyoming. The objectives of this project were to determine which cultural practices and herbaceous species might be best suited for revegetating the microclimate of snowdrift areas behind 3.8 m high snowfences.

Methods and Materials

Study Area

The study area was located in Albany county, Wyo., along a 70 km section of Interstate Highway 80 between Laramie and Arlington, Wyo., at an elevation of approximately 2,165 m. Climate is typical of the Laramie Basin (Martner 1986). Mean annual air temperature is 4.4 C° with a mean daily maximum of 12.5 C° and a mean daily minimum of –2.9 C°. Mean annual precipitation is 300–350 mm with 45% occurring during the growing season. Mean annual snowfall is 150–200 cm. The snow drifting season typically begins around 1 November and ends around 1 April of the subsequent calendar year. Prevailing winds during the snow season are downslope from the west. The average potential growing season (based on temperature) is 113 days, and the actual snow free period for the drift area during the first year of the project was 165 days, 160 days during the second year.

Snow Drift Characteristics

Snow drift depth was measured for all fences at the time of maximum drift accumulation along permanent transects located in the middle of each plot. Measurements were taken in each year of the study. A probe was used to take depth measurements at specified intervals along each transect. These measurements were utilized to calculate drift density described by Tabler (1985).

Pre-melt density:

$$p = 522 - (304/1.485z)(1 - e^{[-1.485 z]}) \quad \mathbf{(1)}$$

where p = density (kg/m^3)

z = depth (m)

Drift density was converted to a water equivalent (WE) by the equation: **(2)**

p = WE/drift crossectional area

where WE = water equivalent (m^3/m of fence length)

The actual precipitation equivalent was calculated by dividing total water equivalent value by the ground surface area covered by the drift.

Combining the drift water equivalent with the actual precipitation occurring outside the drift season provided an average annual precipitation equivalent for drift areas. During the study period, the drift areas received a mean annual precipitation equivalent of 850 mm, approximately 3 times the mean annual precipitation for the adjacent non-drift area. Melt rates rarely exceed infiltration rates, allowing almost 100% of the melt water to infiltrate the soil profile (Tabler 1985). Maximum drift depths were approximately 3 m both winters, and the drift area extended from approximately 9 m to 30 m from the fences. The fences utilized in the study were all constructed in 1973.

The major land use of the area is livestock grazing (both sheep and cattle), and the area also serves as habitat for major wildlife species (antelope, deer, and elk).

Project Design

Two independent studies were conducted on sites with different soil depths, a shallow (<50 cm soil depth) and a deep site (50–100 cm soil depth) representative of the area. Both studies were arranged into a randomized complete block 2 x 2 x 13 factorial design, including 3 replicate blocks (55 m x 91 m) each on the leeward side of a snowfence, 2 tillage treatments (till and no-till), 2 snow drift treatments (drift and non-drift), and 13 herbaceous species treatments (Fig. 1). Drift treatments were designated as drift area (9-30m from fence) and non-drift area (30 m to end of plots, 91 m).

Shallow soil sites were upland sites typical of the area (Typic Argiborolls) with roots penetrating to 35 cm. Deep soil sites were lowland sites typical of the area (Typic Aeric Calciaquolls) with roots penetrating to 80 cm. The no-till alternative was included because much of the soil adjacent to snowfences was extremely rocky and difficult to till. The snow drift treatment was included because of the geometric nature of the snow drift accumulation. It had been observed that in most years snow drifts accumulated in an area beginning approximately 9 m from the fence and extending to about 30 m. This area was designated as drift area.

Species performance was based on foliar cover at the end of the first growing season, and aboveground biomass production at the end of the second growing season.

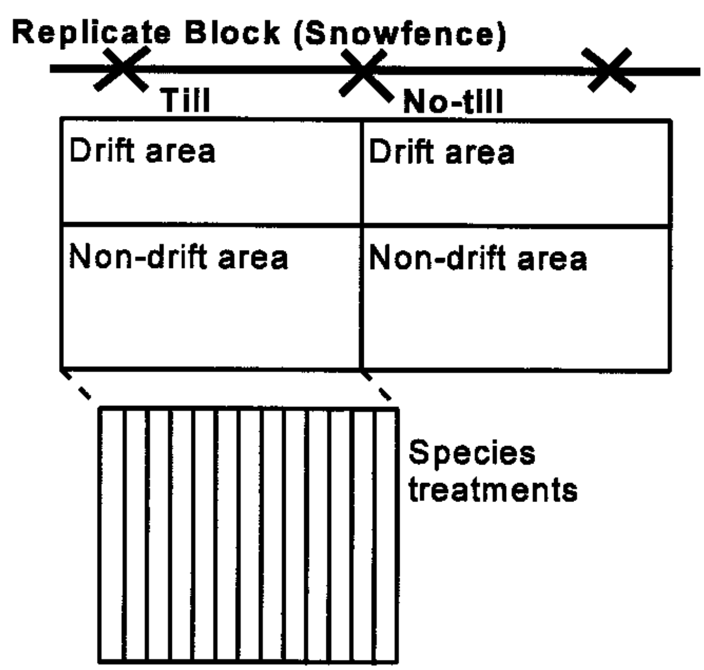

Fig. 1. Field plot diagram of a single replicate block.

Snowfences and plots were located and marked in July 1990. Both till and no-till plots were sprayed in mid-July with an herbicide mixture of glyphosate [*N*-(phosphonomethyl) glycine] and chlorosulfuron [2-chloro-*N*-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]benzenesulfonamide] at a rate of 2.3 kg/ha and 0.07 kg/ha active ingredient respectively, to reduce competition from antecedent native vegetation. Tilling operations were initiated in early September. Plots designated as till plots were tilled twice with a PTO-driven, rotary tiller.

Seeding operations were conducted in October of 1990. A Tye no-till drill with double disc openers and 20 cm row spacing was utilized. Each seeded plot was 2.0 m wide and 91 m in length aligned perpendicular to, and on the leeward side of the snowfence. The individual species assessed in the study were selected by a consensus of plant materials specialists and other natural resource professionals. The list included both native and introduced species, with a range of adaptations from very drought tolerant to more mesic species. Suspected variations in snowdrift extent suggested that some years are drought years, necessitating the testing of some drought tolerant species.

Species evaluated in the study were: mountain brome 'Bromar' (*Bromus marginatus* Nees.); altai wildrye 'Prairieland' (*Leymus angustus* Trin.); basin wildrye 'Magnar' (Leymus *cinereus* [Scribn. & Merr.] A. Love); Russian wildrye 'Bozoisky' (*Psathyrostachys junceus* [Fisch.] Nevski); tall fescue 'Fawn' (*Festuca arundinacea* Schreb.); pubescent wheatgrass 'Luna' (*Elytrigia intermedia* [Host] Nevski); western wheatgrass 'Rosana' (*Pascopyrum smithii* [Rydb.] A. Love); thickspike wheatgrass 'Critana' (*Elymus lanceolatus* [Scribn. & J.G. Smith] Gould); crested wheatgrass 'Ephraim' (*Agropyron cristatum* [L.] Gaertn.); slender wheatgrass 'Pryor' and 'San Luis' (*Elymus trachycaulus* [Link] ex Shinners); big bluegrass 'Sherman' (*Poa ampla* Merr.); and tufted hairgrass (*Deschampsia caespitosa* [L.] Beauv.). All species tested were considered nutritious and relatively palatable to wildlife and livestock. All species were seeded at the rate of 280 pure live seeds (PLS) m^{-2}.

Foliar cover was measured with a 10-point frame at the end of the first growing season (Heady and Rader 1958). Aboveground biomass was estimated at the end of the second growing season utilizing a Neal Electronics Model 18-2000 capacitance meter (Neal and Neal 1966) and expressed as kg ha^{-1}. Measurements for both attributes were taken at prescribed intervals based on distance from the snowfence (10 m, 12 m, 15 m, 18 m, 21 m, 24 m, 27 m, 30 m, 36 m, 43 m, 49 m, 55 m, 61 m, 67 m, 73 m, 79 m, and 85 m). Four, ten-point frames were located at each interval to measure foliar cover. Four capacitance meter readings were taken at each interval, and one capacitance meter sized quadrat was clipped at each interval. The clipped quadrat was located by slipping the quadrat over the capacitance meter so that the area clipped was the actual area read by the meter. A regression was performed with meter readings as the independent variable and biomass production the dependent variable. Biomass production was estimated for each unclipped meter reading based on the regression. Study areas were fenced to exclude livestock during the entire study period.

Analysis of variance (f-test) was performed with the SAS General Linear Model (SAS Institute 1985). All statistical comparisons were evaluated at $P \leq 0.05$.

Results and Discussion

Shallow Soil Site

The analysis of foliar cover revealed benefits generally associated with tillage and enhanced moisture supply (Table 1). Till plot cover was approximately 3 times that of no-till plots (4.2% and 1.2% respectively). Also as expected, drift area produced more cover than non-drift area (3.1% and 2.3% respectively). The 3-way interaction was not significant, however both drift x tillage and tillage x species interactions occurred, reflecting a difference in magnitude and not response.

Table 1. Shallow and deep soil site comparisons of foliar cover (%) and aboveground biomass production (kg ha^{-1}) for all species combined as effected by tillage and drift treatments.

Treatment	%	kg ha^{-1}
(Shallow soil site)		
till	4.2a	574a
no-till	1.2b	88b
drift	3.1a	376a
non-drift	2.3b	335a
(Deep soil site)		
till	8.9a	1,243a
no-till	5.5b	548b
drift	5.0a	517a
non-drift	9.5b	1,266b

Values within a column with the same letter are not different, P< 0.05.

Till plot aboveground biomass production was significantly greater than no-till (Table 1). Till plots produced 574 kg ha^{-1} versus 88 kg ha^{-1} in no-till plots. There was no difference in biomass production between drift and non-drift treatments (Table 1); however, there was a tillage x drift interaction. The non-drift area-till plot combination produced approximately 20% more aboveground biomass than the drift area-till combination. This result was unexpected. These results emphasize the better response provided by tillage, but also reveal how the shorter growing season in the drift area may have suppressed tillage response and the additional moisture supply of drift melt water.

Pubescent wheatgrass (Luna), thickspike wheatgrass, and slender wheatgrass (Pryor) produced the most cover and aboveground biomass (Tables 2 and 3). The poor results of the San Luis slender wheatgrass variety was unexpected given the excellent results of the Pryor variety and positive tetrazolium tests.

Deep Soil Site

Tillage improved foliar cover of planted grasses on this site as well (Table 1). The difference between till and no-till, however, was less than that exhibited on the shallow soil site. This response was probably due to the higher degree of soil development and associated higher soil moisture reducing the magnitude of the tillage treatment effect. There was a difference between drift and non-drift area. Non-drift areas produced about twice as much foliar cover (Table 1), and no interactions were present.

The till treatment produced more biomass (1,243 kg ha^{-1} vs. no-till 548 kg ha^{-1}, Table 1), and higher means for all species than no-till plots (Table 3). The non-drift portion of the plots outperformed the drift areas (1,266 kg ha^{-1} and 517 kg ha^{-1} respectively, Table 1).

As in the Shallow Soil Site study, there was a drift x tillage biomass production interaction. The drift area-till treatment combination performance was less than anticipated and the non-drift-till treatment combination performance was better than anticipated. We expected that the greater amount of available moisture in the drift area would correlate with higher biomass production. In both studies the mechanism responsible for this response may be the shortened growing season created by the presence of the snowdrift. Another possible contributing mechanism may be related to the precipitation equivalent. Unreplicated soil tests were conducted for background information and results indi-

Table 2. Species percent cover as affected by tillage and drift treatments, across tillage and drift treatments.

	till		no-till		drift		non-drift		overall	
shallow soil site	(%)	(SE)	(%)	(SE)	(%)	(SE)	(%)	(SE)	(%)	(SE)
slender wheatgrass (San Luis)	1.4	0.4	0.4	0.1	0.6	0.2	1.2	1.0	0.9	0.8
slender wheatgrass (Pryor)	7.8	0.4	2.4	0.6	6.7	4.4	3.5	2.7	6.4	5.1
thickspike wheatgrass (Critana)	9.1	1.1	2.0	0.9	6.1	5.5	5.0	4.4	5.6	4.7
pubescent wheatgrass (Luna)	8.1	2.8	2.9	0.3	6.6	2.9	4.4	4.3	5.5	3.7
Russian wildrye (Bozoisky)	5.8	2.5	1.2	0.5	2.8	1.4	4.1	4.2	3.5	3.1
western wheatgrass (Rosana)	4.0	1.0	0.9	0.4	2.8	2.1	2.1	1.7	2.5	1.9
crested wheatgrass (Ephraim)	4.1	2.0	1.9	0.6	3.8	1.8	2.2	2.0	3.0	2.0
basin wildrye (Magnar)	3.2	1.4	0.4	0.2	1.9	1.9	1.5	1.9	1.8	1.8
big bluegrass (Sherman)	1.4	0.5	0.4	0.2	1.0	0.8	0.8	0.7	0.9	0.7
altai wildrye	3.3	1.9	0.8	0.3	2.5	1.9	1.6	1.9	2.1	1.9
tall fescue (Fawn)	3.1	1.1	1.3	0.3	2.9	1.3	1.4	1.1	2.2	1.4
tufted hairgrass	0.4	0.1	0.2	0.1	0.4	0.4	0.2	0.2	0.3	0.3
mountain brome (Bromar)	3.4	0.7	1.3	0.3	2.7	0.9	2.0	1.8	2.4	1.4
deep soil site										
slender wheatgrass (San Luis)	22.5	10.2	14.1	5.8	13.2	5.9	23.3	16.3	18.3	12.3
slender wheatgrass (Pryor)	14.6	5.5	12.8	9.7	12.2	5.6	15.3	13.0	13.7	10.0
thickspike wheatgrass (Critana)	19.1	4.6	5.6	2.8	7.1	4.2	17.6	14.0	12.4	11.0
pubescent wheatgrass (Luna)	16.6	1.6	6.0	3.7	10.0	8.7	12.6	17.0	11.3	13.3
Russian wildrye (Bozoisky)	9.0	7.3	8.9	5.0	1.5	1.1	16.3	10.0	9.0	10.5
western wheatgrass (Rosana)	9.1	4.8	6.0	3.4	3.5	1.5	11.6	8.7	7.6	7.3
crested wheatgrass (Ephraim)	7.1	3.6	6.0	5.2	5.7	3.9	7.3	5.4	6.6	4.6
basin wildrye (Magnar)	6.1	1.6	3.6	2.4	3.2	3.8	6.5	4.6	4.9	4.4
big bluegrass (Sherman)	5.6	2.5	3.5	3.1	3.8	2.9	5.4	4.2	4.6	3.5
altai wildrye	3.6	0.8	2.3	1.4	2.5	1.6	3.3	1.3	3.0	1.4
tall fescue (Fawn)	1.4	1.5	1.3	1.3	2.3	2.1	0.5	0.7	1.4	1.8
tufted hairgrass	1.0	1.0	0.2	0.4	1.0	1.0	1.0	0.7	0.9	0.8
mountain brome (Bromar)	1.1	1.4	0.1	0.0	0.2	0.2	0.9	2.2	0.6	1.5

Table 3. Species aboveground biomass production as affected by tillage and drift treatments, across tillage and drift treatments.

	till		no-till		drift		non-drift		overall	
shallow soil site	(kg ha^{-1})	(SE)	(kg ha^{-1})	(SE)	(kg ha^{-1})	(SE)	(kg ha^{-1})	(SE)	(kg ha^{-1})	(SE)
slender wheatgrass (San Luis)	564	105	52	80	152	137	464	92	308	122
slender wheatgrass (Pryor)	2,059	684	265	95	1,245	354	1,079	240	1,162	285
thickspike wheatgrass (Critana)	930	307	208	157	407	129	731	328	569	226
pubescent wheatgrass (Luna)	1,260	338	138	73	782	640	640	120	711	173
Russian wildrye (Bozoisky)	520	150	39	24	203	184	349	150	280	127
western wheatgrass (Rosana)	294	101	44	47	194	182	144	29	169	95
crested wheatgrass (Ephraim)	660	466	174	18	455	354	344	235	347	290
basin wildrye (Magnar)	399	184	92	72	152	164	180	57	166	109
big bluegrass (Sherman)	321	142	42	32	206	160	197	144	182	59
altai wildrye	344	178	27	24	135	79	236	106	186	61
tall fescue (Fawn)	171	60	76	56	199	129	48	26	124	67
tufted hairgrass	81	80	14	21	43	58	54	52	48	48
mountain brome (Bromar)	58	31	65	16	104	59	19	40	62	44
deep soil site										
slender wheatgrass (San Luis)	2,893	1,402	1,003	435	870	663	3,026	1,319	1,948	1,544
slender wheatgrass (Pryor)	2,131	1,457	1,202	807	1,388	668	1,945	1,717	1,667	1,113
thickspike wheatgrass (Critana)	1,860	1,449	697	518	736	174	1,820	1,238	1,279	1,117
pubescent wheatgrass (Luna)	1,974	1,425	764	515	796	588	1,942	1,197	1,369	1,264
Russian wildrye (Bozoisky)	1,390	742	840	195	294	420	1,937	1,135	1,115	850
western wheatgrass (Rosana)	1,050	562	434	290	349	231	1,134	848	742	720
crested wheatgrass (Ephraim)	744	489	638	361	448	306	935	695	691	572
basin wildrye (Magnar)	664	658	168	151	439	467	693	213	416	573
big bluegrass (Sherman)	869	402	582	252	492	477	959	685	726	610
altai wildrye	893	658	234	149	224	226	903	711	564	509
tall fescue (Fawn)	484	201	348	157	215	244	617	572	416	233
tufted hairgrass	72	53	11	13	34	43	49	55	42	53
mountain brome (Bromar)	136	17	39	34	66	77	109	65	88	129

cated available phosphorus and nitrogen are unusually low or deficient in drift areas. One possible mechanism for this condition could be the leaching process occurring in the drift area each year. Drift areas are receiving, as precipitation equivalent, 2 to 3 times more moisture than the mean annual precipitation. Annual infiltration of 800–1,000 mm of additional water through the soil profile over the last 20 years, is sufficient to cause higher than normal leach rates. A more thorough soil analysis would be necessary to elucidate this phenomenon.

The San Luis variety of slender wheatgrass was the best performer in both cover and biomass production attributes. The alternate seedlot utilized for the Deep Soil Site provided a substantial performance improvement over performance of the Shallow Soil Site seedlot. All seedlots used in the project were less than 2 years old and manufacturer germination rates were verified by a second tetrazolium test. For unknown reasons the San Luis slender wheatgrass seedlot used in the Shallow Soil Site study did not germinate. We believe that, given the use of a quality seed lot, San Luis performance would have been excellent in both instances. Pubescent wheatgrass (Luna), slender wheatgrass (Pryor), and thickspike wheatgrass (Critana) were also superior in cover and aboveground biomass production. Overall, the results demonstrated the competitive and vigorous nature of wheatgrasses.

Mitigation Implications

Based on the results of this study, seed bed preparation by tillage was superior to the no-till preparation. This is true for all species tested in both studies. A few species including both slender wheatgrass varieties, and pubescent and thickspike wheatgrasses show some usefulness for no-till situations. Any attempt to reclaim mid-elevation snowfence sites or other areas of high snow accumulations (e.g., ski area mitigations in the Rocky Mountain west), should include species such as pubescent and thickspike wheatgrasses, and one or both varieties of the slender wheatgrasses included in this study. These species could be used successfully on both shallow and deep soil sites, and in drift and non-drift areas. (Non-drift areas are defined as areas without large, growing season limiting drifts). Pubescent wheatgrass (introduced) and thickspike wheatgrass (native) are long lived, rhizomatous and capable of forming a sod, and have the capability to quickly stabilize a site. This characteristic is important for erosion prone areas such as sloping sites and/or sites subjected to strong winds.

Slender wheatgrass varieties included in the study are also capable of quickly stabilizing a site. This native bunchgrass species also offers the option of increasing the morphological diversity of a seeded stand. However, this species is short-lived (Hafenrichter et al. 1968), and may not persist in stands after 5–10 years. Under good moisture conditions this species is an excellent seed producer, and this natural re-seeding ability may offset the short-lived nature (Hafenrichter et al. 1968). Shallow, drier sites may also require the inclusion of more drought tolerant species in a seed mixture along with the previously mentioned species. The introduced species, Russian wildrye and crested wheatgrass, may have some value in the event of dry year sequences. More mesic species such as basin wildrye and tall fescue may have some utility in mixes for reclaiming deeper, meadow sites.

In conclusion, it must be stated that these results are based on two years of observations. Sampling must be conducted in future years in order to determine the long term success of these reclamation efforts. The effect of tillage treatments may be less conspicuous after five or ten growing seasons. Future plant performance may also be strongly influenced by changing soil characteristics. A study of soil parameters as well as a fertilizer response study, may also need to be incorporated into any future assessment of cultural practices and species performance.

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Perceptions and economic losses from locoweed in northeastern New Mexico

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Abstract

Livestock producers and others knowledgeable about the locoweed problem in northeastern New Mexico were surveyed to obtain the production information needed to estimate economic losses from locoweed (*Oxytropis/Astragalus*) poisoning. A partial budgeting approach was used to estimate economic losses based on animal performance differences with increasing levels of poisoning. With current production costs and 1990–96 average beef prices, annual locoweed poisoning losses were estimated to be $75 head^{-1} for moderately poisoned animals, and $282 head^{-1} for severely poisoned animals. The most common locoweed management strategy used by northeastern New Mexico ranchers was to move animals observed eating locoweed into locoweed-free areas. Rehabilitation of these animals for an extended period before sale was found to decrease economic loss relative to immediate sale. Moderately and severely poisoned animals that are rehabilitated were estimated to gain 14% and 29% less than non-intoxicated animals. Other management options including chemical locoweed control, fencing, and locoweed aversion were found to be economically justified when relatively high locoweed infestations are anticipated.

Key Words: Poisonous plants, woolly locoweed, *Astragulus mollissimus* Torr. var *mollissimus*, white locoweed, *Oxytropis sericea* (Nutt.), weed control, grazing management

Resumen

El problema de la intoxicación con hierba loca (*Oxytropis/Astragalus*) fué estudiado a través de datos obtenidos entre productores de ganado y otros expertos del Nordeste de Nuevo Mexico con la finalidad de obtener la información necesaria para estimar las pérdidas económicas ocasionadas por éste problema en novillos de carne. Un enfoque parcial de presupuestos fué utilizado para estimar las pérdidas económicas tomando en cuenta las diferencias de la eficiencia animal al incrementarse los niveles de intoxicación. Considerando costos de producción reales y precios promedio de 1990 a 1996, para ganado de carne, las pérdidas económicas anuales por intoxicación con hierba loca fueron estimadas en $75 por cabeza para animales moderadamente intoxicados y $282 por cabeza para animales severamente intoxicados.Se encontró que la rehabilitación de estos animales, por un período prolongado hasta antes de su venta, disminuye las pérdidas económicas en relación a que si éstos hubieran sido vendidos inmediatamente. A los animales con moderada y severa intoxicación que son rehabilitados se les estimó una pérdida de 14% y 29%, respectivamente, en comparación a los animales no intoxicados. La estrategia de manejo generalmente usada por los productores del Nordeste de Nuevo Mexico fue a cambiar los animales que se observaron comiendo hierba loca a otra área no infestada con dicha hierba. Otras opciones de manejo incluyendo el control químico, cercado y aversión al consumo de hierba loca fueron encontradas económicamente justificadas cuando son previstas altas infestaciones de hierba loca.

Poisoning from locoweeds (*Astragalus* spp. and *Oxytropis* spp.) cause major economic losses to the livestock industry in the western United States (James et al. 1999). Prolonged consumption of *Astragalus* and *Oxytropis* species causes animals to become lethargic and emaciated, and subject to chronic illness and possible death. Economic losses from locoweed include diminished reproductive performance, increased death losses, poor animal health, and reduced weights and sale prices. The magnitude of economic loss depends on the degree of intoxication and the proportion of a herd that is affected by the poisonous plant. The propensity to graze locoweed varies among animals, as some will occasionally eat the plant, while others will develop a preference for locoweed and become chronic eaters (Ralphs et al. 1993).

In this study we examine how locoweed poisoning and the actions taken to rehabilitate animals and minimize losses affect the economics of yearling cattle operations in northeastern New Mexico. In this region, yearling stocker operations are diverse and use widely different production strategies, including retaining yearlings calves, annual purchase of yearling animals, grazing on leased versus owned pasture, and with many different arrangements for the daily care of cattle (Torell et al. 1998). The grazing season typically starts late March to early May and runs through mid-October. Problems resulting from locoweed consumption may occur at any time during this grazing season.

To determine the extent of the region's locoweed problem and to define alternative grazing strategies that might reduce impacts from locoweed, personal interviews and meetings were held with livestock producers and others knowledgeable about managing locoweed problems, including how to deal with locoweed poisoned animals and how to minimize economic losses from the weed. Our objectives were to: 1) evaluate the economic effectiveness of alternative locoweed management strategies based on

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information provided by northeastern New Mexico livestock producers, and 2) determine how much could be spent on added locoweed management while still maintaining a positive benefit/cost ratio for the investment.

Methods

Defining Locoweed Symptoms

Successful recovery from locoweed poisoning depends on recognizing the disease early and preventing animals from eating more plants. Clinical symptoms of locoism include a lack of coordination, visual impairment, depression, unpredictable behavior, and emaciation (Allison 1991). Field definition of locoism is imprecise and detection largely depends on the experience of the observer (Stegelmeir et al. 1996). Visual cues are usually used to broadly categorize the extent to which an animal may be intoxicated (Allison 1991). For this study, we use a *none* categorization to describe animals with no visual signs of locoweed poisoning, such as those having a healthy, thrifty appearance with a bright hair coat. *Moderately* poisoned animals were defined to be cattle showing early signs of dead and dull hair, eyes with a glazed and clouded look, and animals not yet exhibiting symptoms of trembling or obvious weight loss. By contrast, *severely* poisoned animals were considered to clearly have an unhealthy appearance. At this stage animals tremble when startled, they cannot focus their eyes, the hair coat is shaggy and dead, and weight loss is obvious compared to other non-eating locoweed cattle in the herd.

Estimating effects from locoweed poisoning

Information needed to estimate locoweed poisoning losses was largely obtained from personal interviews and group panel meetings with northeastern New Mexico livestock producers. Cooperators were surveyed in summer 1997 and included 17 northeastern New Mexico ranchers, 1 feedlot operator, 1 veterinarian, 2 County Extension agents, and a manager from the Clayton, N. M. livestock auction. All had first hand experience with locoweed poisoning and had dealt with the poisoning problem in various ways. Interviewees were asked specific survey questions, but during the interviews there was also open discussion about the symptoms, losses and management of locoweed. Those interviewed compared production differences between *none*, *moderate* and *severely* intoxicated yearling cattle. They provided their best estimates of how average daily gain (ADG) might vary over the grazing season; how common the locoweed problem is in their area; how long symptoms of locoweed poisoning might last; how much death loss occurs; how animals respond to a detoxification period; and what management strategies might best be employed to minimize economic losses. They were also asked to estimate how rates of gain and sale prices could be expected to change once animals were removed from locoweed infested areas.

In addition to the general observations from northeastern New Mexico producers, information for our economic analysis was also obtained from grazing trails conducted in 1996 and 1997 near Clayton, N.M. (Owen et al. 1999). In these grazing trails 2 groups of cooperator-owned cattle were monitored for weight gain and frequency of locoweed poisoning. As described in more detail by Owen (1998) and Owen et al. (1999), producer animals were monitored to determine differences in ADG between cattle poisoned and not poisoned by locoweed, and to investigate poisoning and performance differences between steers versus heifers, by whether cattle where imported from out-of-state versus those locally purchased, by grazing strategy, and by the amount of locoweed in pastures where cattle grazed. These studies indicated that yearlings (both steers and heifers) not suffering from locoweed poisoning[1] can be expected to gain about 0.70 to 0.87 kg^{-1} $head^{-1}$ day^{-1}. Yearling steers and heifers with visual signs of locoism gained an average 0.35 kg^{-1} $head^{-1}$ day^{-1}.

In a separate grazing trial also conducted in 1997 near Clayton, N.M., Ralphs et al. reported yearling steers not eating locoweed gained 0.71 (±0.02) kg^{-1} $head^{-1}$ day^{-1}. They reported ADG for locoweed intoxicated animals to average 0.44 (±0.04) kg^{-1} $head^{-1}$ day^{-1}. The estimated range in measured rates of gain reported from the Owen (1998) and Ralphs et al. (2000) studies were consistent with experiences expressed by those participating in the interviews and panel meetings. Survey participants also detailed how ADG typically varies over the grazing season and how rates of gain increase once animals are removed from locoweed infested areas.

[1]These animals were apparently not consuming locoweed because they showed no visual signs of poisoning or in other cases they had been grazing a locoweed free pasture. Measures of data dispersion and individual animal weights were not recorded.

This information was used to define expected ADG over the grazing season for the *none*, *moderate*, and *severe* locoweed poisoning categorizations (Fig. 1).

Defining Management Alternatives

Various strategies have been devised from practical and research experience to minimize locoweed poisoning and to rehabilitate animals once they are intoxicated. For this study, we compared 3 management alternatives that have been employed by northeastern New Mexico ranchers. The first alternative, called *loco and pull*, requires that cattle be checked frequently and when an animal is observed eating locoweed it is immediately moved from the herd to a separate locoweed-free pasture (Allison and Graham 1999). Detection and roundup delays often occur, thus some animals may already be intoxicated and show definite signs of poisoning when removed.

A second potential management alternative, called *delayed grazing*, was proposed by Ralphs et al. (1993), and prevents grazing in locoweed infested pastures until dominant grasses, such as blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Griffiths), are actively growing. Typically, in northeastern New Mexico, blue grama initiates green up in late May or June, so under this alternative the start of the grazing season is delayed until this time. This alternative, as well as the *loco and pull* alternative, obviously require that locoweed-free areas be available. If a locoweed-free area is not available then ranchers must decide if leasing locoweed-free land, feeding animals in a drylot, or immediately selling animals is more practical than grazing a locoweed infested pasture and risking poisoning. With adequate financing, planning and timing, chemical control or fencing could be used to create locoweed-free pastures (McDaniel 1996). We do not provide an economic evaluation of the *delayed grazing* alternative because more research is needed to clearly determine the willingness (or lack thereof) of cattle to eat locoweed when the start of the grazing season is delayed until green grasses are present. We do draw broad estimates about the feasibility of *delayed grazing* based on similarities with other management alternatives.

The third management alternative evaluated, called *locoweed aversion*, has recently been proposed by Ralphs et al. et al.. Under this alternative cattle are fasted overnight and then given an emetic (lithium chloride) the next morning with freshly chopped locoweed (or other poisonous plant) to cause gastro-intestinal distress and thereby discourage animals from eating the plant. In our analysis we considered the costs of giving the emetic and monitoring the cattle under experimental conditions (Michael Ralphs and David Graham, personal communications). Similar labor requirements and costs were assumed for commercial herds.

Economic Model Definition

The economic model, which is Lotus 1-2-3™ spreadsheet-based, consists of 3 major components. First, the rate of gain for a herd of yearling cattle carried over a specified grazing season and with a defined level of locoweed poisoning is given as user input. Figure 1 details the daily gains and animal weights defined in the model. Animal weights are computed for each day of the grazing season based on specific assumptions about purchase date, degree of locoweed poisoning, and timing of detection and rehabilitation (Table 1). The ADG definitions were based on estimates provided from the producer surveys and grazing trials conducted by Owen (1998) and Ralphs et al. 2000.

The number of livestock eating and poisoned by locoweed is obviously a very important determinant of economic impacts from locoweed. Based on estimates provided by livestock producers, in a typical year about 68% of yearlings could be expected not to consume large enough quantities of locoweed to become intoxicated, 25% would become moderately intoxicated, and 7% would be severely poisoned. While we assumed this break down for our analysis, it must be emphasized that the proportion of a herd poisoned by locoweed is highly variable from year-to-year and from ranch-to-ranch and that these averages are merely a reasonable estimate of expected intoxication levels.

The second model component is a livestock pricing model that estimates purchase and sale prices for cattle with selected characteristics and sale weights. This price adjustment is necessary because sale weights and sale prices will be different for different levels of locoweed poisoning. Livestock purchase and sale prices were estimated using a reduced form of a beef pricing model developed by Sartwelle et al. (1995, 1996a, and 1996b). Parameters from the pricing model were used to adjust prices for sale weight (w) differences. Base prices were set using 1990–96 average prices from livestock auctions in Clovis, N.M. Purchase price was based on 204 kg steer calves ($Base_c$= \$1.98 kg^{-1}) and sale price on 295 kg feeder steers

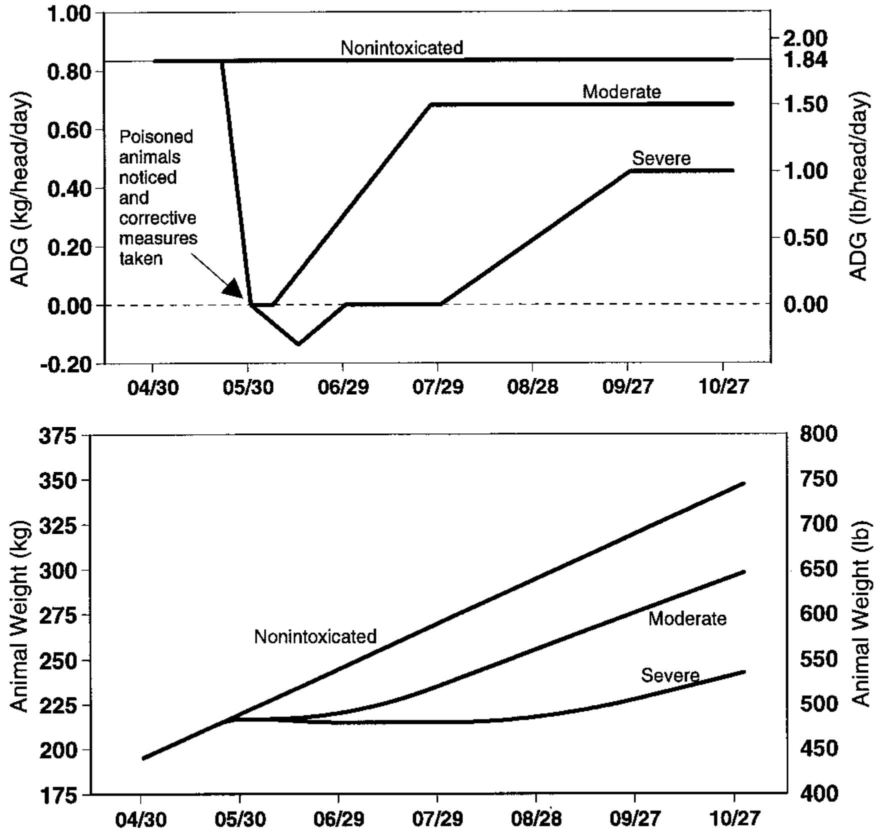

Fig. 1. Expected variations in ADG and animal weight over the grazing season.

($Base_f$= \$1.72 kg^{-1}). Using the reduced Sartwelle price model, equations were developed for both purchase and sale prices as follows:

$$P_p = Base_c - 1.77 \times 10^{-3}(w - 204) - 1.46 \times 10^{-6}(w^2 - 204^2) \quad \text{Steer Purchase Price}$$

$$P_{s1} = Base_f - 7.29 \times 10^{-5}(w - 295) - 7.29 \times 10^{-7}(w^2 - 295^2) \quad \text{Sale Price, Weight} \geq 272 \text{ kg}$$

$$P_{s2} = Base_c - 4.41 \times 10^{-3}(w - 204) + 1.46 \times 10^{-6}(w^2 - 204^2) \quad \text{Sale Price, Weight} < 272 \text{ kg}$$

The third model component generates cost and return estimates for a specified management scenario. The economic analysis was conducted with specific assumptions about production expenses, labor requirements, prices and rehabilitation costs by intoxification category (*none, moderate,* and *severe*). Parameters of the economic model were then altered to generate cost and return estimates for alternative management scenarios.

Loco and pull management was first compared to a situation in which no locoism occurred. In this comparison, differences in sale weights, sale prices, and rehabilitation costs were computed for each of the 3 intoxication categories. This provided a direct estimate of economic losses to locoweed by intoxication category, and an estimate of how much overall economic returns are reduced because some animals are poisoned by locoweed.

Other management options are compared to *loco and pull* to determine their economic advantage or disadvantage. *Loco and pull* management was used as the base for comparison because, according to the producer survey, it is the alternative most widely practiced. Under the *loco and pull* alternative a livestock operator may decide to rehabilitate an animal in a locoweed-free area or choose to sell the animal immediately after it is identified.

Specific assumptions were made about the timing of diagnosis, rehabilitation and sale of animals (Table 1). It was assumed that poisoned animals would be identified 30 days after being placed in a locoweed-infested pasture. With the ADG definitions used in the economic model (Fig. 1), animals purchased at 195 kg would weigh approximately 218 kg after 30 days of grazing. Selling the animals at this early date saves the producer additional feed

Table 1. Economic model definition for loco and pull management.

Model Parameter	Definition		Source/Description
1. Date yearlings are turned out on rangeland	May 1		Source: Producer panel meetings. Turn out dates are variable. Most producers start buying yearlings in early spring and have accumulated the entire herd by early to mid-May.
2. Sale date	October 15		Source: Producer panel meetings. Sale dates generally ranged from mid-September to the end of October.
3. Length of yearling grazing period	167 days		
4. Number of cattle purchased	550 head		Source: NMSU Livestock Cost and Return series, Torell et al. (1998).
5. Type of calves purchased	Steers		
6. Livestock weights			
a. Average weight of steers at purchase	195 kg		Source: Torell et al. (1998) and producer panel meetings.
b. Average weight of steers at sale	Variable		Varies with locoweed poisoning and the resulting differences in ADG over the grazing season.
7. Percent of herd in each intoxication category			
a. Nonintoxicated	68%		Source: Producer panel meetings
b. Moderate	25%		
c. Severe	7%		
8. Seasonal death loss by intoxication			
a. Nonintoxicated	1%		Source: Producer panel meetings.
b. Moderate	2%		
c. Severe	3%		
9. Sale price discounts			
a. Non-locoweed eaters and rehabilitated animals	None		Source: Producer panel meetings and Sartwelle et al. (1996a, 1996b)
b. Poisoned animals	Moderate 10%		
	Severe 50%		
10. Expected ADG for nonintoxicated cattle	0.83 kg		Source: Weight gain monitoring of cooperator livestock in 1996 and 1997, and the observations of producer panel participants.
11. Variation in ADG over grazing season for moderately and severely intoxicated cattle (see Fig. 1 for additional clarification)			Source: Producer panel meetings.
Event		Moderate	Severe
a. Days after entering pasture until ADG is affected by locoweed poisoning		21	21
b. Days with declining ADG		9	24
c. Days after entering pasture until visual signs of poisoning are observed		30	30
d. Days of weight loss (negative ADG)		0	30
e. Minimum ADG		0 kg day^{-1}	–0.14 kg day^{-1}
f. Days until positive gain resumes from time moved to recovery area		7	60
g. Days until peak gain is reached on the rebound after moving to recovery area		50	120
h. Maximum ADG on rebound		0.68 kg day^{-1}	0.45 kg day^{-1}
i. Supplemental feeding during recovery		0.45 kg^{-1} head^{-1} day Cottonseed cake	0.45 kg^{-1} head^{-1} day corn and 4.53 kg kg^{-1} head^{-1} day alfalfa
12. Ranch size, production costs, input use and overhead expenses		See Appendix Table A1	Source: Medium sized northeast New Mexico yearling enterprise as defined by Torell et al. (1998).

costs for rehabilitation. However, if light weight animals are visibly intoxicated they will have a significant price discount.

In the economic analysis, no price discount was used for animals rehabilitated before sale, but a 10% price reduction was used for moderately intoxicated cattle and a 50% reduction for severely poisoned cattle that are immediately sold without rehabilitation. This is similar to price reductions observed in Kansas for health problems that are also commonly associated with locoweed poisoning (Sartwelle et al. 1996a,1996b).

To evaluate the *locoweed aversion* alternative, it was assumed that naïve cattle (i.e. imported cattle or animals not familiar with locoweed) would be purchased and the aversion treatment would be 100% successful. Ralphs et al. 2000 reported this high success rate with aversion trials conducted in 1996 and 1997 with naïve cattle. The cost associated with the aversion treatment was estimated to be \$7 head^{-1} based on the time and input required to conduct the aversion treatment in research trials. This cost includes a lithium chloride treatment, labor for harvesting fresh locoweed for the aversion, and monitoring cattle to assure successful aversion.

Results

Producer Observations

Questions posed from the producer survey and subsequent discussions with livestock producers in northeastern New Mexico provided insight into the locoweed problem and identified many areas in need of future research. All interviewees reported having locoweed problems in the past, but this was expected because this was part of the selection criterion for those interviewed. Producers reported the highest incidences of poisoning in spring and fall when locoweed was the dominant green forage, rather than mid-summer when warm season grasses were actively growing. They reported on average that locoweed poisoned yearlings could be expected to have end-of-season weight losses from 23 to 68 kg head^{-1} depending on the degree of locoweed intoxication, compared to non-poisoned animals. It was agreed by all participants that incidences of locoweed poisoning are widely variable between locations and years.

Supplementation with a high-energy feedstuff and removal of animals to a locoweed-free area was felt to be necessary for poisoning recovery. Consequently, most producers interviewed reported they try to immediately move locoweed intoxicated animals to recovery areas. While in a recovery area (which varied from locoweed-free pastures to holding pens and corrals), a variety of supplementation treatments were used to expedite the recovery process. Reported treatments included feeding a combination of protein block, alfalfa hay and grain with additional vitamin/mineral supplements.

Only one producer preferred to immediately sell animals after visual signs of locoweed poisoning were observed. Other producers felt that keeping the animals for an extended recovery period was more economical because the reduced sale weight from immediate sale, and especially the price discount for intoxicated animals, was too great.

Depending on the degree of intoxication, producers reported reduced sale prices from 10% to 85% for affected animals with visible poisoning symptoms. Interviewees generally agreed that local buyers were knowledgeable about locoweed poisoning and they could readily identify cattle that had been eating the weed. Livestock producers noted that animals, even severely poisoned animals, could be rehabilitated to where the poisoning was no longer visibly apparent and that this would eliminate the price discount.

Research has shown reproductive effects will be greatly reduced once animals are removed from locoweed diets (Stegelmeir et al. 1996). All interviewees reported that reproductive performance should eventually improve following an extended recovery period, but most believed that long-term damage does occur and animal performance never completely recovers. All but one of the producers reported that they later sell rehabilitated animals, including brood stock, because they do not believe the cattle will ever completely recover from locoism.

Livestock producers concurred that proper management is the key to minimizing problems associated with locoweed. Every producer interviewed believed that social facilitation[2] (Ralphs et al. 1994) plays a major role in causing cattle to begin eating locoweed. For this reason, the *loco and pull* strategy was used by many of those interviewed to prevent habitual eaters from influencing naïve animals. Time spent monitoring cattle varied between the interviewees, as did the degree of success with this management strategy.

None of those surveyed indicated they use *delayed grazing* as outlined by Ralphs et al. (1993). Primary reasons reported for not employing this approach was that grazing deferment was perceived to be too costly, locoweed-free pastures were not available, and delayed grazing complicated contractual obligations for leased yearlings. However, producers generally did not disagree with the concept of delayed grazing.

All producer panel participants recognized that significant economic losses occur after cattle become intoxicated by locoweed. Yet, when asked to give their perception about how widespread and severe the locoweed problem is in northeastern New Mexico, producer responses ranged from one individual who believed that it was "not a widespread and persistent problem" because management practices that producers have adopted satisfactorily deal with the problem, to the more common belief that "locoweed presents the most severe economic problem that producers in the area are faced with."

Economic Losses and Management of Locoweed

Economic losses from locoweed poisoning are substantial and include both reduced sales value and increased production costs. Given the parameter specifications used in the economic analysis (Table 1), locoweed poisoning in northeastern New Mexico was estimated to reduce net ranch income from $75 to $282 per head depending on whether the yearling steers were moderately or severely intoxicated (Table 2).

Table 2. Economic losses from locoweed poisoning for yearling stocker operations in northeastern New Mexico.

	Moderate	Severe
	----($/head eating locoweed)----	
Lost gross revenue from diminished livestock performance	$68	$184
Added costs for rehabilitating locoweed-poisoned animals	7	98
Net difference in ranch income	75	282

Note: The comparisons for moderate and severe locoweed poisoning are made relative to nonintoxicated cattle. Average 1990–96 beef prices and 1996 production costs are considered in the analysis. See Appendix Table A1 for a more detailed listing of production and economic differences.

Feeding practices adopted and the extent to which animals are intoxicated influences rehabilitation costs. Moderately intoxicated steers were assumed to be supplemented with 0.45 kg head^{-1} day^{-1} cottonseed cake for 57 days and this added $7 head^{-1} in feed costs. Severely intoxicated cattle supplemented with 4.53 kg head^{-1} day^{-1} of alfalfa and 0.45 kg head^{-1} day^{-1} of corn for 120 days in the recovery area added $98 head^{-1} in feed cost. Sale weights were still reduced after supplementation and recovery. Given the defined differences in ADG (Fig. 1), average sale weights with *loco and pull* management were estimated to be 334 kg for non-intoxicated animals, 288 kg for moderately poisoned animals, and 236 kg for severely poisoned animals (Appendix Table A1).

Immediate sale of poisoned animals results in significantly higher economic losses than rehabilitating animals with *loco and pull* management (Table 3). With 1990–96 average beef prices and with the price discounts assumed for intoxicated cattle, the economic loss per animal from immediate sale was estimated to increase by $103 head^{-1} and $68 head^{-1} for moderately and severely intoxicated animals, respectively. This comparison is made relative to animals rehabilitated before sale using *loco and pull* management.

The economic penalty for immediately selling a severely intoxicated animal is less than a moderately intoxicated animal because the recovery period is longer, supplemental feed costs are higher and thus rehabilitation costs are higher. When the relative number of moderately and severely poisoned animals on a ranch are considered (assumed to be 25% and 7% of the herd, respectively in this analysis) the weighted average value of healing intoxicated animals (versus immediately selling them) is estimated to be $95.35 head^{-1}.

Having locoweed-free pastures is crucial

[2]Social facilitation is defined as the initiation of a particular response as the result of observing others engage in that behavior (Galef 1988).

Table 3. Economic losses associated with immediate sale of yearlings poisoned by locoweed.

	Loco and pull Management		Immediate Sale		Added Loss from Immediate Sale	
	Moderate	Severe	Moderate	Severe	Moderate	Severe
	($/head eating locoweed)					
Gross returns	$486	$370	$370	$204	$110	$166
Total costs	497	587	490	490	–7	–98
Net ranch income	–11	–217	–114	–286	103	68

to successfully implementing *loco and pull* and *delayed grazing* management. The $95.35 $head^{-1}$ added value from rehabilitating animals can be used to estimate the economic value of having this locoweed-free area if immediate sale is the only other option. The value of rehabilitation can be converted to a $ ha^{-1} value by considering the standard stocking rate allowance used in northeastern New Mexico of 6.1 ha $yearling^{-1}$ for a 6 month grazing season (Stuckey and Henderson 1969). The rehabilitation period assumed in our analysis was 4 ½ months, thus the equivalent grazing allowance for this shorter time would be 4.86 ha $head^{-1}$. The $95.35 $head^{-1}$ rehabilitation value means that the estimated value of a locoweed free area is $19.62 ha^{-1} ($95.35 $head^{-1}$/4.86 ha $head^{-1}$). This assumes that locoweed-free pastures are or can be made available on the ranch and poisoned animals can be moved to these areas, fed additional supplements, and rehabilitated before sale in late fall.

If a locoweed-free area does not exist, the estimated $19.62 ha^{-1} added loss from forced immediate sale is the amount one can afford to spend creating a locoweed-free area. With costs ranging from $35 to $40 ha^{-1} for chemical and aerial application costs (McDaniel 1996), a herbicide treatment could be economically feasible provided the area remains loco-free for at least 2 years. Under these circumstances, a successful spray treatment made before the start of the grazing season and lasting 1 additional year would yield a 12.6% rate of return on investment. Conventional and electric fencing can also be used to preclude grazing of localized problem areas.

Leasing locoweed-free rangeland is another option. Considering forage value to be the amount of added loss from forced sale of intoxicated animals, a producer could afford to spend about $23 $month^{-1}$ $head^{-1}$ to lease locoweed-free forage for moderately poisoned animals and $15 $month^{-1}$ $head^{-1}$ for severely poisoned animals (i.e. $103/4 ½ months = $22.89 $month^{-1}$ $head^{-1}$ for moderately poisoned animals, and $68/4 ½ months = $15.11 $month^{-1}$ $head^{-1}$ for severely poisoned animals). By comparison, average rangeland lease rates in the 11 western states were $11.80 $head^{-1}$ during 1997 (USDA-NASS 1998).

Spending $7 $head^{-1}$ to establish an aversion for eating locoweed was estimated to result in a net economic benefit of $32 $head^{-1}$ (Table 4). This results largely from the added livestock sales from averted animals, but an estimated $2 $head^{-1}$ cost savings also results. This savings occurs because the cost of the aversion was estimated to be $2 $head^{-1}$ less than supplemental feed costs that would have been required to rehabilitate intoxicated animals without the aversion. This will be highly variable, however, and will depend on the cost of supplemental feeds and how many animals would have been poisoned without the aversion treatment. We assumed 25% and 7% of the herd would have been moderately and severely poisoned without the aversion treatment. The improved performance of this part of the herd economically justifies the aversion.

As a sensitivity analysis, the proportion of the herd potentially affected by locoweed was decreased from the assumed levels defined above, while keeping the relative number of moderately and severely poisoned animals the same. This was done to determine at what point the *aversion* treatment and *loco and pull* management would be economically equivalent. It was estimated that if more than 9% of the herd (7% moderate and 2% severe) would have been poisoned by locoweed without the aversion then the *locoweed aversion* treatment would be superior to the *loco and pull* management strategy. At levels below this point, the cost of averting the entire herd would be greater than the production losses realized, given the relatively small number of animals that would have been poisoned without the aversion. The practical problem is knowing how many animals would be poisoned without the aversion treatment.

Table 4. Economic benefits of conditioned feed aversion.

	Loco and pull Management	*Feed Aversion*	Benefit of Aversion
	($/head purchased)		
Gross returns	524	555	31
Supplemental feed costs for rehabilitation	–9	0	9
Cost of aversion	0	–7	–7
Net ranch income	26	58	32

Discussion and Conclusions

Locoweed poisoning has a substantial economic impact on yearling operations. This economic loss is extremely variable from year-to-year and ranch-to-ranch. Some of this variability can be attributed to the cyclical occurrence of locoweeds, especially woolly locoweed (*Astragalus mollissimus* Torr. var *mollissimus*). Weather patterns, insects, and type and intensity of grazing management contribute to this variability (Pomerinke et al. 1995, Ralphs et al. 1993).

The unpredictable nature of locoweed infestation makes the determination of what proportion of livestock will become intoxicated highly complex. Further, projecting economic losses is difficult because there is no straightforward management approach available to deal with the poisoning problem. Strategies that have been used or considered in research generally attempt to prevent animals from eating locoweed, or they limit grazing use of locoweed infested areas.

Northeastern New Mexico ranchers have largely adopted the *loco and pull* management strategy. However, how efficient producers are in selecting and removing livestock from locoweed-infested areas is widely variable. Some leave animals in a pasture until visible signs of poisoning are apparent while others are less willing to allow animals to continue eating the poisonous plant. Regardless of when livestock are removed, it is important to have locoweed-free areas in which to rehabilitate animals. According to our partial budgeting assessment, it is generally profitable to invest in weed control or fencing to create and maintain needed locoweed-free areas.

Research experience with livestock aversion has been successful in training animals not to eat locoweed (Ralphs et al. 2000). However, further practical experiences and commercial application is needed to refine the procedure and further define costs. Another potential and similar management alternative where attempts are made to keep animals from eating locoweed is *delayed grazing*. While not specifically considered and budgeted here, *delayed grazing* could also be an economically feasible way to minimize losses from locoweed. As reported by Owen et al. (1999), monitoring and weighing of producer cattle during 1997 indicated that animal performance for *delayed grazing* was similar if not improved over that of the aversion treatment. The economic benefit of *delayed grazing* could then potentially be similar to the $32 ha^{-1} estimated for the *aversion* treatment. The cost of the aversion would be spared with *delayed grazing*, but other expenses to create and maintain locoweed-free areas would be expected. As more and more effort is required to create locoweed free areas the net economic benefit of *delayed grazing* and *loco and pull* management would be diminished. However, with substantial improvement in livestock gains, spraying or fencing selected areas to create locoweed free areas for spring grazing may be economically justified. More grazing trials replicated across years are needed to further evaluate the feasibility of the *delayed grazing* treatment.

In this study, definition of the locoweed economic model was based on cost and animal production differences estimated from surveys with knowledgeable livestock producers in northeastern New Mexico, and from limited grazing trials that studied production differences (Owen 1998, Ralphs et al. 2000). To better estimate economic losses from locoweed, further animal research is needed to determine how animal performance is affected at different stages of locoweed poisoning. Reproductive impacts of locoweed poisoning should be investigated. Further research is also needed to develop indicators defining the extent of locoweed intoxication for particular animals. Many alternative management strategies have the potential for reducing economic losses from locoweed and even more options would be available if locoweed-eating animals could be identified earlier.

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Appendix table A1. Cost and return estimates for loco and pull management.

Number			Sale Weight	Total	Purchased No Loco	Purchased Moderate Loco	Purchased Severe Loco	Weighted Average
		($/Kg)	(Kg)	($)	($/Head)			
I. GROSS RETURNS								
370	Non-Loco Steers	$1.68	334	$207,244	$554.13			
135	Moderate-Loco Steers	$1.72	288	$66,866		$486.29		
37	Severe-Loco Steers	$1.63	236	$14,238			$369.81	
	Total			$288,348	554.13	486.29	369.81	524.27

					$/Head Purchased			
II. COSTS		Unit	$/Unit	Total $	No Loco	Moderate Loco	Severe Loco	Weighted Average
A. VARIABLE COSTS								
1. Feed:								
26.5	Purchased Hay	MT	141	3,738	1.63	1.63	78.43	7.01
0.9	Grain	MT	387	352	0.64	0.64	0.64	0.64
2.0	Corn	MT	385	777	0.00	0.00	21.00	1.47
3.5	Cottonseed Cake	MT	275	962	0.00	7.13	0.00	1.78
7.0	Protein Supplements	MT	278	1,948	3.54	3.54	3.54	3.54
1.8	Salt	MT	143	260	0.47	0.47	0.47	0.47
6.4	Minerals	MT	355	2,261	4.11	4.11	4.11	4.11
	Total			10,298	10.40	17.52	108.20	19.02
2. Livestock Expenses:								
550	Purchased Steers	195	2.02	217,008	394.56	394.56	394.56	394.56
	Miscellaneous Other Expenses			24,739	44.98	44.98	44.98	44.98
	Total			241,747	439.54	439.54	439.54	439.54
	TOTAL VARIABLE COSTS			252,044	449.94	457.06	547.74	458.56
B. FIXED COSTS								
	TOTAL FIXED COSTS			21,855	39.74	39.74	39.74	39.74
	TOTAL COSTS			273,899	489.67	496.80	587.47	498.30
C. NET RANCH INCOME				14,448	64.46	–10.50	–217.66	25.97
Proportion of Yearlings Purchased					68%	25%	7%	100%

Adapted from medium-sized yearling stocker enterprise budgets presented in the New Mexico Livestock Cost and Return Series, 1996 (Torell et al. 1998). Assumes that 550 head of yearling steers are purchased. The feed costs of healing intoxicated animals are included in the appropriate expense categories.

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Fire and cattle grazing on wintering sparrows in Arizona grasslands

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Abstract

This paper reports on the results of a 3-year field study of the effects of spring/summer burning and cattle grazing on wintering sparrows in the grasslands of southeastern Arizona. The effects of fire were studied with 1 year of pre-burn data and 1 year of post-burn data from 1 fire, plus limited sampling from a second fire at Buenos Aires National Wildlife Refuge in Pima County, Ariz. The effects of grazing were studied by comparing study plots at a site that has not been grazed by cattle since 1968 with a nearby grazed pasture in Santa Cruz County, Ariz. Sparrow abundance was measured as the number of captures from flush-netting sessions conducted by groups of 13–30 volunteers. Vesper (*Pococetes gramineus* (Gmelin)) and Savannah (*Passerculus sandwichensis* (Gmelin)) Sparrows responded positively to fire, while Cassin's Sparrows (*Aimophila cassinhi* (Woodhouse)) responded negatively. The ecologically and geographically restricted Baird's (*Ammodramus bairdil* (Audubon)) and Grasshopper (*A. savannarum* (Gmelin)) Sparrows utilized burned areas during the first post-burn winter and did not significantly respond to fire. Both *Ammodramus* sparrows also utilized the grazed pasture; they were more abundant there than in the ungrazed study area in 1 year. While field observations and a prior study suggest that heavy grazing can have a strong detrimental effect on *Ammodramus* sparrows, the results of this study suggest that moderate cattle grazing may be compatible with the conservation of these species.

Resumen

Este articulo reporta los resultados de un estudio de campo de 3 años en el que se determinaron los efectos de la quema en primavera/verano y el apacentamiento de ganado sobre los gorriones invernantes en los pastizales del sudeste de Arizona. Los efectos del fuego se estudiaron con datos de 1 año antes de la quema y con datos de 1 año después de una quema, mas un muestreo limitado de una segunda en el Refugio Nacional de Fauna Silvestre Buenos Aires situado en el condado de Pima, Ariz. Los efectos del apacentamiento se estudiaron mediante la comparación de parcelas localizadas en un sitio que no había recibido apacentamiento desde 1988 y en parcelas situadas en potrero cercano que estaba siendo apacentado, estos sitios se ubican en Santa Cruz, Ariz. La abundancia de gorriones se midió como el número de capturas en sesiones de redeo conducidas por grupos de 13 a 30 voluntarios. Los gorriones "Vésper" (*Pooecetes gramineus* (Gmelin)) y "Savannah" (*Passerculus sandwichensis* (Gmelin)) respondieron positivamente al fuego, mientras que los gorriones "Cassin" (*Aimophila cassinii* (Woodhouse)) respondieron negativamente. Los gorriones "Baird" (*Ammodramus bairdii* (Audubon)) y "Grasshopper" (*A. savannarum* (Gmelin)), que están ecológicamente y geográficamente restringidos, utilizaron las áreas quemadas durante el primer invierno después de la quema y no respondieron significativamente al fuego. Ambas especies de gorrión del genero *Ammodramus* también utilizaron los potreros apacentados, en un año, ellos fueron más abundantes allí que en los potreros sin apacentamiento. Mientras las observaciones de campo y un estudio previo sugieren que el apacentamiento severo puede tener un fuerte efecto detrimental en los gorriones *Ammodramus* los resultados de este estudio sugieren que el apacentamiento moderado puede ser compatible con la conservación de estas especies.

Key Words: birds, conservation, bird-banding

The grasslands of the borderlands region of the southwestern United States are a crucible for the interaction between, and the coexistence of, ecologically restricted biodiversity and economically important cattle grazing. These are the most biologically diverse grasslands in the country and they contain many specialized and endemic species (Whitford et al. 1995, Parmenter and Van Devender 1995). During winter, these grasslands are home to endemic subspecies of Grasshopper Sparrow (*Ammodramus savannarum ammolegus* (Gmelin)) and Eastern Meadowlark (*Sturnella magna lilianae* (Linnaeus)), and geographically-restricted Baird's Sparrow (*Ammodramus bairdii* (Audubon)) and Sprague's Pipit (*Anthus spragueii* (Audubon)), all of which are restricted to grassland habitats within their limited geographic ranges (Phillips et al. 1964). Among the species in this study, Grasshopper, Baird's, and Cassin's Sparrows (*Aimophila cassinnii* (woodhouse) have been identified as species of management

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concern both nationally (USFWS 1995) and in Arizona (Latta et al. 1999).

The grasslands of the southwestern borderlands are also the most productive lands for cattle grazing in the region. The plains and semidesert grasslands in this region have been described as, "...the lifeblood of southern Arizona's cattle industry." (Bahre 1995). It is therefore essential that we understand the interaction between cattle grazing management practices and wildlife to develop management strategies that meet both economic and conservation goals.

The current study examines the responses of wintering sparrows to the 2 most significant range management practices in the grasslands of southern Arizona: fire and cattle grazing. Fire is currently used in southern Arizona grasslands both to manage for native grassland biodiversity and to enhance herbaceous forage production for cattle. While historical evidence of grassland fires is scarce, it is widely accepted that fires ignited during spring and summer by lightning and/or native Americans were a regular historical occurrence (Bahre 1991, McPherson 1995). In this region, fire kills most shrubs and reduces mesquite (*Prosopis* spp.) recruitment for up to 20 years (Humphrey 1949), while grasses and herbaceous dicots generally return to pre-burn densities in 1 to 3 years (Cable 1967, Bock et al 1976, Wright and Bailey 1980, Cox et al. 1990, Bock and Bock 1990, 1992).

Cattle are currently grazed on virtually all grassland habitat in the borderlands region. The historical and ecological roles of cattle grazing on southwestern rangelands are complex and controversial (see Bahre 1991, reviews by Fleischner 1994, Brown and McDonald 1995). While large ungulate grazers may be viewed, on the one hand, as a natural and coevolved component of some grassland ecosystems (McNaughton 1993), the arid grasslands of the borderlands region are among the least productive grasslands and are dominated by grasses with life history attributes that make them relatively intolerant of cattle grazing (Mack and Thompson 1982, Fleischner 1994). Nonetheless, cattle grazing is much less disruptive to the native grassland community than are several alternative land uses such as row crop agriculture or residential development (Brown and McDonald 1995). Despite the ecological and economic prominence of cattle grazing in southern Arizona, we know very little about the effects of cattle grazing on plant and animal communities of this region (Bahre 1995, but see Fleischner 1994). Some attribute the widespread conversion of the region's grasslands to shrublands largely to the effects of cattle grazing (Bahre 1991), while others believe that this transition came about largely because of a drying climate (Hastings and Turner 1965, Johnson and Mayeux 1992).

Although grassland bird communities are typically low in diversity, they are a top national conservation priority because of the high proportion of threatened and declining species they contain (Knopf 1994, USFWS 1995). All 6 sparrow species in this study have been identified as threatened or of management concern by various state and/or federal wildlife regulatory agencies. The Baird's Sparrow is of special concern because of its extremely restricted geographic range, its narrow habitat restriction within this range, its recent range contraction and population declines, and the virtual lack of any information on the winter biology of this species (USFWS 1995, Jones and Green 1998, Latta et al. 1999). The congeneric Grasshopper Sparrow is also a species of management concern because of its similar restriction to grassland habitat, recent population declines, and a subspecies (*A. s. ammolegus*) that is endemic to the borderlands region (USFWS 1995, Latta et al. 1999). The Cassin's Sparrow is less of a grassland specialist than the previous 2 species but is also a species of management concern in the Southwest based on its small geographic range and recent population declines in some areas (USFWS 1995, Latta et al. 1999, Ruth 1999). Savannah Sparrow (*Passerculus sandwichensis* (Gmelin)), Vesper Sparrow (*Pooecetes gramineus* (Gmelin)), and Brewer's Sparrows (*Spizella breweri* Cassin) are all species of management concern in other regions, but are abundant, widespread, and not currently considered to be of significant management concern in the southwestern United States (USFWS 1995).

Emberizine sparrows comprise a predominant component of the wintering grassland bird community of southern Arizona. Six species of sparrows account for over 99% of all birds captured during this study. Vesper, Savannah, Baird's, and Brewer's sparrows only occur in this region as migrants and winter residents, while Cassin's and Grasshopper sparrows can be found in southern Arizona grasslands year-round (Rising 1996).

Previous information on the effects of fire and grazing on the wintering grassland sparrow community of southern Arizona is limited to 3 published data sets. After a fire in April 1974, Bock et al. (1976) reported that in the subsequent winter, Grasshopper Sparrows were more abundant on unburned areas while Vesper and Savannah Sparrows were more abundant on the burned area. After a fire at the same study site in July 1987, Bock and Bock (1992) reported that Grasshopper and Cassin's Sparrows showed no preference for burned versus unburned areas while Vesper and Savannah Sparrows again were more abundant on the burned area during the subsequent winter. Furthermore, they reported that all significant differences in abundance disappeared by the second or third post-burn winter. In the only published study of the effects of cattle grazing on wintering grassland birds in southern Arizona, Bock et al. (1984) found that Cassin's and Grasshopper Sparrows were more abundant in an ungrazed area while Brewer's Sparrows were more abundant in a grazed pasture.

Materials and Methods

Sparrow Flushing

Standard sparrow flushing plots consisted of a 100-m net line, with a 3.5-ha flushing zone fanning out on each side (Fig. 1). For each day of flush-netting, crews of 13–30 people (avg 22) assembled at 0830 hour at the field site to perform the following field protocol: Eight, 2 x 12 m, 36-mm mesh mist nets were set up along the net line at the first plot. When the nets were ready, the field crew fanned out along the 300 m back edge of one flushing zone. With people spread out evenly along the periphery of the flushing zone, a signal was given and the group walked through the flushing zone toward the net line. This caused the sparrows to flush toward the nets. Many were caught in the nets because of the low-flying behavior of sparrows in this habitat. The crew would then repeat this procedure for the second flushing zone on the other side of the net line.

After flushing both sides of a study plot, all netted birds were banded with individually-numbered, USFWS aluminum leg bands. If they already possessed a band (recaptures), the band number was recorded.

We then disassembled the nets at the first plot and repeated the entire procedure at the next plot. In this way, we flush-netted all plots at a study site in random sequence on each day of flush-netting.

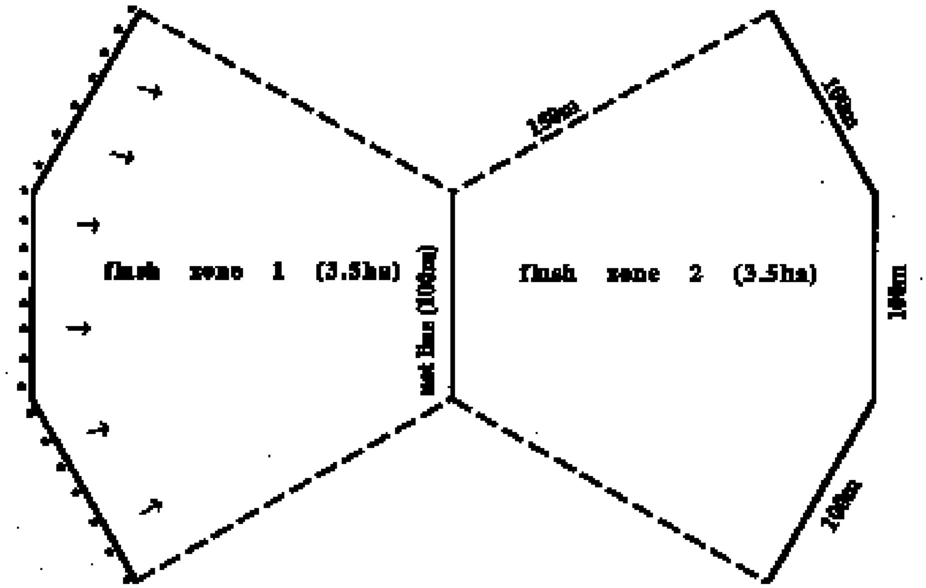

Fig. 1. Schematic representation of a standard sparrow flushing plot. Asterisks represent people (22 = avg) ready to flush one of the zones by walking together in the direction ofthe arrows.

Fire Effects

The prescribed burning program at the Buenos Aires National Wildlife Refuge in Pima County, Ariz. provided the vehicle for examining the effects of fire on wintering grassland sparrow communities. The main portion of this 46,640-ha refuge is located in the broad, flat Altar valley, (Lat. 32°30'N, Long. 111°30'W) between 940 and 1,372 m elevation, and is dominated by mesquite savannah and semidesert grassland vegetation. Domestic livestock were removed when it was established as a National Wildlife Refuge in 1985. Although controlled burns have been conducted on the Buenos Aires National Wildlife Refuge since 1988, an aggressive program of prescribed burning was implemented in 1996 with the goal of managing for the native plant and animal communities of semidesert grassland.

Six sparrow flushing plots were established in upland grassland that had not been burned for at least 3 years. Because of the high density of shrubs, especially concentrated in washes on the Refuge, plot locations were determined by visual selection of relatively flat, shrub-free areas. Each of these plots was flushed for sparrows (see below) once per week for 9 weeks between early January. and early March 1997. In April 1997, 3 of the study plots were burned in a single fire (plots 1, 2, and 3). The 1997 sparrow flushing sampling scheme was then repeated on the same 6 plots between January. and March 1998. In April 1998, another fire burned plot 5 and half of plot 6. Sparrow flushing was then conducted on all 6 plots 3 times between January and March 1999, although data for plot 6 (half-burned) are not reported.

Grazing Effects

The study of the effects of cattle grazing on wintering grassland sparrow communities was conducted at 2 sites in the Sonoita Valley in Santa Cruz County, Ariz. The Audubon, or Appleton-Whittell Research Ranch near Elgin, Ariz., (Lat. 31°38'N, Long. 110°33'W) has not been grazed by domestic livestock since 1968. The Ranch covers 3,160 hectares of plains grassland and oak savannah vegetation between 1,400 and 1,500 m elevation. Six flushing plots were established in relatively treeless upland mesa grassland in the northwestern quarter of the Ranch. These plots were flushed once per week for 7 weeks between early January and early March 1997. The same 6 plots were again flushed once per week for 7 weeks between January and March 1998. Between January and March 1999, the same 6 plots were flushed 3 times. To standardize the 1997 and 1998 Research Ranch data with the other data sets, data from only 3 of the 7 sampling days were used, corresponding to the dates closest in time to the 3 sampling days at the grazed study site.

Grazed study plots were located on the Davis Pasture at the southern end of the USBLM’s Empire Cienega Resource Conservation Area. This 1501-ha pasture is located between Elgin and Sonoita, Arizona, (Lat. 31°41'N, Long. 110°39'W) roughly 10 km from The Research Ranch. Sparrow flushing was conducted during 3 dates per year from 1997 to 1999 between early January and early March. During 1997 and 1998, flushing was conducted on 3 to 9 plots, some of which were half-sized, and new plots were used on each flushing day. In the subsequent analysis, numbers of captures from half-sized plots were doubled to make them comparable to standard plots. In 1999, 6 standard flushing plots were used for all 3 flushing days. In the calendar years of 1996, 1997, and 1998 that immediately preceded the 3 winter seasons of sparrow flushing, this pasture received 1387, 868, and 645 AUMs of grazing pressure, respectively, concentrated during summer. No precipitation data are available but summer rainfall is reported to have been poor during 1996, 1997, and 1998 in this pasture (Grant Drennen, pers. comm.). The desired stocking rate for this pasture is 1091 AUMs given the distribution and estimated production of USDA-NRCS range sites in the pasture, the desired utilization levels for the pasture, and excellent range condition (USBLM 1995, 1997, USDA-NRCS 1982, 1988). The USBLM rated this pasture in excellent condition in October 1995 and 1997 (USBLM 1995, 1997).

Statistical Analyses

Two-tailed t-tests for samples with heteroscedastic variance were used for statistical comparisons of sparrow densities across treatments and years for both fire and grazing studies. In both cases, the sampling units were the number of sparrow captures in individual plots on single days. While repeated sampling of plots violates the assumption of independence of samples, this violation is not serious because samples were conducted at intervals of at least a week. This sampling interval provided adequate time for birds to redistribute themselves. In essence, statistical significance was achieved only if spatial differences in density were consistent in time. Temporal constancy of spatial differences in sparrow abundance suggests that these differences resulted from biologically-real differences among study plots or years rather than random fluctuations.

Results

Effects of Fire

Twenty-one days of flushing over 3 years resulted in 1,617 captures of 8 species of sparrows at Buenos Aires National Wildlife Refuge (Table 1).

Table 1. Mean (± SE) captures per plot per day for 8 species of sparrow on fire study plots at Buenos Aires National Wildlife Refuge.

Species	1997		1998		1999
	Plots 1,2,3 pre-burn)	Plots 4,5,6 (unburned)	Plots 1,2,3 (1 year post-burn)	Plots 4,5,6 (unburned)	Plots 1,2,3 (2 years post-burn)
Grasshopper Sparrow	11±1.1[1]	5.6±0.74	7.4±1.2[1,2]	2.8±0.33[2]	8.1±1.5
Baird's Sparrow	0.41±0.18[1]	0	0.74±0.19[1]	0.11±0.062	0.56±0.24
Savannah Sparrow	1.1±0.45	2.9±0.68[1]	2.3±0.634[3]	2.3±0.42	0.56±0.29[2]
Vesper Sparrow	3.2±0.65	4.8±1.2	2.6±0.57[13]	0.74±0.31[2]	0.11±0.11[2]
Cassin's Sparrow	0.26±0.10	0.22±0.11	0.93±0.23[2]	1.7±0.19[1,2,3]	2.0±0.47
Brewer's Sparrow	1.2±0.46	1.6±0.54	0.19±0.093[2]	0.11±0.062[2]	0.11±0.11
White-crowned Sparrow	0.074±0.074	0.30±0.12	0	0	0
Lincoln's Sparrow	0.11±0.062	0.074±0.051	0	0.11±0.062	0

[1]significantly higher than the other set of plots in the same year p<.05 (see text)
[2]significantly different from the same set of plots in the previous year p<.05 (see text)
[3]response attributable to fire effect (see text)

Because of various non-fire-related sources of variation in sparrow abundance (see discussion), only 3 of the abundance responses shown in Table 1 can be attributed to the effects of fire. These are positive responses to fire by Savannah and Vesper Sparrows and a negative response by Cassin's Sparrow.

Effects of Grazing

Twenty-six days of flushing over 3 years resulted in 1,232 captures of 4 species of sparrows at The Research Ranch and the Davis Pasture (Table 2). Baird's Sparrows were more abundant on the grazed area than the ungrazed area in 1997 but did not differ significantly among study sites in subsequent years. Grasshopper Sparrows were more abundant on the grazed area in 1997, but were more abundant on the ungrazed area in 1998 and 1999.

Discussion

Effects of Fire

Interpreting the effects of fire on the wintering sparrow community is somewhat complex because of several additional sources of variation in sparrow density. First, there were pre-burn differences between some of the study plots. Although study plots were selected to be as similar as possible based on visual inspection of the structure and composition of the vegetation, no 2 study plots in ecological field studies can ever be perfect, identical replicates. Plots 1, 2, and 3 had significantly more Grasshopper and Baird's Sparrows than did plots 4, 5, and 6 both before and after the 1997 fire. This difference in sparrow density may have resulted from habitat differences among plots that were not measured in this study. Second, there were significant between-year differences in the density of certain sparrows that occurred regardless of fire treatment. Brewer's and Grasshopper Sparrows declined, while Cassin's Sparrows increased, in 1998 relative to 1997 on both burned and unburned plots. These differences may have resulted from differences in breeding success or wintering habitat conditions other than fire.

Three species exhibited significant abundance differences that can more likely be attributed to the effects of fire. Savannah Sparrows were significantly more abundant on plots 4, 5, and 6 than on plots 1, 2, and 3 in 1997 before the fire. In the winter subsequent to the fire, this difference was erased, suggesting that Savannah Sparrows responded positively to the burn. Vesper and Cassin's Sparrow abundance did not differ among plots in pre-fire 1997, but after the 1997 fire, Vesper Sparrows were more abundant on the burned plots, and Cassin's Sparrows were more abundant on the unburned plots, suggesting that Vesper Sparrows responded positively, and Cassin's Sparrows negatively to fire during the first post-burn year. The significant declines of Vesper and Savannah sparrows on plots 1, 2, and 3 in 1999 relative to 1998 may indicate that the positive response of these species to fire only lasted 1 year. However, because the occurrence of the second fire prevents a comparison with unburned control plots, a general decrease in these sparrows from 1998 to 1999 cannot be ruled out.

As with the 2 prior studies of the effects of fire on wintering grassland sparrows, this study only reports statistically-significant effects for a single fire. Because fire is not replicated as a treatment factor, the scope of inference is limited to this particular fire at the Buenos Aires National Wildlife Refuge. Nonetheless, some general conclusions can be drawn about the effects of fire on wintering grassland sparrows in southeast Arizona by comparing the results of this study to results from the

Table 2. Mean (± SE) captures per plot per day for four species of sparrow on grazed (Davis Pasture) and ungrazed (The Research Ranch) study plots in the Sonoita Valley, Arizona.

Species	Year	Davis Pasture (grazed)	The Research Ranch (ungrazed)
Grasshopper Sparrow	1997	4.7±1.1[1]	0.44±0.17
	1998	4.8±1.5	15±2.2[1]
	1999	1.3±0.68	3.2±0.67[1]
Baird's Sparrow	1997	1.3±0.39[1]	0.50±0.19
	1998	1.9±0.78	1.3±0.33
	1999	0.39±0.12	0.83±0.32
Savannah Sparrow	1997	0.32±0.20	0.17±0.090
	1998	0	2.8±1.6
	1999	0	0.11±0.076
Vesper Sparrow	1997	0	0
	1998	0	4.3±2.7
	1999	0	0.056±0.056

[1]significantly higher than at other study site in the same year, p<.O5 (see text)

2 fires previously reported in the literature. Bock et al. (1976) and Bock and Bock (1992) also found that wintering Savannah and Vesper Sparrows were more abundant in burned areas after both of the fires they studied. The effects of fire on Grasshopper and Cassin's Sparrows are somewhat less consistent. In the Bock's studies, Grasshopper Sparrows were more abundant on the unburned area following the first fire (Bock et al. 1976) but showed no preference following the second fire (Bock and Bock 1992). Data for Cassin's Sparrows are only reported by Bock and Bock (1992) for their second fire, after which Cassin's Sparrows showed no preference for the burned or unburned area. No prior data are available for the effects of fire on Baird's Sparrow.

The limited replication of fire as a treatment factor adds weight to the effects of the 1998 fire. This fire only burned 1 plot completely and sparrow sampling was less intense in 1999. Therefore, sample sizes are lower and the results are not statistically significant. Nonetheless, sparrow abundances measured by 3 censuses each in plot 5 (burned in spring 1998) and plot 4 (unburned) are consistent with the 4 main patterns that emerged from the 1997 fire. Plot 5 had more Vesper (7 vs. 2) and Savannah (3 vs. 2) Sparrow captures than did plot 4, and fewer Cassin's Sparrow captures (1 vs. 4). It can also be said that the *Ammodramus* sparrows utilized the burned area in the first post-burn year (18 Grasshopper Sparrow captures and 1 Baird's Sparrow capture on plot 5).

Effects of Grazing

In the grazing study, the scope of inference is again limited to the study sites because the treatments were not replicated. It is notable, however, that the data demonstrate at least 1 case in which cattle grazing and *Ammodramus* sparrows coexisted. This pattern is worth highlighting because these species are the most ecologically (and geographically in the case of Baird's Sparrow) restricted sparrows in this community, and are both species of management concern. The coexistence of cattle grazing and *Ammodramus* sparrows is likely a complex balance that must be studied in more detail. Although some cattle grazing may be compatible with *Ammodramus* sparrows, overgrazing may reduce the abundance of these sparrows drastically. Observations in 1997 and 1998 in the Hilton Pasture, another summer pasture adjacent to the Davis Pasture on the same ranch, suggest heavier utilization of forage plants by cattle, and an almost complete lack of *Ammodramus* sparrows in those years (C. Gordon pers. obs.). Bock et al. (1984) also reported a case in which wintering Grasshopper and Cassin's Sparrows were more abundant on an ungrazed pasture than a grazed pasture.

Management implications

Keeping in mind the limitations on the inferences that can be made from this and previous studies, a few generalizations about the effects of fire and cattle grazing on wintering sparrows in the grasslands of Arizona are now possible. Spring burning is generally beneficial to wintering grassland sparrows. Three fires have now been examined for the short term responses of wintering sparrows to spring burning. In all 3 of these cases, 2 widespread and abundant species, Vesper and Savannah sparrows, responded positively to fire. The effects of fire on the 3 species of management concern, the Baird's, Grasshopper, and Cassin's Sparrows, are either not significant or ambiguous. Although significant decreases in response to fire have been found in single cases for Cassin's and Grasshopper Sparrows, non-significant responses to fire have also been found for both of these species. Furthermore, because fire is important for maintaining the structural characteristics of grassland habitat, the long term effects of fire are likely to be positive on these grassland dwelling sparrow species.

The effects of cattle grazing on wintering grassland sparrows are less clear. Limited data suggest that severe grazing appears to have a negative effect on the abundances of the 3 sparrow species of management concern. Nonetheless, the current study describes 1 case in which a summer-grazed pasture on an active cattle ranch had significantly higher winter abundances of both Grasshopper and Baird's Sparrows than did a nearby area that had not had livestock for 30 years. Further study is needed to assess the impacts of cattle grazing on wintering grassland bird communities. Long term as well as short term responses should be measured at multiple sites in multiple years. The current study suggests that it should be possible to find a management solution that includes both economically-feasible cattle ranching and suitable winter habitat for Grasshopper and Baird's Sparrows.

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Evaluating breeding seasons for cows grazing winter range and bahiagrass

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Abstract

Florida native range is grazed in winter and cows are moved to bahiagrass (*Paspalum notatum* Flugge) pasture in March for breeding and calf rearing. Winter weight loss of cows is a major problem, and one possibility to reduce it is to alter the breeding season. This 4-year study evaluated October–February range grazing with movement of cows to bahiagrass in late February for breeding and calf rearing beginning in March (spring-bred cows) vs. December–April range grazing with movement of cows to bahiagrass in May (summer-bred cows). Spring-bred cows weighed less coming off range (439 kg) than summer-bred cows (459 kg), but spring-bred cows gained more weight on bahiagrass (38 kg) by the time calves were weaned than summer-bred cows (1 kg). At weaning, there were no differences in weights of cows. Weight loss of cows on range was related to weight going onto range in the fall (r = –0.62 and –0.49 for spring- and summer-bred cows). Declining nutritive value of bahiagrass and heavy rains in the late summer and early fall appeared to lead to the inability of summer-bred cows to regain weight on bahiagrass. In 2 years, rain interfered with range burning in October which was needed to improve the palatability and nutritive value of forages for spring-bred cows, but this appeared to have no effect on cow performance. Weaning weight of calves from the spring-bred cows (205 kg) tended to be higher than that of calves from summer-bred cows (181 kg). There were no differences in pregnancy rates (74.5%). A March–May breeding season is recommended over a May–July breeding season for cows using a combination of range and bahiagrass.

Key Words: native forages, cattle, reproduction, weight change, management

Resumen

Los pastizales nativos de Florida son apacentados en invierno y en Marzo las vacas se mueven a praderas de "Bahiagrass" para el apareamiento y la crianza de becerros. La perdida de peso de las vacas durante el invierno es un problema importante y una de las posibilidades de reducirlo es modificar la época de apareamiento. En este estudio de 4 años comparamos el apacentamiento en el pastizal de Octubre a Febrero con el movimiento de las vacas a praderas de "Bahiagrass" (*Paspalum notatum* Flugge) a fines de Febrero para el apareamiento y el inicio de la crianza de becerros en Marzo (vacas con apareamiento en primavera) contra el apacentamiento del pastizal de Diciembre a Abril con el movimiento de las vacas a las praderas de "Bahiagrass" en Mayo (vacas con apareamiento de verano). Al dejar el pastizal, las vacas apareadas en primavera pesaron menos (439 kg) que las vacas apareadas en verano (459), pero en las praderas de "Bahiagrass", en el tiempo de destetar los becerros, las vacas apareadas en primavera ganaron mas peso (38 kg) que las apareadas en verano (1 kg). Al destetar los becerros no hubo diferencias de peso en el peso de las vacas. La perdida de peso de las vacas en el pastizal se relaciono con el peso con que llegan al pastizal en el otoño (r = –0.62 y –0.49, para vacas apareadas en primavera y verano respectivamente). La disminución del valor nutritivo del "Bahiagrass" y las fuertes lluvias a fines de verano e inicios de otoño parecen conducir a la incapacidad de las vacas apareadas en verano para ganar peso en las praderas de "Bahiagrass". En 2 años, la lluvia interfirió con la quema del pastizal en Octubre, lo cual es necesario para mejorar la gustocidad y valor nutritivo de los forrajes para las vacas de apareamiento en primavera, pero esto pareció no tener efecto en el comportamiento de la vaca. El peso de destete de los becerros de vacas apareadas en primavera (205 kg) tendió a ser mayor que el de los becerros de vacas apareadas en verano (181 kg). No hubo diferencias e las tasas de preñez (74.5%). Para vacas utilizando la combinación de pastizal -"Bahiagrass" se recomienda la época de apareamiento de Marzo a Mayo en lugar de Mayo a Julio.

The nutritive value of Southeastern range forages is lowest from January to March and highest from April to June (Long et al. 1986, Kalmbacher et al. 1986). Range forages in the winter do not provide sufficient nutrition for lactating beef cows, and cows lose considerable weight and body condition and do not conceive their next calf (Kirk et al. 1945,Hughes 1974). Research has demonstrated that the reproductive performance of cows grazing range year-round can be improved by burning the range in the fall (Duval and Whitaker 1964) and supplementing the cow with cane molasses or cottonseed meal in the winter (Kirk et al. 1974).

To improve calf production further, it has become an accepted practice to utilize range in the fall and winter then move cows to tame pastures in March for breeding (Lewis and McCormick 1971). Because of the higher nutritive value of range forages during the spring (Lewis et al. 1975, Long et al. 1986, Kalmbacher et al. 1986), grazing range during this period then moving cows to tame pastures in May for breeding on tame pasture could better utilize range resources than traditional fall-winter range grazing. Also, October burning is often not possible because of late season rains and high soil moisture. December burning would provide for a more reliable source of higher quality forage for late gesta-

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tion and prepare the cow for summer breeding.

This study evaluated an October to February range grazing period with movement of cows to bahiagrass for breeding beginning 1 March vs. a December to April range grazing period with movement of cows to bahiagrass for breeding beginning 15 May.

Materials and Methods

Approximately 400 ha of south Florida flatwoods range (White 1973) at the Range Cattle Research and Education Center (REC) (27° 26' N, 81° 55' W) were divided into 16 units averaging 25 ha each. Sixteen soils were found on the area with Myakka, Ona, and Pomona fine sands (sandy, siliceous hyperthermic, Aeric [Myakka], Typic [Ona], Ultic [Pomona] Alaquods) predominating. Range was roller chopped for control of saw-palmetto (*Serenoa repens* [Bartr.] Small) and other brush in February and March 1988. Half the range was forested with longleaf (*Pinus palustris* Mill.) and slash (*P. elliotti* Engelm. var. *densa* Little & Dorman) pines, which were thinned in the summer of 1988.

One permanent transect (approximately 250 m) was established in each range unit. Fifty, 0.25 m^2 quadrats were examined in each unburned range unit in which the cows started grazing in the fall of each year (burning and grazing described below). Presence of plants growing in the 50 quadrats was recorded, and aboveground biomass of the following plant groups was clipped at the soil surface and weighed: shrubs, preferred grasses, less desirable grasses, and forbs. Grouping grasses into preferred and less desirable categories was based on earlier research (Kalmbacher et al. 1984). Grasslike plants (i.e., sedges [*Cyperus* L. spp.]) were combined with less desirable grasses. Plant components were dried in a forced-air oven at 60°C for 72 hours and reweighed to determine dry matter content.

In January 1993, 76 Brahman-crossbred cows (mostly Braford, 4 to 12 years of age) were randomly assigned to 1 of 2 breeding season herds. A spring-bred herd was exposed to 2 Braford bulls for 90 days beginning 1 March. A summer-bred herd was exposed to 2 Braford bulls for 90 days beginning 15 May. From each of the above herds, 32 pregnant cows were selected to start this study in the fall of 1993, which was continued for 4 years. A schedule of range and cattle management practices followed annually is presented in Table 1.

In October and December cows were placed on range for the spring and summer breeding season treatments, respectively. Eight cows were randomly assigned to 4 blocks (replications) in each treatment. For the spring-bred treatment 32 mature Braford cows were placed on range every year. For the summer-bred herd, 32 cows were used in the first and third years, but 28 cows (7 per subgroup) were placed on range in the second and fourth years due to the lack of cows.

Over 4 years, 19 and 17 bred, mature, pregnant Braford cows from a surplus cow herd maintained year round on bahiagrass were added to the spring- and summer-bred herds, respectively, as replacements. Due to the lack of pregnant cows and the need to maintain stocking density, 10 and 8 open cows were used in the spring-bred herd, and 8 and 6 open cows were used in the summer-bred herd in the third and fourth years, respectively. Six cows in each breeding season treatment either died (reason unknown) or were removed from the study for reasons unrelated to treatment. Five cows in the spring-bred herd and 7 cows in the summer- bred herd were palpated as pregnant but were not observed to calve.

Cows from each treatment in each block were grazed on 25 ha of unburned pine-palmetto, flatwoods range. After 2 months, cows were allowed to graze an additional 25 ha of burned range (Table 1). Range was burned in October and December for the spring and summer breeding season treatments, respectively. Range units did not receive the same grazing/burning treatments throughout the 4 years, as the 8 range units (2 units x 4 blocks) grazed by 1 treatment in 1993–94 would be grazed by cows in the other treatment in 1994-95, etc.

Two weeks before the start of each breeding season, cows were removed from range, combined as 1 group (32 or 28 cows), and grazed on two, 16-ha bahiagrass pastures (Table 1). Cows from each group remained on separate 16 ha bahiagrass pastures until placed on range in October or December, respectively, for the spring and summer breeding herds. Herds alternated bahiagrass pastures over years. Bahiagrass was fertilized annually in late February with 55 kg N/ha. Cows in each breeding season herd were exposed to 2 Braford bulls for 90 days. Bulls were semen tested annually.

Spring- and summer-bred cows were fed a cane molasses-urea supplement on range from mid-December to mid-February and from early-March to early-May (average of 68 days), respectively. This supplement contained 18% crude protein (CP) and 60% total digestible nutrients (TDN) (as-fed basis) and was formulated with 955 g molasses/kg and 45 g urea/kg. Molasses-urea was fed twice weekly on a free-choice basis in 1-m diameter open troughs at 2.3 kg/cow/day (as-fed basis). Molasses provided 414 g of CP and 1.4 kg of TDN/cow/day, which was 44% and 25%, respectively, of the requirements of lactating cows (National Research Council 1996).

For the first 68 days on bahiagrass (Table 1), cows in both breeding season herds were fed a molasses-natural protein

Table 1. Schedule for management of range and cattle for breeding season treatments.

Item	Breeding season[1] Spring	Summer
Cows/treatment	32	32[2]
Cows removed from bahiagrass and placed on range	4 October	1 December
One-half of range burned	October	December
Cows given access to burned range	December	February
Began molasses-urea supplementation	9 December	1 March
Average calving date	9 January	3 April
Cows and calves removed from range and placed on bahiagrass	15 February	7 May
Began molasses-natural protein supplementation	15 February	7 May
Bulls placed with cows	1 March	15 May
Stopped molasses-natural protein supplementation	24 April	14 July
Bulls removed from cows	30 May	13 August
Calves weaned and cows pregnancy checked	24 August	17 November

[1]Breeding seasons were March–May for spring and May–July for summer.
[2]For the second and fourth years, 28 cows were placed on range due to a lack of animals.

Table 2. Monthly rainfall at the Range Cattle Research and Education Center from 1993 to 1997 compared to the 50-year monthly means.

Year	Months												Total
	J	F	M	A	M	J	J	A	S	O	N	D	
	(mm)												
1993	148	48	139	158	48	167	174	107	91	148	6	27	1261
1994	74	37	102	17	58	226	185	301	511	83	47	66	1707
1995	71	36	38	128	47	413	315	210	139	208	61	17	1683
1996	90	28	98	45	117	139	47	199	53	86	6	31	939
1997	35	20	39	217	62	116	316	138	215	60	285	219	1722
50-yr[1]	53	66	78	59	99	217	223	207	180	76	46	47	1351

[1]Kalmbacher and Linda 1994.

supplement which contained 15% CP and 63% TDN (as-fed basis). It was formulated from 860 g molasses/kg, 70 g feather meal/kg, and 70 g cottonseed meal/kg. Molasses slurry was fed to provide natural protein in place of urea during the breeding season. Molasses slurry was fed twice weekly on a free-choice basis in 1-m x 2.8-m open troughs at 2.3 kg/cow/day (as-fed basis). Cows had free-choice access to a loose mineral mixture year-round which contained 25% NaCl, 12% P, 1% Fe, 0.13% Cu, 0.03% Co, 0.05% Mn, 0.10% Zn, 0.04% I, and 0.0016% Se.

Calf date of birth, but not calf birth weight, was recorded. Cows were weighed and body condition scored before being placed on range, upon removal from range, and when calves were weaned (Table 1). Body condition scores were visual evaluations based on a range of 1 to 9, with 1 = very thin cows, 5 = cows in average condition, and 9 = very fat cows (Herd and Sprott 1986).

Calves were weighed and weaned in late-August and mid-November for the spring and summer breeding herds, respectively (Table 1). Calf weaning weights were adjusted for sex and to a mean weaning age of 230 days as follows: Adjusted weaning weight = ((actual weaning weight + (average weaning weight - average weaning weight by sex))/(calf age at weaning in days)) * 230. Cows were pregnancy checked by rectal palpation when calves were weaned.

Cow weights and body condition scores on and off range were analyzed as a split plot in time with whole plots as years and subplots as breeding seasons in 4, randomized complete blocks (SAS 1985). This model was used for range forage mass and frequency of occurrence of selected plant species. Significant year x breeding season interactions for range data were examined with the p-diff option (SAS 1985). Relationships between cow weight going onto range and weight loss on range were examined with CORR and GLM procedures (SAS 1985). Cow weights and body condition scores of cows at weaning and calf weaning weights were analyzed as a randomized complete block with years as blocks because there were no true bahiagrass replicates within years. Response variables in all analyses were means over cows in a block or quadrat in a transect. Duncan's multiple range test was used to separate means for year. The difference in pregnancy rate between breeding seasons and years was tested with the Chi-square procedure.

Results

Vegetation

Late summer and early fall rain (Table 2) made it impossible to burn range in October 1994 and 1995 for the spring-bred cows grazing range, but burning was always done in December for the summer-bred cows. When we were not able to burn in October 1994, those units were burned according to schedule which was December 1996. When we could not burn in October 1995, those units were burned after cows came off range in February 1996.

There was an average of 98 plant species encountered on the range over 4 years. Major preferred grasses were creeping bluestem [*Schizachyrium scoparium* (Michx.) Nash var. *polycladus* (Scribner & Ball)], chalky bluestem (*Andropogon capillipes* Nash.), and maidencane (*Panicum hemitomon* Schult.). The chance of finding these 3 grasses in a quadrat (4-year mean) was 36%, 22%, and 15%, respectively, and these probabilities were not affected by year, breeding season, or their interaction. Because breeding season treatments alternated over years between range units in a block, this indicates those cows from the breeding season treatments had similar grasses and would not have affected the composition of the range vegetation. Frequency of occurrence of saw-palmetto, the major shrub, was not affected by year or breeding season and averaged 40%. Broomsedge (*Andropogon virginicus* L.), wiregrass (*Aristida stricta* Michx.), and *Dichanthelium* spp. (Hitchc. & Chase) Gould were major less desirable grasses with average frequency of occurrence at 33%, 25%, and 65%, respectively. Frequency of occurrence of less desirable grasses was not affected by year or breeding season. Goldenrods (*Solidago* L. *and Eupatorium* L. spp.) were major forbs whose frequency of occurrence averaged 33%.

Forage mass of all biomass groups except forbs depended on year (Table 3), with greater mass in 1995 compared to other years. This was due to the inability to burn in October 1994. Forb biomass was not affected by year or breeding season.

Cow weights and body condition on range

Spring-bred cows weighed less coming off range than summer-bred cows, and there was an effect due to year (Table 4). Average weight of cows off range was higher in 1993–94 compared with

Table 3. Biomass of preferred and less desirable grasses, shrubs, forbs and for total biomass of herbaceous plants.

Item	Year				SE
	1993	1994	1995	1996	
	(kg/ha)				
Preferred grasses	630 b[1]	630 b	990 a	760 b	90
Less desirable grasses	660 b	660 b	1570 a	840 b	48
Forbs	320 a	460 a	370 a	440 a	70
Total grasses and forbs	1610 b	1750 b	2930 a	2040 a	205
Shrubs	1940 b	1990 b	2980 a	1770 b	265

[1]Means within a row followed by the same letter are not different (Duncan's multiple range test, P>0.05).

Table 4. Effect of breeding season on the performance of cows grazed on Florida range in winter followed by breeding and calf rearing on bahiagrass. 1994–1997.

Item	Breeding season (BS)[1] Spring	Summer	Year 1993–94	1994–95	1995–96	1996–97	SE	Level of Probability BS	Year	Year x BS
Number of cows	125	115								
Cow weight to range, kg[2]	491	487	514	464	464	513	11.9	0.72	0.09	
Cow condition to range[3]	5.6	5.3	5.8	5.1	5.0	5.8	0.2	0.26	0.09	
Cow weight off range, kg[4]	439	459	475	431	437	453	18.7	0.05	0.002	0.98
Cow condition off range[3]	4.3	4.5	4.9	3.7	4.4	4.7	0.3	0.41	0.004	0.72
Cow condition loss on range	–1.2	–0.8	–0.9	–1.4	–0.7	–1.0	0.3	0.01	0.10	0.13
Cow weight at weaning, kg[5]	475	460	459	445	486	476	12.5	0.30	0.27	
Cow weight change on bahia, kg	38	1	–11	15	52	23	13.0	0.06	0.13	
Cow condition at weaning[3]	5.4	4.6	4.6	4.2	5.9	5.3	0.5	0.24	0.26	
Cow condition change on bahia	1.1	0.2	–0.2	0.6	1.6	0.5	0.5	0.15	0.24	
Calf weaning weight, kg[6]	205	181	186	197	183	208	10.4	0.12	0.43	
Pregnancy, %	76.4	72.6	89.5	65.0	69.0	—[7]	—	0.59	0.01	

[1]Breeding seasons were March–May for spring and May–July for summer.
[2]Average date off bahiagrass was 4 Oct. for spring- and 1 Dec. summer-bred cows.
[3]Body condition scores were visual observations ranging from 1 to 9; with 1 = very thin, 5 = average, and 9 = very fat (Herd and Sprott 1986).
[4]Average date off range was 15 Feb. for spring- and 7 May for summer-bred cows.
[5]Average date at weaning was 24 Aug. for spring- and 17 Nov. for summer-bred cows.
[6]Weaning weight adjusted to 230 days of age. Actual average age of calves at weaning was 227 and 228 days for spring-bred and summer-bred cows, respectively.
[7]Data only for first 3 years. In 1996–97, summer-bred cows not exposed to bulls in order to prepare for subsequent study.

1994–95 and 1995–96 with 1996–97 being intermediate (Table 4). Breeding season had no effect on body condition scores of cows coming off range, but year had an effect (Table 4). Cows had the highest body condition scores in 1993–94 and lowest scores in 1994–95 with other years intermediate. Cow body condition loss on range was greater for the spring-bred cows than for summer-bred cows (Table 4).

There was a trend for cow weight loss on range to depend on the breeding season x year interaction (P = 0.07). This interaction occurred because spring-bred cows lost more weight on range than summer-bred cows in 1993–94 and 1996–97 with no difference between breeding seasons for intervening years (Table 5). Weight loss on range for spring-bred cows was greatest, but not different, in 1993–94 and 1996–97, with the least loss in 1995–96. For summer-bred cows, weight loss on range was greatest in 1996–97 and least in 1993–94, with intervening years not different from the extremes.

Cow weight and body condition on bahiagrass

There were no differences between breeding seasons or years for cow weights or body condition scores at weaning (Table 4). There were no differences between breeding seasons or years for cow weights or condition scores at the end of the bahiagrass grazing period when cows were returned to range. Calf weights tended (P = 0.12) to be higher for spring-bred compared with summer-bred cows. There were no differences in pregnancy rates.

Discussion

Because summer-bred cows lost less weight and were in better condition than spring-bred cows during the range grazing period, it would appear that grazing range later into the spring best utilized native forage resources. The problem was that the higher body weight and better body condition scores of cows when removed from range in May, as compared with February, were not maintained, probably due to a declining nutritive value of bahiagrass from April to November (Sumner et al 1991). As a consequence, in the cycle of a year, summer-bred cows were similar to spring-bred cows in weight and condition, yet summer-bred cows produced an average 24 kg lighter (P = 0.12) calf at weaning.

We believe declining nutritive value of bahiagrass is largely responsible for the overall poorer performance of the summer-bred cows and their calves compared with spring-bred cows. Declining nutritive value of bahiagrass in summer and the resulting poor cattle performance has been well documented (Moore et al. 1969, Prates et al. 1975). Spring-bred cows could take advantage of higher nutritive value of bahiagrass early in the growing season. While available forage is initially low (averaging about 800 kg/ha) in March to May for bahiagrass fertilized with 55 kg N/ha, it contains about 11% CP and 53% TDN (Sumner et al. 1991). From May to July, bahiagrass becomes relatively abundant, averaging 1,200 kg/ha with 9% CP and 52 % TDN (Sumner et al. 1991). From August–November, available forage is greatest, averaging 1,400 kg/ha, but CP and TDN declines to 7% and 46%, respectively (Sumner et al. 1991). The requirement of lactating cows is 10% CP and 58% TDN (National Research Council 1996). Heat, insect pests, and flooding further depress livestock performance in August and September, and the term "summer slump" is often used to describe it (Sollenberger et al. 1988, Williams et al. 1991). During all of this period, summer-bred cows were nursing calves, while

Table 5. Effects due to year x breeding season interactions for cow weight lost on range.

Item	Year 1993–94	1994–95	1995–96	1996–97
	(kg)			
Cow weight loss on range				
Spring breeding season[1]	–64 ab[2]	–41 bc	–28 c	–74 a
Summer breeding season	–12 b	–26 ab	–27 ab	–47 a
Probability of a difference between breeding seasons within years	0.001	0.27	0.97	0.05

[1]Breeding seasons were March–May for spring and May–July for summer.
[2]Means for years within a breeding season followed by the same letter are not different (P > 0.05).

calves from spring bred cows were weaned in late August.

In August to November 1994 and 1997, the Range Cattle REC received 942 and 698 mm of rain, respectively, well above the 509 mm 50-year mean (Table 2). Pastures were flooded and summer-bred cows lost 42 and 5 kg, respectively. Their calves were 53 and 19 kg lighter at weaning in 1994 and 1997, respectively, than calves nursed by spring-bred cows. August to November 1995 and 1996 were drier years with rainfalls of 618 and 344 mm, respectively, and summer-bred cows gained 11 and 39 kg on bahiagrass, but their calves were 5 and 14 kg lighter at weaning than calves nursed by spring-bred cows.

Although cows in both breeding season treatments lost weight on range every year (Table 5), the degree of weight change on range is not explained by the range environment. Greater weight losses for spring- compared with summer-bred cows in 1993–94 and 1996–97 do not coincide with expected differences in forage quality (lower in years when October burns were not possible for spring-bred cows), in winter rainfall (Table 2), or available biomass (Table 3). We do not have an explanation for these deviations in cow weight loss on range from anticipated results.

Weight loss of cows on range appeared to be partially explained by cow weight going onto range. Over all years, correlation coefficients for the relationship between the weight of spring-bred cows going onto range and weight loss on range was $r = -0.62$ ($P = 0.0001$, $n = 125$) compared with $r = -0.49$ ($P = 0.0001$, $n = 115$) for summer-bred cows.

Conclusions

Spring-bred cows grazing range from October to February lost more weight than summer-bred cows grazing range from December to May. While there was no difference in pregnancy rates between cows in the 2 breeding season treatments, calves nursed by spring-bred cows tended to have heavier weaning weights. The problem with summer breeding appears to be related to the low nutritive value of bahiagrass and the hot, wet conditions that face cows and calves in late summer and early fall. Calves are weaned from spring-bred cows before this time and the cows return to range, while summer-bred cows and their calves remain on bahiagrass.

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Herbage volume per animal: a tool for rotational grazing management

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Abstract

The objective of this study was to provide a tool for maintaining a high grazing efficiency. In a rotational grazing system, the residual sward height does not provide enough information in advance to make the recommendation. The grazing management of 4 commercial dairy farms which differed greatly in their stocking rate, was monitored over 3 spring seasons. Data were collected on the overall grazing area (sward height measurements, stocking rate, indoor feeding, nitrogen supply) and on 3 grazed fields (herbage mass, height, and nitrogen status). At the whole grazing area level, computed data were herbage volume per animal unit (HVAU).

We show that the HVAU depends on the residual herbage height. Both criteria decreased when stocking rate increased. The HVAU reflects, at the whole grazing season and area levels, how the system works on grazed field over grazing cycle. The HVAU has 2 advantages: (i) It gives rough estimation of the size of the whole grazing area to achieve a high grazing efficiency; (ii) it is a means to assess *a posteriori* the efficiency of the grazing system regarding the consistency between stocking rate and nitrogen supply management.

Resume

L'objectif de cette étude est d'élaborer un outil permettant maintenir une efficience de pâturage élevée. Dans un pâturage tournant, la hauteur résiduelle ne permet pas à elle seule de fournir une information suffisamment à l'avance pour atteindre les recommandations. La gestion du pâturage dans quatre fermes laitières qui diffèrent par le chargement a été suivie durant trois printemps. Les données sont enregistrées à l'échelle de la sole pâturée (hauteur de l'herbe, chargement, distribution à l'étable, apport d'azote) et pour trois parcelles (masse et hauteur d'herbe, niveau de nutrition en azote de la prairie). Au niveau de la sole pâturée, le volume d'herbe par équivalent vache est calculé (HVAU).

Nous montrons que le HVAU dépend de la hauteur d'herbe résiduelle. Les deux variables diminuent quand le chargement augmente. Le HVAU reflète à l'échelle de la sole pâturée et de la saison de pâturage comment la prairie est gérée sur une parcelle et un cycle de pâturage. Le HVAU a cependant deux avantages: (i) il fournit une première estimation de la surface à pâturer pour atteindre une efficience de pâturage élevée; (ii) c'est un moyen d'estimer *a posteriori* l'efficience de pâturage en observant la cohérence entre le chargement et l'apport d'azote.

Key Words: herbage height, nitrogen, stocking rate, management, dairy farms

Despite its low production cost grazingland for feeding dairy cows and ewes is poorly utilized and is tending to give way to silage-making in many parts of Europe (Pflimlin 1995). We hypothesized that this trend is not merely the result of economic factors. In many areas in France, as fields were divided up, a rotational grazing system was imposed. In theory, this system allows greater flexibility than continuous stocking, because it is easy to add or to remove one or more grazed fields according to the herbage needs. In practice for convenience of management this implies (i) that the grazing system is designed, and feed budgets are established to define the area for grazing for different climatic assumptions; models in management research built from grass growth and intake models could be used (Bywater and Cacho 1994, Cacho et al. 1995) (ii) the need for a simple indicator to decide in real time to what extent the grazing area must be varied through the growing season (iii) a method to assess a posteriori the relevance of the grazing management beside output objectives.

We discuss the 2 last items. The usual recommendations are based on residual sward height (Le Du et al. 1979). But this indicator, observed at the grazed field level, does not provide enough information in advance about the grazing area needed to match the recommendation on each of the grazed fields, i.e., to permit the anticipation of a possible change due to an excess or a lack of grass. It does not give any indication if the size of the whole grazing area is designed to achieve a high grazing efficiency, as defined by Scarnecchia (1988, 1994). Furthermore, it is difficult to assess in a simple way the respective effect of grazing intensity and nitrogen supply on the stocking rate at the farm enterprise level.

The intensity and frequency of sward defoliation determines both the net herbage growth following a grazing and herbage intake (Parsons 1988). These practices also determine the efficiency of fertilizer use, nitrogen in particular (Mazzanti et al. 1994). Numerous studies have shown that high grazing intensity is necessary to optimize the balance between the uptake of herbage which depends mainly on stocking rate, and the loss of herbage, which depends mainly on the amount of residual herbage mass. In this way, the stocking rate is a driving variable used to optimize herbage production and consumption, rather than an aim (Hodgson 1985). From a practical point of view, a target height (H) is recommended to manage a continuous graz-

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ing system. For a given stocking rate (N animals on an area A), this rule corresponds to a sward volume per animal, i.e., A*H/N. The sward height or the herbage volume per animal are the result of 3 fluxes: growth, consumption and senescence. The growth depends mainly on nitrogen and climatic variables. The consumption and senescence fluxes are maximized and minimized respectively for the target height. For perennial ryegrass swards, with high nitrogen supply, the sward height recommendations are accurate (Hodgson 1985, Parsons 1988). They vary according to the field and the animal type (Le Du et al. 1981, Maxwell et al. 1994). For other forms of grazing management than continuous grazing, there is not such a global indicator which allows one to decide how much grazing area to add or to remove to maintain a high grazing intensity on a set of grazed fields throughout a growing season. Using a simulation model to compare continuous and intermittent defoliation, Parsons et al. (1988) concluded that for a rotational grazing system, sward management would need an average state to be calculated in practice. This is why we hypothesized that a method which takes into account the sward state at the whole grazing area level could usefully supplement the usual indicators. Furthermore, previous studies have shown that some farmers already use such an empirical method, based on the herbage volume per animal measured on all the grazed fields in the same time, throughout a growing season (Duru et al. 1988). The aim of this study is to explain this type of methodology, and to analyze if it is relevant to manage a rotational grazing system.

Using a simple model of herbage growth, we analyze the relationship between net herbage accumulation at field level and available herbage per animal at the whole grazing area level, to identify if the residual sward height is a relevant variable at the both levels. To assess the value of this approach, we collected data on a set of grazing systems (herbage nitrogen status, stocking rate, herbage volume per animal) and among them on a set of grazed fields (herbage mass).

Materials and methods

Model of net herbage accumulation at grazed field level

The nutritional status of herbage depends on the previous management of the swards and on the fertilizer applied. To assess N status, we used the "dilution curve" method (Lemaire and Salette 1984). During herbage regrowth, the nitrogen concentration decreases as the above-ground dry matter increases $N\% = \alpha\ HM^{-\beta}$, N being the nitrogen concentration in g $100g^{-1}$, HM the above-ground herbage mass in tonnes of dry matter per ha, α the nitrogen concentration when HM = 1 t ha^{-1}, β the coefficient of nitrogen dilution. With optimum nitrogen nutrition, the α and β parameters are the same no matter what the year or the species, even for legumes: α = 4.8 and β = 0.32 (Lemaire and Gastal 1997, Duru et al. 1997). We used the parameters of this control curve to calculate an index for herbage nitrogen status (Ni) taken as the ratio between the measured N concentration (N) of the above-ground herbage mass matter (HM) and the optimum N concentration as previously defined, (Lemaire and Gastal 1997):

$$Ni = 100*N/4.8\ HM^{-0.32} \quad \textbf{(1)}$$

When the index was equal to 100, it indicated a non-limiting nitrogen status of the sward.

To establish a model of net herbage accumulation between post and pre-grazing times, we selected variables which influence growth : herbage nitrogen index, accumulated temperatures and accumulated incident radiation between 2 defoliations (Bélanger et al. 1992) and those which favored senescence. The residual herbage mass limits the amount of intercepted radiation when it is low, but increases the daily senescent herbage when it increases (Parsons et al. 1988). In our case, we considered that it did not limit the amount of radiation intercepted because in most cases, it was greater than 1 t ha^{-1}. Knowing pluviometry, evapotranspiration and an assessment of the soil water capacity, we show that there was no drought over the studied grazing seasons.

Net herbage accumulation = growth - senescence = f(Ni, HMr, Tac, Rac) **(2)**

Ni: herbage nitrogen index, HMr: residual herbage mass, Tac and Rac: respectively accumulated temperatures and incident radiation between 2 defoliations

Relationship between herbage mass per animal and stocking rate at the whole grazing area level, and residual herbage mass at field level

We expressed the herbage mass per animal unit in relation to sward management variables defined at the whole grazing area level (stocking rate, number of animals) or averaged at the grazed field level : herbage mass (defined as the average between dry matter before and after grazing), herbage nitrogen status and residual herbage at the grazed plot level A, a and b being constants:

herbage mass $animal^{-1}$ = herbage mass ha^{-1} /animal ha^{-1} **(3)**

average herbage mass ha^{-1} = residual herbage ha^{-1} + (residual herbage ha^{-1} + net growth ha^{-1})/2 **(4)**

stocking rate = animal ha^{-1} = A* net herbage accumulation ha^{-1} **(5)**

using eq 5,
herbage mass $animal^{-1}$ = (1.5* residual herbage ha^{-1} + 0.5 *net herbage accumulation growth ha^{-1})/ (A* net herbage accumulation ha^{-1} **(6)**

herbage mass $animal^{-1}$ = (a* residual herbage ha^{-1}/net herbage accumulation growth ha^{-1}) +b **(7)**

herbage mass $animal^{-1}$ = (a* residual herbage ha^{-1} /stocking rate)+b **(8)**

The data

The study was done in the south-west of France (Aveyron department : 49°15'N, 0.30°E) on 2 dairy cow farms (Holstein breed) and 2 dairy ewe commercial farms (Lacaune breed) at an altitude of 600m and within 50km of each other. For each livestock type, one of each location, farms were chosen to have different stocking rates at the beginning of the study (Bossuet and Duru 1994). Farms were labeled both with a letter and a number : C (cow) or E (ewe), 1 (highest stocking rate), 2 (lowest stocking rate). The results given here are only for data collected from 1992 to 1994.

Calving was in autumn (September, October) and lambing in winter (December), so animals were dry in summer. The field pattern was usually scattered, and fields were small (less than 2 ha), which imposed a rotational grazing system. Soils are loamy sand and well drained. Grasses were the most common species in these natural or permanent grasslands, and cocksfoot (*Dactylis glomerata* L.) is the commonest grass.

Indoor feeding was mainly with maize silage. It was on average greater for ewe than for cow systems during the grazing season (Table 1). However, the average amounts varied greatly throughout the grazing season. The grazing area varied more or less according to the livestock farm and the season as indicated by the minimum and the maximum values observed in the different grazing cycles throughout the grazing season. The differ-

Table 1. Livestock farms characteristics and grazing management for commercial farms (C: cow, E: ewe, Number 1 and 2) and grazing seasons from turnout date up to the middle of July) ; Ma: March, Ap: April.

Livestock farm	Cl			C2			E1			E2		
Growing seasons	1992	1993	1994	1992	1993	1994	1992	1993	1994	1992	1993	1994
Number of Animal Unit (AU)	32	31	27	46	51	60	32	30	26	54	60	56
Silage (kg day^{-1} AU^{-1})	2.5	1.0	2.9	2.5	4.3	2.9	7.3	6.0	6.1	10.5	4.8	8.2
Grazing area[a] (ha)	4.8–5.8	5.6-6.7	3.8-6.1	12-18.5	10.5–19.5	10-18	4.3-6	4.5–6	5.8–6.8	11.3–15.8	10.3–12.6	10–12.4
Number of grazing cycles[b]	4	4	4	5	6	5	4	5	6	4	4	4
Average number of fields[b]	6	6	5	9	5	8	6	6	5	6	6	5
Turnout date	13 Ap	5 Ap	10 Ap	2 Ap	21 Ma	22 Ma	9 Ap	31 Ma	6 Ap	10 Ap	8 Ap	10 Ap
Nitrogen supply (kg ha^{-1})	100	90	105	70	6-	70	50	40	70	70	60	55

[a]minimum and maximum values according to the grazing cycle
[b]for plots used over the full grazing period

ence between the minimum and the maximum was particularly high for the C2 system. The number of grazing cycles varied from 4 to 6, and the number of grazed fields over the grazing season varied from 5 to 8 (Table 1). The average number of grazing days per field varied from 2 to 5, according to the field size. The amount of nitrogen supply varied from 40 to 105 kg $ha^{-1.}$

Measurements and data collection were applied both to the whole grazing area and animal feeding in spring, and to 3 specific grazed fields. Measurements were made from the middle of March until the beginning of July. At the grazing season level, we recorded the number of grazing animals, the fields used for grazing, the amount of nitrogen applied, and the indoor feeding (silage, concentrates) every 3 weeks, at the time of surveys. Herbage height was measured on all grazed fields expected to be used, 6, 8, and 11 times respectively in 1992 1993, and 1994. For reasons of convenience and speed, we used a sward-stick (Bircham 1981), which was automated (Duru and Ducrocq 1998). On each grazed field, a transect was laid down. Measurements were made 5 to 7 meters apart, corresponding to about 35 data per ha. At the end of the study period, we assembled the grazing plans to know which fields were effectively grazed to calculate the stocking rate and the herbage volume on the whole grazed fields.

Within each of the livestock farms, we sampled 3 fields which were not consecutively grazed, but which were to be used during the grazing season. Throughout the length of a 30 meter transect, marked with permanent sticks, sward height was measured and herbage was weighed (4 subplots of 0.25 m^2) after cutting at 2 cm above ground level with a small clipping machine. These subplots were distributed along the transect, each time at different places, just before or after animals grazed. To assess the residual herbage mass at the beginning of the grazing season, the first measurement was taken at the middle of March. Each sample was dried at 80°C for 48 hours to assess the above-ground dry matter, then milled through a 0.8mm screen to analyze total nitrogen content (Kjeldahl procedure).

Average daily radiation, temperature, and rainfall were recorded on each of the 2 locations. Data were similar between the 2 locations. For the cow farm locations, the average temperatures are shown in Fig. 1. For the 3 study periods, the rainfall was 558, 493, and 450 mm from 1 April to 20 July, respectively in 1992, 1993, and 1994.

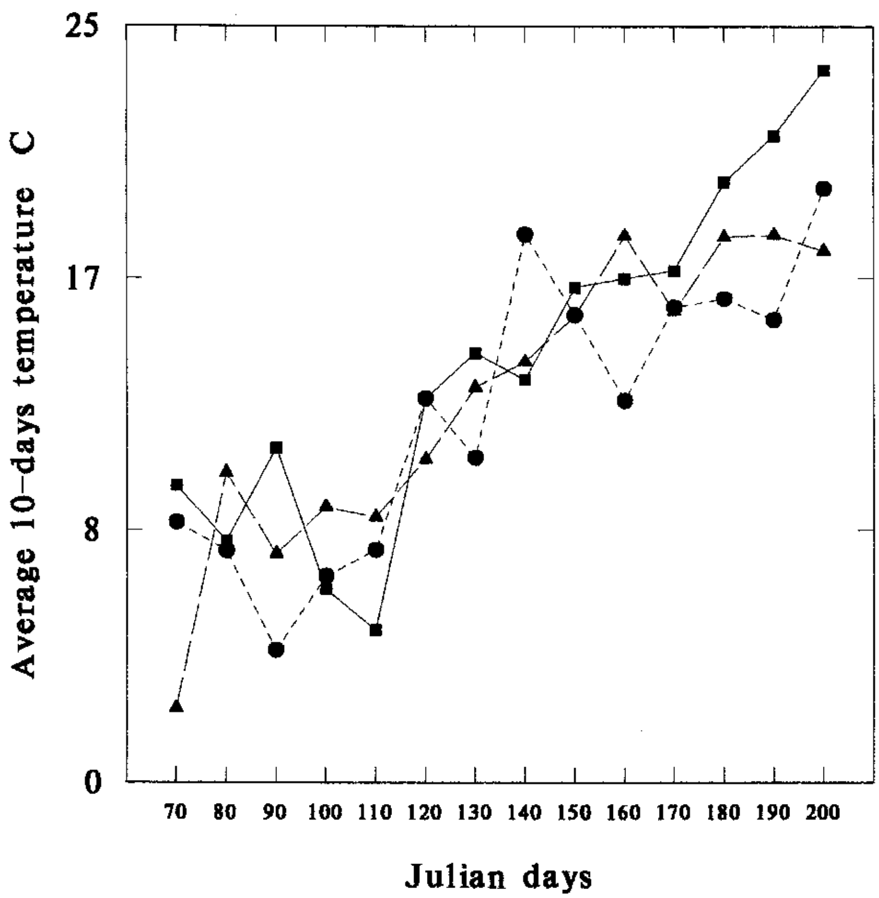

Fig. 1. Average 10-days air temperature on the cow-location for the 3 growing seasons: 1992 ●, 1993 ▲ and 1994 ■.

Data calculation and statistical analysis

To have a simple and practical indicator, we used sward height instead of sward mass at grazed field and whole grazing area levels. Sward heights were measured from soil level. However, to compare grazing systems with different stocking rates, we adjusted them to a 5 cm base to get closer to the herbage available in grazing conditions (no measurements below this height). Detailed studies showed that the variability of the herbage density (HM/H) between fields was reduced if the residual layer of herbage was not included (Duru and Ducrocq 1998).

The interval between 2 defoliations was expressed in degree-days (dd using 0°C as base temperature), because leaf blade growth and its lifespan depends mainly on temperature (Gastal et al. 1992). For the first grazing cycle, we used the first date of sward measurement, and the herbage biomass at this date was regarded as residual herbage mass.

To calculate the net stocking rate, we found a common basis to compare the cow and ewe livestock farms. We chose 1 cow = 7 ewes =1 animal unit (AU), (Jarrige 1978). Second, to assess the grazing contribution to feed animals, we assumed that the average daily intake per AU is 15 kg of dry matter (Hoden et al. 1986).

A 2-way analysis of variance was performed to compare grazing management between livestock farms and grazing seasons (net stocking rate, herbage volume per ha or per animal) and sward states (herbage nitrogen status), in which the different sampling dates were considered as replicates.

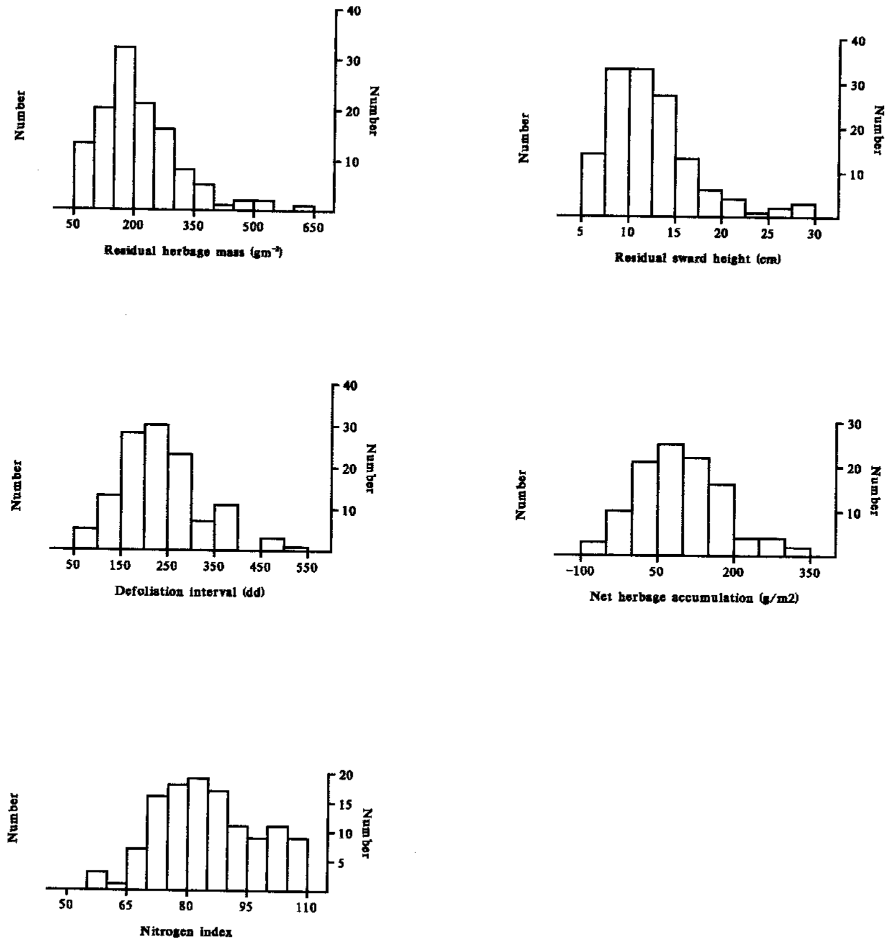

Fig. 2. Frequency distribution of the main sward characteristics and management at field grazed level.

Results

Herbage measurements on the three sampling fields

The residual herbage mass varied greatly. For 80% of the data (extreme values excluded), the values were between 125 and 400 gm^{-2} (Fig. 2a). On an average, they were lowest for the first grazing cycle. They were very variable for each of the fields since the coefficient of variation between the different measurements done on a given field was, in each grazing season, greater than 50% for 8 of the 12 fields. Similarly, the residual sward height varied from 7.5 to 15 cm (Fig. 2b). The interval between 2 defoliations was very variable. For 90% of the data, it varied from 100 to 400 degree-days (Fig. 2c). The net herbage accumulation between post and pre grazing was negative for 10% of the grazing cycles (Fig. 2d).

The herbage nitrogen index was usually between 70 and 90 (Fig. 2e). It was on an average highest for the first grazing cycle, then decreased for the others ($P < 0.001$). There was a significant relationship between the herbage nitrogen index and the nitrogen supply on each field ($P < 0.01$), but the coefficient of correlation was low ($r = 0.49$).

We used field data in Equation 2 to determine the significance of management and climate variables on the net herbage accumulation (NHA) between post and pre-grazing time. Using a stepwise regression, we found the following relationship ($r^2 = 0.56$, n = 1 21, RSR = 62); where Ni is a herbage nitrogen index, HMr (residual herbage mass) and NHA were expressed in gm-2 and Tac (accumulated temperatures between 2 defoliations) in degree-days:

$$NHA = -116 - 0.42\ HMr + 2.80\ Ni + 0.29\ Tac \quad (9)$$

As expected, there was a positive effect of the herbage nitrogen index and a negative effect of the residual herbage mass ($P < 0.05$). The effect of incident radiation was not significant. For Tac = 250 (average observed value), NHA was equal to zero or became negative when HMr = 430 (Ni = 80) or 360 gm^{-2} (Ni = 70).

Sward characteristics and grazing management over the whole grazing period and area

In the first growing season, the net stocking rate was greater for livestock farms Number 1 than those of Number 2, in accordance with a previous study (Bossuet and Duru 1994). It was the highest and most regular for the cow farm Number 1. It was also for this farm that the amount of silage used was the lowest. For the 3 other farms, the stocking rate was lower and more variable over the 3 growing seasons. There was a significant effect of the livestock farm and its interaction with the growing season (Table 3).

Table 2. Average sward characteristics over the grazing period (from turnout date up to the middle of July) according commercial farms (C: cow, E: ewe, Number 1 and 2) and grazing seasons.

Livestock farm		Cl			C2			E1			E2		
Growing seasons		1992	1993	1994	1992	1993	1994	1992	1993	1994	1992	1993	1994
Net Stocking rate (AU)	m	4.6	4.6	4.7	2.8	2.4	3.8	3.6	3.2	2.3	2.3	3.5	2.6
AU ha^{-1}	se	0.53	0.34	0.75	0.39	0.33	0.61	0.68	0.21	0.44	0.34	0.49	0.53
Herbage $volume_0$ *	m	1847	1743	1918	2205	1560	1807	1231	1362	1486	1826	1599	1441
(m^3 ha^{-1})	se	80	152	170	217	95	143	125	133	108	111	103	84
Herbage $volume_5$*	m	321	271	341	614	514	384	256	298	403	600	299	644
(m^3 AU^{-1})	se	25	32	39	114	47	31	30	31	65	125	62	195
Herbage nitrogen index	m	96	90	93	80	76	87	74	84	83	77	68	76
	se	4.6	4.7	4.5	2.8	2.4	4.8	3.0	3.2	2.5	1.2	3.1	4.0

Mean (m), standard error (se) calculated from the different sampling dates; AU animal unit;*sward height base (0 or 5 cm) to calculate herbage volume.

The average herbage volume per ha varied greatly over livestock farms and growing seasons. Generally it was lower for ewe farms. There was a significant effect of livestock farm, growing season and their interaction.

The average herbage volume per AU was the lowest and the most regular between sampling dates for cow farm Number 1. It was about twice as much for cow farm Number 2. On other farms, the stocking rate was lower and more variable over the 3 growing seasons. There was a significant effect of the livestock farm and its interaction with the growing season (Table 3). For cow farm Number 2 and the 2 ewe farms, there was a trend of net stocking rate increase as the herbage volume per AU decreased (Table 2).

The herbage nitrogen status was highest and most uniform for cow farm Number 1, corresponding with the stocking rate. It was lower for the 3 other livestock farms. There was a significant effect of the livestock farm and its interaction with the growing season (Table 3).

Collecting data over 3 grazing seasons allows us to assess the regularity of the grazing management. We observed it was very stable for the cow farm Number 1 and that it varied considerably for the cow farm Number 2, where the stocking rate increased by more than 50% and the herbage volume per animal decreased by about 50%. The stocking rate and the herbage volume per AU changed the most on the cow farm Number 2 (Table 2).

We compared the net stocking rate, calculated on the whole grazing area, and the net herbage accumulation on the 3 studied fields (eq 5). There was a significant relationship between the 2 variables ($r^2 = 0.47$, $P < 0.01$, Fig. 3). This is a way to assess the consistency of the simplifications we made previously when we assessed the grazing contribution to the animals' diet, subtracting the amount of silage supplied. Figure 3 shows the line corresponding to a daily herbage consumption of 15 kg per

Table 3. Levels of significance of the effects of livestock farm, growing season and their interactions on the components of herbage management and sward characteristics

	Livestock farm	Growing season	Livestock farm * growing season
Net stocking rate (AU ha^{-1})	***	ns	***
Herbage $volume_0$ a (m^3 ha^{-1})	***	*	***
Herbage $volume_5$ a (m^3 AU^{-1})	***	ns	***
Herbage nitrogen index	***	ns	***

* $P<0.05$, ** $P<0.01$, *** $P<0.001$, ns non significative; AU: animal unit; a sward height base (0 or 5 cm) to calculate herbage volume.

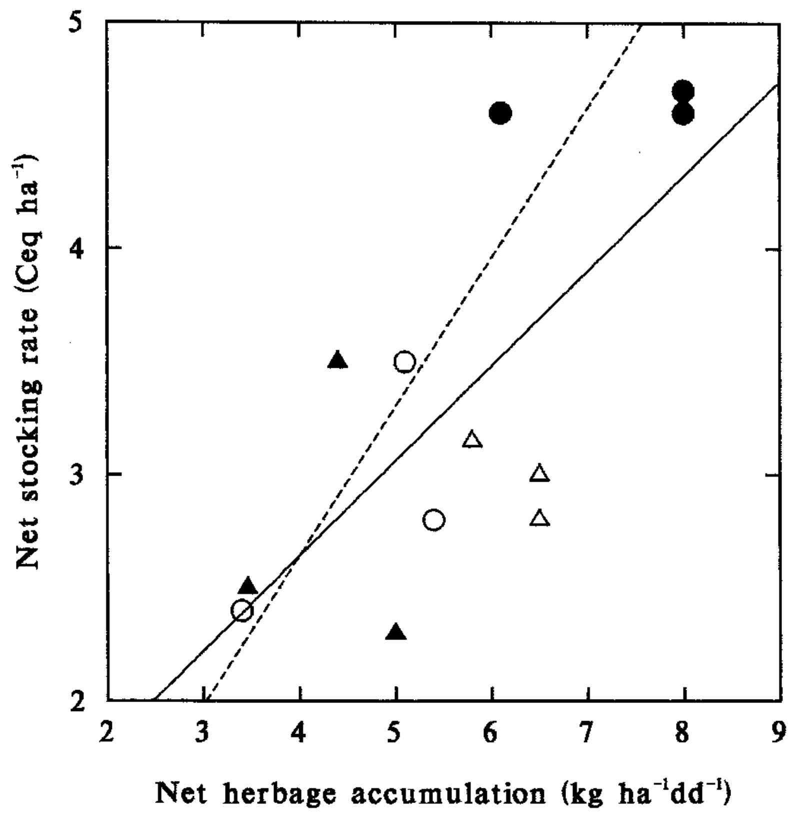

Fig. 3. Relationships between net stocking rate (whole grazing period) and net herbage accumulation rate (kg ha^{-1} and degree-days, data collected on 3 grazed plots); one data point per livestock farm (Cl ●, C2 ❍, El▲, E2 △); the broken line represents a daily herbage intake of 15 kg per cow (Y axis * 15) versus a net herbage accumulation rate for an average temperature of 10°C (x axis * 1).

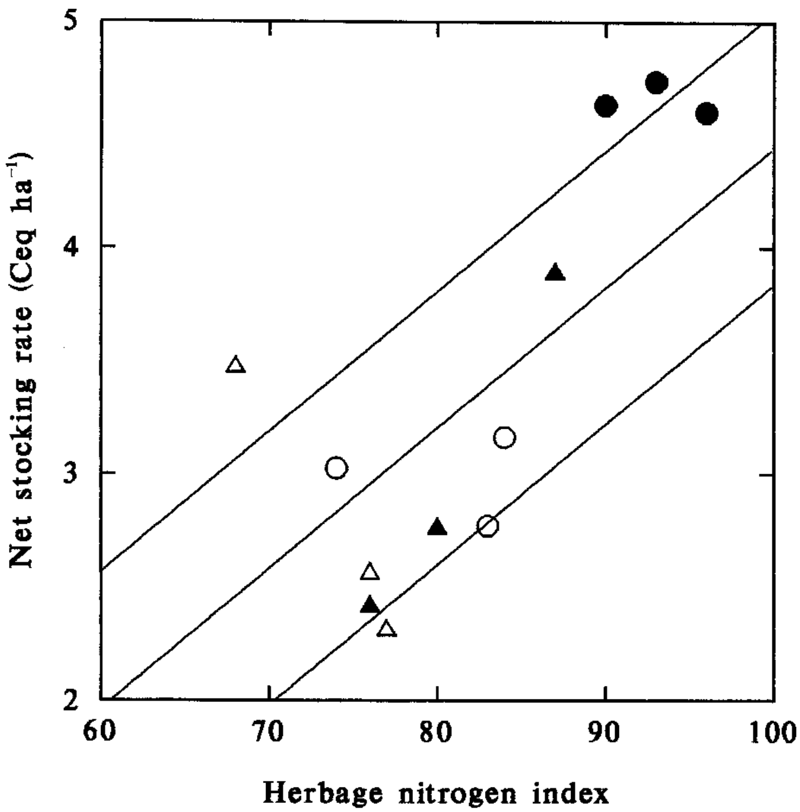

Fig. 4. Relationship between the net stocking rate and the herbage nutrient index; lines drawn represent the herbage volume per Cow equivalent (1 AU = 1 cow or 7 ewes) respectively 200, 400 and 600 m^3 AU^{-1} from top to bottom; livestock farms : Cl ●, C2 ❍, El ▲, E2 Δ.

AU (Y axis * 15) in relation to the net growth for an assumed daily temperature of 10°C (X axis * 10). The 2 lines do not differ very much. Differences could result from errors in the assessment of feed silage supply or daily intake.

As we did previously for the net herbage accumulation, we establish a model of the net stocking rate over the grazing season, selecting factors which influenced growth (herbage nitrogen index, average temperature) and those which favored senescence (herbage volume per AU). As we see in Figure 4, the net stocking rate was negatively correlated with the herbage volume per AU. Using a stepwise regression, we found the following relationship (Ni herbage nitrogen index, HV_5 AU^{-1} herbage volume (5 cm basis) per Animal Unit r^2=0.64, n = 1 2, RSR = 0.53):

$$\text{Net stocking rate} = -0.23 + 0.06\ \text{Ni} - 0.003\ HV_5AU^{-1} \quad \textbf{(10)}$$

As defined in theory (eq 8), we verified if there was a significant relationship between herbage volume per animal unit and residual herbage mass. We found:

$$HV_5AU^{-1} = 78\ \text{Hs/net stocking rate} + 103;\ r^2 = 0.78\ (P < 0.001) \quad \textbf{(11)}$$

When the residual sward height increases the herbage volume per animal unit increases, both because the numerator is higher and the denominator lower (eq 5 and eq 9).

Consistency between the different measurements

Does sward height accurately predict the standing herbage mass?

Taking into account all the sward height measurements which were taken just after or before grazing, there was a significant relationship between the herbage mass and the sward height, with a positive effect of the sampling date (r^2 = 0.62, P < 0.001, n = 295). The high standard error of estimation (60g m^{-2}) indicates a great variability among fields and/or grazing cycles. However, when we established this relationship for each livestock farm and growing season, the accuracy was similar. This means that there was a large variability of herbage density (HM/H) on each of the livestock farms, related to the field or grazing management. Moreover, the standard error of estimate fell to 29.5 g m^{-2} when we compared the average data for each livestock farm and growing season (Fig. 5a). We concluded that in the present study the sward height was on average a satisfactory indicator to assess the herbage mass at the livestock farm and the whole grazing season levels.

Were the 3 fields studied representative of the overall grazing area?

The number of grazing days on the 3 fields studied represent about 50% of the total grazing days over the study period for the cow farm Number 1 and the 2 ewe farms and about 35% for cow farm Number 2. There is a close relationship between the average herbage volume per ha and the average sward height on the 3 fields (Fig. 5b), r^2 = 0.68, P < 0.001, RSR = 150. These 2 independent sets of data indicate that the 3 fields could be considered representative of the whole grazing area.

Discussion and Conclusion

Effect of grazing management on net herbage accumulation

The 3 studied fields could be considered as representative of the whole grazing area. This allows us to use herbage nitrogen status for modeling stocking rate according to data collected at the whole grazing area level.

Using the statistical model, the herbage accumulation rate was positively correlated with herbage nitrogen status as observed in many studies (Bélanger et al. 1992, Duru et al. 1995). According to these authors, this parameter is a basis for assessment of the actual herbage accumulation rate compared with the potential one. For the cow farm Number 1 where the N index was close to 100, there is no justification for increasing the stocking rate by giving more nitrogen. The fact that incident radiation was not found to be important in regression analysis could be because it was correlated with temperature. The negative relationship with the residual herbage mass could have 2 causes. First, the length of leaves which become senescent is directly proportional to the residual herbage mass through their lifespan (Davies 1988), which is usually rather constant for a given species when expressed in degree-days (Duru et al. 1993). Second, part of the respiration depends on plant mass, about 1.5% per day (Parsons 1988). So, for a given herbage nitrogen index, the net herbage accumulation per day should be lower when the residual herbage mass increases. However, we might qualify this view, as a

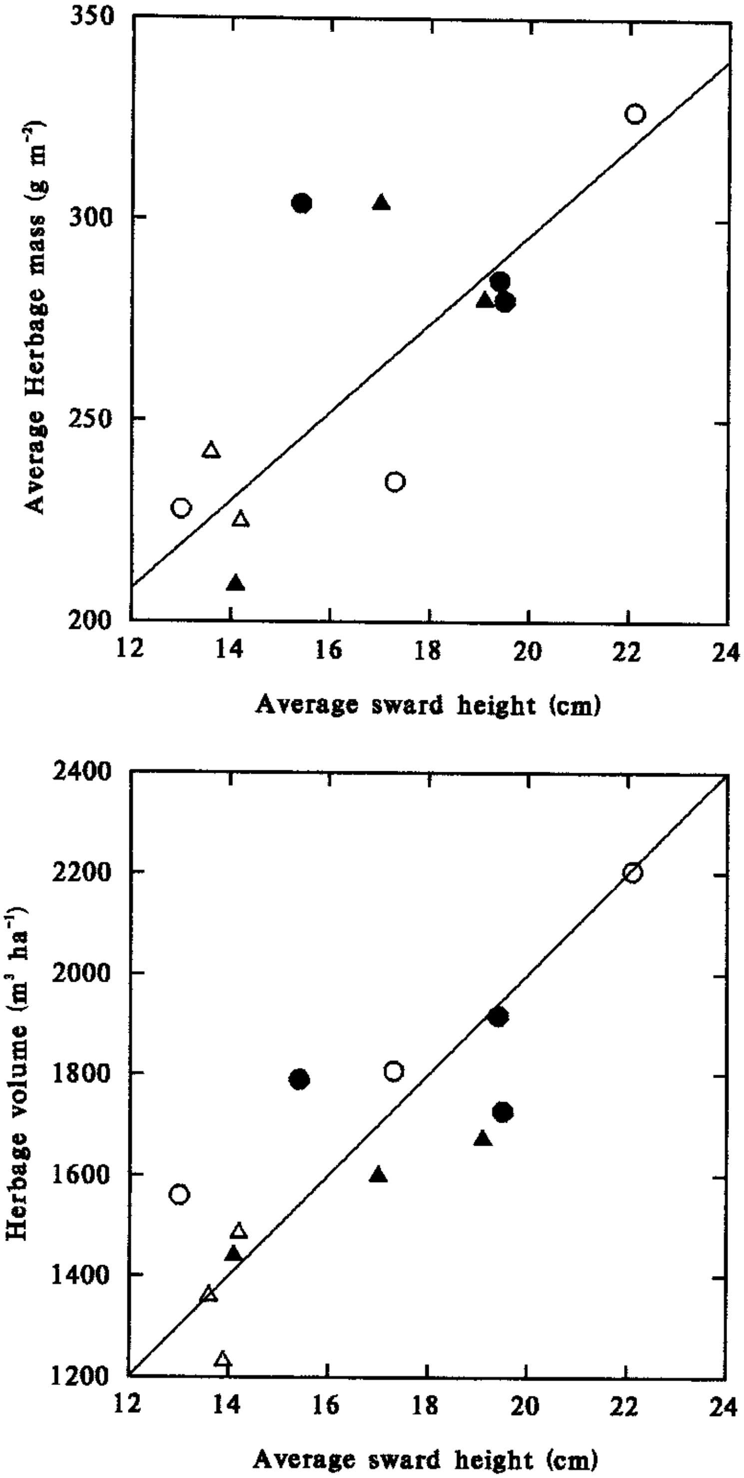

Fig. 5. Average herbage mass and average sward height (mean of pre and post grazing measurements on 3 grazing plot per farms) (Fig 5a), herbage volume (whole grazing area) and average sward height (3 grazing plots) (Fig 5b) ; one data point per livestock farm (Cl ●, C2 ❍, El ▲, E2 Δ) and grazing season, full line were linear fitting between the 2 variables.

lower residual herbage mass could limit the radiation interception. But in our case, residual herbage mass was normally high (Fig.2), so that it would not limit the radiation interception, as shown by measurements in most of these fields (Ducrocq, unpublished data). These results were in agreement with those of Mayne et al. 1987, which showed that most often the net herbage accumulation decreases when the residual sward height increases. This means that for the livestock farms studied, the net stocking rate or the net herbage accumulation rate should be greater, for the same amount of applied N, if the residual bioinass is lower.

There is a trend towards an increase in grazing efficiency when the herbage volume per AU decreases. The available herbage volume per AU is an indicator of the efficiency of grazing management. It reflects, at the whole grazing season and area levels, how the system works in average on 1 grazed field over 1 grazing cycle. Indeed, the main variables which were selected to express the net herbage accumulation rate (field level) or the stocking rate (whole grazing area level) were the same at the 2 levels.

Herbage volume per animal unit for monitoring and assessing of a rotational grazing system

The great variability of stocking rate, particularly on commercial farms, was observed previously (Peel et al. 1988). In this study, the highest values of utilized metabolizable energy output were not always obtained at higher fertilizer N inputs, but more often on the more flexible system. Such assessments at commercial farm level point towards the need for tools for successful integration of rotational grazing into livestock farming. This implies close integration of grazing with cutting for conservation and a very flexible approach which could result in the area and quantity of herbage cut for conservation varying widely from year to year, according to growing conditions (Wilkins, 1995). In this area, the herbage volume per animal unit should be considered as a global state variable resulting of rates of herbage growth, disappearance, and intake, rates which could be used as indicators in grazing research and management.

For monitoring a rotational grazing system, the observation of the residual herbage mass is insufficient to decide when to add or to remove a grazed field. Firstly, under such a system, the degree to which animals harvest the accumulated herbage is unpredictable, compared with cutting or continuous grazing, and sometimes leads to relatively light defoliation (Parsons et al. 1988). This is particularly true when the size of the grazed fields is small and differs within the grazing area, allowing only a few and variable number of grazing days on each of them, as in our study. Secondly, the residual herbage mass does not provide an overview of the grazing system a few days ahead, to permit the anticipation of a possible change due to an excess or a lack of grass. The herbage volume per animal unit could do this, and in this way, possible errors due to an assessment of the sward state on a particular grazed field could be avoided. This is why the periodical assessment of the sward state at the whole grazing area level could be used as a supplementary indicator to decide the number of grazed fields to get through the grazing period. From a practical point of view, the need is to define an optimal herbage volume. There are 2 limitations with our set of data. First, the relationship between sward height and sward mass depends greatly on the species and the sward structure on one hand and on the tool used to measure the sward height (sward stick, plate meter) on the other. Further studies must be done to provide accurate recommendations for a large range of species and sward structures (Duru and Ducrocq 1998). Secondly, there was not a complete "stocking rate x herbage nitrogen status" design, and above all, the herbage volume varied too much throughout the grazing season. We only aim to give an approximate herbage volume per animal unit assuming optimal grazing management. Experiments could be used to complete the comparison of commercial farms. Past results are available for this purpose.

The herbage volume per animal unit could be also a tool to assess a posteriori the efficiency of the grazing system. Knowing only the grazing calendar (turnout date, interval between 2 defoliations) or the stocking rate, as in many studies, is inadequate to assess the grazing system. The relationship established between stocking rate on one hand, herbage nitrogen index and herbage volume per animal unit on the other hand, can be used to assess the effect of low grazing pressure on the net stocking rate. It appears that a decrease in the herbage volume from 600 to 300 m^3 per AU gives the same increase in the stocking rate as an increase of 15 points in the herbage nitrogen index (Fig. 4). In this way, the herbage volume per animal unit provide useful information to discuss on the flexibility of the grazing management. This allows a diagnosis of the grazing management, i.e., to assess the appropriateness of the stocking rate in relation to the nitrogen supply and the grazing area.

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Hydrologic responses of shortgrass prairie ecosystems

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Abstract

Runoff hydrographs from 3 separate rainfall simulation runs at 11 different shortgrass prairie sites were evaluated to determine the hydrologic similarity within a single ecosystem at widely separated sites. There were no consistent patterns in the equilibrium runoff among sites and simulator runs. When the sites were stratified by soil type, there were differences in time-to-peak of the runoff event and the regression slope of the rising limb of the runoff ratios. Spearman's rank correlation showed no relation of the rising limb slope regression coefficient to measured vegetative characteristics across all sites. There was minimal correlation between the runoff regression coefficient and the percent cover and bare soil. Differences in the biotic components of the sites were not useful in predicting runoff characteristics. If equilibrium runoff was the measured hydrologic response, the sites were dissimilar. Using the time-to-peak and slope of the rising limb components of the runoff hydrograph, the sites were similar on the same soil type. The technique of comparing components of the runoff hydrograph, other than equilibrium runoff has promise to allow one to quickly compare responses among ecosystems to determine if they have similar hydrological functions. Our study on shortgrass prairie sites indicated that easily estimated factors such as biomass, cover and litter were not good indicators of hydrologic function. Also, it is necessary to identify which portion of the runoff event is most important in the assessment. Future hydrologic and erosion models need to develop nonlinear prediction equations to estimate infiltration rates as a function of cover, biomass, and soil properties and also to stratify soils into functional units to accurately estimate runoff rates.

Resumen

Se evaluaron hidrográficas de escurrimiento de 3 eventos de simulación de lluvia independientes conducidos en 11 sitios diferentes de pastizal corto, esto con el objetivo de determinar la similitud hidrológica de sitios ampliamente separados dentro de un solo ecosistema. Entre sitios y eventos de simulación de lluvia no hubo patrones consistentes en el equilibrio de escurrimiento Cuando los sitios se estratificaron por tipo de suelo, si hubo diferencias en el tiempo de máximo escurrimiento y la pendiente de la parte de la curva de regresión que representa el mayor aumento de los porcentajes de escurrimiento. Las pruebas de correlación del rango de Spearman no mostraron relación entre el coeficiente de la pendiente de la parte de la curva de regresión que representa el mayor aumento de los porcentajes de escurrimiento y las características de vegetación medidas a través de los sitios. Hubo una correlación mínima entre el coeficiente de regresión del escurrimiento y el porcentaje de cobertura y de suelo desnudo. Las diferencias de los componentes bióticos de los sitios no fueron útiles para predecir las características del escurrimiento. Si el equilibrio del escurrimiento fue la respuesta hidrológica medida, los sitios fueron disímiles. Utilizando el tiempo de máximo escurrimiento y la pendiente de la parte de las hidrográficas de que representan el mayor aumento de los porcentajes de escurrimiento los sitios fueron similares en el mismo tipo de suelo. La técnica de comparar los componentes de la hidrográfica de escurrimiento en lugar del equilibro de escurrimiento promete permitirle a uno comparar rápidamente las respuestas entre ecosistemas para determinar si ellos tienen funciones hidrológicas similares. Nuestro estudio en sitios de pastizal corto indico que factores fácilmente estimados como la biomasa, cobertura y mantillo no fueron buenos indicadores de la función hidrológica. También, es necesario identificar cual porción del evento de escurrimiento es más importante para esta evaluación. Los futuros modelos de escurrimiento y erosión necesitan desarrollar ecuaciones de predicción no lineales para estimar las tasas de infiltración como una función de la cobertura, biomasa y propiedades del suelo y también estratificar los suelos en unidades funcionales para estimar con exactitud las tasas de escurrimiento.

Key Words: Runoff, rainfall simulation, hydrograph, time-to-peak

Rangelands and permanent pasture comprise approximately 51% of the world's land surface with grazinglands covering 364 million hectares in the 17 western states of the United States (Child and Frasier 1992). Rangeland ecosystems are complex and many of the interacting abiotic and biotic processes are not clearly defined with regards to their resistance and resilience to stress, making the assessment of health or stability of a rangeland ecosystem extremely difficult. Recent efforts have been devoted to developing techniques to assess the stability and health of rangeland ecosystems (NRC 1994, USDA-NRCS 1997). The USDA-Natural Resources Conservation Service (NRCS) proposed that rangeland health be evaluated using 17 indicators to describe 3 attributes (soil site stability, watershed and hydrologic cycle, and soil and plant community integrity) of a functioning ecosystem. Each of these indicators is ranked within 1 of 5 categories. The categories range from the most degraded state to the condition expected for the site based upon the site ecological site description. Many of the indicators are used in more than 1 of the 3 attributes of a healthy ecosystem. Five of the 17 rangeland health indicators are directly associated with the hydrologic com-

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ponents of a site. The NRCS procedure is qualitative and poses difficulty for someone not familiar with the site where specific baseline data is not available for comparison. The reliance on expert opinion to define "preponderance of evidence" as the methodology to define the health of the 3 components and no method to define the health of the entire site may result in distrust of the system and failure to adopt the approach as a method to estimate the health or stability of the site. Within the past decade, a number of studies using similar equipment and techniques have been conducted to evaluate infiltration, runoff and soil erosion across the broad spectrum of rangelands in the western part of the United States (Simanton et al. 1991). While the primary purpose of the many studies was to provide data for the Water Erosion Prediction Project (WEPP) (Flanagan and Livingston 1995), the data sets provide a unique opportunity to provide information on the hydrologic similarity of a single ecosystem type across a large geographical area and to develop a quantitative method to define hydrologic function that could be incorporated into any rangeland health evaluation technique.

Our study utilizes data sets collected from selected rainfall simulation studies to evaluate the surface runoff response of 11 different shortgrass prairie sites as affected by canopy cover, ground cover, standing biomass, litter, and soil texture. Data sets used in the analysis were collected on semiarid shortgrass prairies located in; Colorado, New Mexico, South Dakota, and Texas (Weltz 1995).

Many factors influence the shape of the runoff hydrograph curve, but the most important variables are rainfall characteristics, soil properties, vegetation, and land use (Dunne and Leopold 1978). In our study, variability was reduced by restricting the analysis to shortgrass ecosystems and controlled rainfall simulated events. Our hypothesis was that ecosystems with similar dominant plant species composition and soil textures should have similar hydrological runoff responses.

Because runoff is time dependent and varies continuously, it is difficult to derive a single index for statistical comparisons across different experimental sites and rainfall events. The most common method used to evaluate differences between sites have been to compare either total runoff or final infiltration rates (Blackburn 1975, Weltz and Wood 1986, Wood 1987). Other researchers have utilized time to peak, runoff rate, or total runoff volume to compare hydrographs (Stone et al.1992, Tiscareno-Lopez et al. 1993). Weltz et al. (1992) used an optimization technique to fit the rising limb of the hydrograph to determine the hydrologic roughness of rangelands. Spaeth et al. (1996) used indirect gradient analysis to define relationships between plant communities, soil variables, and infiltration rates.

Our study utilized the concept of subdividing the hydrograph into separate components for analysis to see if any or all of the hydrograph components are similar or dissimilar among sites (Frasier et al. 1998a). This allows an evaluation of the entire hydrograph shape between sites and within sites in relation to site characteristics.

Methods and Materials

Study Sites:

Study sites were all located within shortgrass plant communities (Table 1). One data set was originally collected for the Water Erosion Prediction Project (WEPP) research studies by the USDA-National Resource Soil Conservation Service (NRCS) and USDA-Agricultural Research Service (ARS) Interagency Rangeland Water Erosion Team project (IRWET). The second set was collected for the USDA-ARS Water Erosion Prediction Project database (unpublished data). The third data set was collected at the ARS-Central Plains Experimental Range, Nunn, Colorado (CPER) (Frasier et al.1995).

Range site classification of the study sites varied from sandy plains to clayey with range condition from poor to excellent. Slopes of the study plots were mostly in the range of 5 to 8% and soil textures varied from sandy loam to clay. The predominant plant species were *Bouteloua gracilis* (H.B.K.) Lag. and *Buchloe dacty - loides* (Nutt.) Engelman. Average annual precipitation ranged from 250 to 400 mm yr^{-1} (Table 1). The site in South Dakota (H2) was classified as a mixed prairie potential plant community but the site had been historically heavily grazed causing the plant community to shift to a shortgrass plant community (Hanson et al. 1978).

Rainfall Simulation:

Runoff experiments for all sites used large rotating boom rainfall simulators similar to the one developed by Swanson (1965). All studies used the same general procedures with a few minor differences. Plot size varied from 3.0 to 3.5 m wide and 10.0 to 10.7 m long. All plots had sheet steel metal borders driven into the soil around the upper and side edges. Troughs at the lower edge of each plot collected and directed the runoff water through small critical depth flumes. With the exception of the Texas sites (Table 1), depth of water flowing through the flumes was measured and recorded with bubble flow meters at 1 minute intervals. The flow depths were converted to equivalent runoff rates. At the Texas sites, runoff rates were measured volumetrically at 2 min intervals.

While the various rainfall simulation studies were conducted by different investigators with slightly different procedures, it was possible to select data sets with the same general antecedent soil moisture conditions and the same basic water application quantity and pattern (rainfall simulation). The rainfall simulation pattern selected for this evaluation consisted of 3 separate water application periods. 1) Dry run—simulated rainfall applied at a nominal rate of 50 to 60 mm hr^{-1} onto soils with existing soil moisture (no prewetting). Simulation duration was sufficient to reach equilibrium runoff, usually within 45 to 60 min. 2) Wet run–following a 30 min interval of no water application after the dry run (or an equivalent pre-conditioning water application) simulated rainfall was applied at nominal rate of 50 to 60 mm hr^{-1} until runoff reached equilibrium, usually within about 30 min. 3) Very wet run—without stopping the rainfall simulation at the end of the wet run, the water application rate was increased to 100 to 130 mm hr^{-1} until runoff equilibrium was achieved, usually within about 20 min.

While the rainfall simulators were all the same design, it should be noted that for each application phase, simulator application rates were slightly different because of changes in water level in the water storage tanks, blowing wind, and different pressures on the simulator nozzles. This caused some variation in application rates. Actual water application rates and quantities were measured on each plot during the simulation events.

Vegetation Measurement:

The Interagency Rangeland Team (IRWET) estimated standing biomass using the NRCS double sampling procedure (USDA-SCS 1976). Five sample quadrats were collected on each runoff plot. The sample sites were horizontally centered within the plot at intervals of 1, 3, 5, 7, and 9 m from the bottom of the plot. The quadrats were clipped to a height of 1 cm above the ground surface. Standing biomass was separated by species into 3 categories: 1) previous

Table 1. Site location, range site, range condition, number of years sampled, number of samples per year, soil texture, percent slope, and dominant plant species (percent composition by weight) for rainfall simulation study areas.

Site	Range site	Range condition	Number of years	Samples per year	Average annual precipitation	Soil texture	Slope	Plant species
					(mm)		(%)	
C1 Texas[1]	clay loam	fair	1	6	375	clay	2-3	*Bouteloua gracilis* (H.B.K.) Lag. *Buchloe dactyloides* (Nutt.) Engelman
C2 Texas[1]	clay loam	poor	1	6	375	clay	2-3	*Bouteloua gracilis* (H.B.K.) Lag. *Buchloe dactyloides* (Nutt.) Engelman
F1 Colorado[1]	loamy	good	1	6	350	loam	7-8	*Bouteloua gracilis* (H.B.K.) Lag. *Pascopyrum smithii* (Rydberg) Love
F2 Colorado[1]	loamy	fair	1	6	350	loam	7-8	*Bouteloua gracilis* (H.B.K.) Lag. *Carex* spp.
F3 Colorado[1]	loamy	poor	1	6	350	loam	7-8	*Buchloe dactyloides* (Nutt.) Engelman *Bouteloua gracilis* (H.B.K.) Lag.
H1 South Dakota[2]	clayey	excellent	2	2	390	clay	7-8	*Stipa viridula* Trin. *Sphaeralcea coccinea* (Pursh)Rydb.
H2 South Dakota[2]	clayey	fair	2	2	390	clay	7-8	*Bouteloua gracilis* (H.B.K.) Lag. *Buchloe dactyloides* (Nutt.) Engelman
J1 New Mexico[2]	loamy	fair	2	2	280	clay loam	9	*Hilaria jamesii* (Torrey) Bentham *Bouteloua gracilis* (Torrey)(H.B.K.) Lag
L Colorado[3]	sandy plains	good	3	4	257	sandy loam	5-6	*Bouteloua gracilis* (H.B.K.) Lag. *Aristida* spp.
M Colorado[3]	sandy plains	fair	3	4	257	sandy loam	5-6	*Bouteloua gracilis* (H.B.K.) Lag. *Aristida* spp
H Colorado[3]	sandy plains	poor	3	4	257	sandy loam	5-6	*Bouteloua gracilis* (H.B.K.) Lag. *Buchloe dactyloides* (Nutt.) Engelman

[1] Data supplied by NRCS, [2] data supplied USDA-ARS, [3] data from CPER.

year's growth, 2) current year growth, and 3) standing litter. Detached litter within the quadrat was also collected. All biomass samples were dried at 60° C for 72 hours and weighed.

For the USDA-ARS Water Erosion Prediction Project (WEPP) standing biomass was estimated by clipping six, 0.5 m by 1 m quadrats located outside of the large rainfall simulation plots. Quadrats were clipped to 1 cm of the soil surface by life form (grass, forb, shrubs, and cacti). The quadrats were located 1 m from the runoff plots and placed 1 m from the top and the bottom of the plot and at the midpoint of the plot. Once the standing biomass was removed from the quadrats, all litter was removed. All biomass samples were dried at 60° C for 72 hours and weighed.

In the CPER study, aboveground biomass was estimated with a double-sample procedure on 10 randomly located quadrats (0.31 by 0.31 m). Every fifth quadrat was clipped by species, dried at 60° C for 72 hours and weighed. Litter weights were not recorded.

Canopy cover was defined as the soil surface area protected from raindrop impact by standing plant material looking straight down into the canopy (0–100%). Ground cover was defined as the amount of litter, cryptogams, plant basal area, and impervious material that protects the soil surface from raindrop impact (0–100%). For this study we combined canopy and ground cover and represented it as total cover (0–200%).

For the Interagency Rangeland Team (IRWET) and ARS studies, canopy and ground cover was estimated with a 49-pin point-sampling frame. The frame was placed at 10 even intervals (1 m) on each plot, starting at 0.5 m from the outlet of the plot. Canopy cover was recorded by life form and ground cover by class (soil, rock, litter, basal, and cryptogams). In the CPER study, basal cover was measured using a 10 point frame. Four transects were established down the length of the plot at equal intervals from the plot sidewalls. The point frame was set perpendicular to the transect and basal cover was estimated at 3 m intervals on each transect.

Data Analysis:

It should be noted that sites within this study should not be considered as replications. Because of small differences in water application rates from the various rotating boom rainfall simulators, the runoff rate was adjusted (normalized) by the water application rate (rain) for each recorded time interval and each simulation period (Frasier et al. 1998a).

The normalized runoff (percent runoff) hydrograph for each simulation period is separated in 3 sections, time to runoff initiation, the rising limb, and equilibrium runoff. The end points of the segments (rising limb and equilibrium runoff phases) are determined using the break-point approach originally developed for analyzing precipitation data (Brakensiek et al. 1979). This approach uses an iterative least squares regression analysis and maximizes the coefficient of determination for the segment being evaluated. If the time to initiation of runoff, time to runoff equilibrium, regression slope of the rising limb, and final equilibrium runoff rate are statistically similar, then there is no difference in the treatment response. Differences in 1 or more characteristics may indicate different hydrologic responses to the variables or treatments (Frasier et al. 1998a).

Descriptive statistics (mean, SE, median, mode, SD, and range) were used to compare the time to runoff peak, regression slope of the rising limb, and the steady state portions of the hydrographs. ANOVA was used to find significant differences ($P < 0.05$) in vegetation characteristics (biomass, litter, and cover) among sites and within the sites. Correlation analysis among and between sites evaluated effects of vegetation characteristics on the hydrologic responses.

Results and Discussion

Vegetation—The mean percentage for total cover (canopy plus ground) over all sites was 86% with a standard deviation of 17. The mean total aboveground biomass for all the sites was 725 kg ha^{-1} with a maximum of 1974 kg/ha at the Texas C1 site and a minimum of 380 kg ha^{-1} at the Colorado site F3 (Table 2). The mean litter over all sites (except CPER sites where litter was not estimated) was 533 kg ha^{-1} with a maximum of 1893 kg ha^{-1} at the Colorado site F1 and the minimum of 247 kg ha^{-1} at the South Dakota site H2.

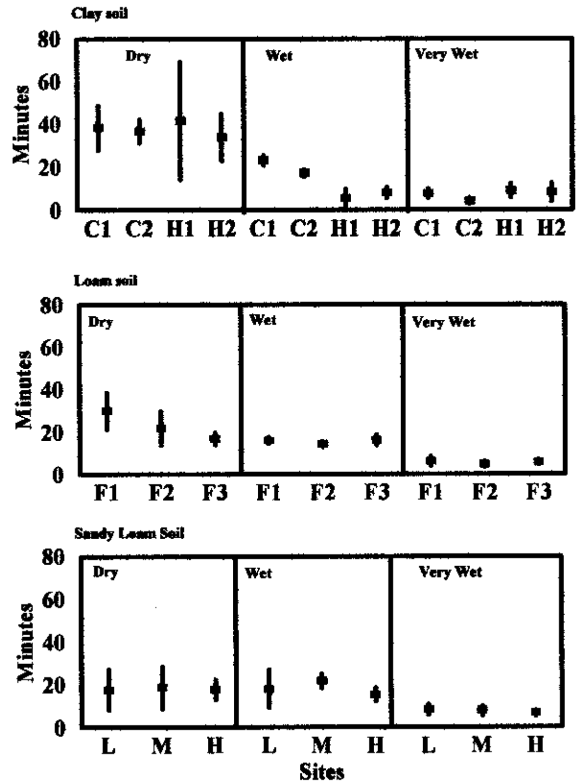

Fig. 1. Mean and standard deviations of time-to-peak for dry, wet, and very wet rainfall simulation runs on shortgrass prairie sites (stratified by soil texture).

Runoff Time-to-Peak—As the soil texture became finer (sandy loam → clay) the time-to-peak of the runoff event during the dry run became progressively greater ranging from 20 to 30 min on the sandy loam and loam soil to nearly 40 minutes on the clay soil (left side, Fig. 1). This is contrary to common concepts where the infiltration rate increases (runoff decreases) as soil texture becomes coarser. A possible explanation is that the clay soil textured sites develop cracks, which, when dry absorb considerable water until they swell shut. Another explanation is that a vegetation characteristic such as litter may be having a possible influence on the infiltration rate of the clay site. The differences among soil types became less as the soil became wet (wet run) (center groups, Fig. 1) and with increased water application rate (very wet run) (right side, Fig. 1).

Runoff Rising Limb Slope—The regression slope of the rising limb of the runoff ratios during the initial phase (dry run) of the runoff events were similar, with regression coefficient slope values varying from 2 to 4 across all sites (left side, Fig. 2). In the wet runs the slope regression coefficients remained unchanged on the sandy loam soil (2 to 4) but increased to 4 to 8 on the loam and clay sites (center groups, Fig. 2). In the very wet runs the slope regression coefficients were 6 to 12 for the clay sites, 6 to 8 for the loam sites and 2 to 4 for the sandy loam sites (right side, Fig. 2).

As the regression slope of the runoff hydrograph rising limb increased, so did the variability among plots especially in the wet and very wet runs on the clay and loam soil sites, (standard deviation bars, Fig. 2). The variability among runs (large standard deviations) with the higher rainfall intensities (very wet runs) indicated that there were additional factors affecting

Table. 2. Total cover, mean standing biomass and total litter at rainfall simulation sites.

Site	Total Cover (% ± SD)	Mean Standing Biomass (Kg ha^{-1} ± SD)	Total Litter (Kg ha^{-1} ± SD)
C1 Texas	94 ± 9.2	1974 ± 881	1778 ± 1235
C2 Texas	93 ± 9.9	651 ± 234	1511 ± 583
F1 Colo	129 ± 2.9	1005 ± 277	1893 ± 1354
F2 Colo	105 ± 17.7	746 ± 255	1567 ± 705
F3 Colo	102 ± 3.4	380 ± 141	685 ± 241
H1 SD	84 ± 11.6	1600 ± 274	753 ± 125
H2 SD	92 ± 18.6	450 ± 141	247 ± 99
J1 NM	52 --	649 ± 90	164 ± 28
L Colo	82 ± 1.3	519 ± 35	—
M Colo	79 ± 2.3	490 ± 68	—
H Colo	76 ± 3.4	412 ± 14	—

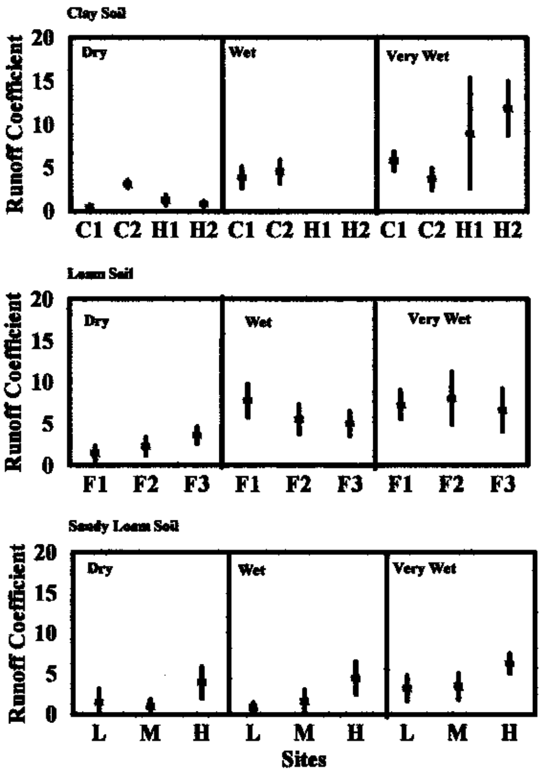

Fig. 2. Mean and standard deviations of the regression coefficient of the slope of rising limb of hydrographs for dry, wet, and very wet rainfall simulation runs on shortgrass prairie sites (stratified by soil texture).

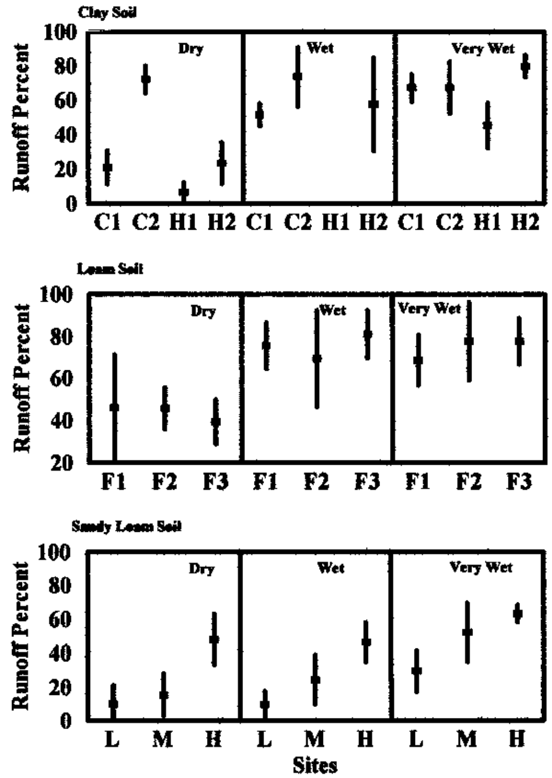

Fig. 3. Mean and standard deviations of the equilibrium runoff percentage for dry, wet, and very wet rainfall simulation runs on shortgrass prairie sites (stratified by soil texture).

the runoff and/or infiltration rates not apparent during the dry runs. There has been some speculation that in high intensity rainstorms the impact of raindrops can separate soil aggregates on the surface and ultimately wash these particles into the soil pores, reducing the infiltration rate. Therefore, in such storms it is the final rate of infiltration that primarily determines how much total runoff is generated (Dunne and Leopold 1978). Dunne et al. (1991) proposed that as rainfall intensity increases there will be a non-linear change in infiltration rate. They speculated that the reason for this increase could be the interaction of flow depth (head) with the hydraulic conductivity of the mineral soil, the influence of microtopographic features on routing of water, and that the impact of hillslope gradient and length becomes greater with increased flow velocities.

For most clay and loam sites, as the rainfall rate increased there was an increase in the regression coefficient of the runoff hydrograph rising limb. In contrast, the sandy loam sites at CPER did not show a consistent pattern of increased runoff at the higher rainfall events. Varying the intensity of the rainstorm event (50 mm hr^{-1} to 100 mm hr^{-1}) had little effect on the slope of the runoff hydrograph rising limb. The hypothesized reason that the sandy loam site did not respond in the same manner as the loam and clay soils is that the rainfall intensity was not sufficient to overcome the high infiltration rates of the non-contributing portions (basal area of plants) of the sandy loam plots.

The relationship between the regression coefficient of the slope of the runoff hydrograph rising limb for the dry, wet, and very wet runs and biotic characteristics was evaluated using a correlation matrix (SAS 1988). Spearman rank correlation (r_s) values show no consistent correlation between the regression coefficient of the slope of the runoff hydrograph rising limb and measured vegetative characteristics across all sites. There was no correlation between the runoff regression coefficient and the percent cover and bare soil (Table 3).

There was a moderate negative correlation (r_S) with the regression coefficient of the slope of the runoff hydrograph in the dry run indicating slower runoff on sites with more vegetation. There was no correlation of biomass to the regression coefficient for the wet and very wet rainfall simulation events. This indicated that biomass was more important in reducing surface runoff for dry soils than it was for wet soils. One possible explanation is that during the initial rainfall sequence, runoff was slowed down (increased hydraulic resistance to water flow by the standing vegetation) allowing the water to infiltrate into the soil. During the wet and very wet runs

Table 3. Spearmans coefficient of rank correlation(r_S) of the slope of the rising limb of runoff hydrograph for dry, wet, and very wet rainfall simulation events and biotic characteristics across all shortgrass prairie sites.

Runoff event	Number observations	Cover (%)	Bare soil (%)	Biomass (kg/ha)	Litter (kg/ha)
Dry	19	0.12	–0.18	–0.47	–0.04
Wet	14	0.27	–0.12	–0.02	0.62
Very wet	19	0.25	0.09	0.05	0.42

Table 4. Coefficient of determination (r^2) of slope regression coefficient of rising limb of the runoff hydrograph for the dry, wet, and very wet rainfall simulation events and biotic characteristics stratified by soil texture for all shortgrass prairie sites.

		Rainfall sequence		
Soil texture	Vegetation	Dry	Wet	Very wet
Clay	Biomass (kg/ha)	0.10	M	0.15
Clay	Cover (%)	0.01	M	0.28
Clay	Litter (%)	0.20	M	0.40
Loam	Biomass (kg/ha)	1.00	0.82	0.28
Loam	Cover (%)	0.73	0.99	<0.01
Loam	Litter (%)	0.98	0.68	0.42
Sandy loam	Biomass (kg/ha)	0.58	0.58	0.18
Sandy loam	Cover (%)	0.18	0.78	0.18
Sandy loam	Litter (%)	M	M	M

M is data missing or not available.

the infiltration rate may have decreased sufficiently to reduce the impact of increased hydraulic resistance associated with increased biomass. At sufficiently high water application rates the runoff rate may be minimally affected by biomass.

Litter was not correlated with the runoff rising limb regression coefficient in the dry run, but was highly correlated in the wet run and to a lesser degree in the very wet run (Table 3). These results conflict with other reports showing that runoff rate deceases as litter increases, (Simanton et al. 1991, Blackburn et al. 1992, Thurow et al. 1986, and Packer 1951). The difference in apparent results from other studies is attributed to the portion of the runoff hydrograph used in the analysis. Our studies used the rising limb portion while many other studies use equilibrium runoff values. This illustrates the need to insure that the portion of the runoff event be clearly identified and also representative of the factors being investigated. While the exact cause for the difference between the dry and wet or very wet runs can not be determined, we speculate that there is a transient hydrophobic response in shortgrass plant communities similar to that for burned chaparral sites in California (Debano 1975). During the initial rainfall event the soluble organic compounds on the litter significantly affect the infiltration rate independently of the quantity of litter on the soil surface. This effect can become more pronounced as the litter quantity increases. After the litter has been wetted for a period of time (wet run) the influence of the water repellency is reduced (Frasier et al. 1998b). This litter effect is minimized somewhat during the very wet run because of the high volume of water. In addition, the slight increase in head pressure caused by the increased depth of overland flow can help offset the hydrophobic conditions in the soil profile. More research will be needed to determine if and under what circumstances hydrophobic layers exist in short grass prairies, as litter builds up due to changes in management practices or climate.

Soil type modified the impact of biotic characteristics (biomass, cover, and litter) on the regression coefficient of the slope of the rising limb of the runoff hydrograph (Table 4). For the clay soils, standing biomass, litter, and cover had little correlation with the regression coefficient of the rising limb especially in the dry run. As rainfall intensity and soil moisture increased (very wet run), there were higher correlations of the biotic components with the rising limb runoff regression coefficient.

On the loam soils there were significant biotic effects on the slope of the rising limb runoff regression coefficient in both the dry and wet runs. As rainfall intensity and soil moisture increased (very wet run), these influences decreased (Table 4). The influence of cover was more important during the wet run, as opposed to the dry runs where biomass and litter were more correlated with the rising limb of the runoff hydrograph. Cover was not related to the runoff coefficient of the rising limb for the very wet runs.

For the sandy loam soils the biomass had a moderate effect on the rising limb runoff regression coefficient in the dry and wet runs but no effect in the very wet run. Cover had an effect on only the wet run. Litter was not measured on the sandy loam soils.

Equilibrium Runoff—The equilibrium runoff ratios (runoff rate divided by rainfall intensity) did not consistently vary among sites and simulator runs (ie., dry run vs. wet run) (Fig. 3). Mean equilibrium runoff rates on the clay soils ranged from 10 to 75% in the dry run, 55 to 60% in the wet run and 40 to 80% in the very wet run. On the loam soil sites the mean equilibrium runoff was 40 to 45% in the dry run and 70 to 80% for the wet and very wet runs. On the sandy loam sites at CPER (Colo L, M, H) mean equilibrium runoff ranged from 10 to 50% on the dry and wet runs and was 30 to 60% on the very wet runs. Frasier et al. (1995) had found on these sites an increase in equilibrium runoff rates with higher grazing intensity (Fig. 3). Some of the CPER sites never reached an equilibrium runoff rate during the time allowed for their dry, wet and very wet runs because the applied rainfall rate did not exceed the saturated hydraulic conductivity of the soil. Plots where equilibrium runoff was not achieved were not used in calculating the mean and standard deviations.

Summary and Conclusions

We evaluated the hypothesis that shortgrass prairie ecosystems with similar vegetation and cover would have similar hydrological runoff responses. Runoff hydrographs from 3 separate rainfall simulation runs (dry, wet, very wet) at 11 different shortgrass prairie sites were evaluated to determine the hydrologic similarity within a single ecosystem type at widely separated sites. To obtain a clearer understanding of the interaction of the biotic and abiotic factors affecting runoff, the runoff hydrographs were separated into time-to-peak, slope of the rising limb, and steady state runoff components. To evaluate the effect of site biotic components, the regression slope of the rising limb of the runoff hydrograph was correlated to selected biotic factors.

When the sites were stratified by soil type differences, some runoff characteristics were detected. As the soil texture became finer, the time-to-peak of the runoff event during the dry run became progressively greater. The differences in time-to-peak among soil types became less as the soil became saturated (wet run) and with increased water application rate (very wet run). The regression coefficients of the slope of the runoff hydrograph rising limb during the initial phase (dry run) were similar across all sites. In the wet runs the mean runoff regression slope coefficients remained unchanged on the sandy loam soil but doubled on the loam and clay sites. In the very wet runs the mean runoff regression slope coefficients continued to increase for the clay sites but were unchanged on the loam and sandy loam sites. Spearman rank correlation coefficient (r_s) values show no consistent correlation pattern of the slope of the runoff hydrograph rising limb regression equation to measured vegetative characteristics across all sites. There was no consistent correlation between the runoff regression coefficient and the percent cover and bare soil. Equilibrium runoff (runoff rate divided by rainfall intensity) was not a good comparative parameter among sites and simulator runs.

The data analysis showed that biotic components (biomass, cover, litter) across all the sites were not useful in predicting hydrologic differences as measured by the slope of the rising limb of the runoff hydrograph. When stratified by soil type, biomass, cover and litter were significantly correlated to the slope of the rising limb, of the runoff hydrograph.

Were the 11 shortgrass prairie sites used in the evaluation hydrologically different? If equilibrium runoff was the measured hydrologic response, the sites were dissimilar. When using the time-to-peak and the regression coefficient of the slope of the runoff hydrograph rising limb the sites on the same soil type were hydrologically similar.

Can we assess the hydrologic components of rangeland health or sustainability by visual assessment of a site? Our study on shortgrass prairie sites indicated that easily estimated factors such as biomass, cover and litter were not good indicators of hydrologic function. Also, it is necessary to identify which portion of the runoff event is most important in the assessment. Future hydrologic and erosion models need to develop nonlinear prediction equations to estimate infiltration rates as a function of cover, biomass, and soil properties and also to stratify soils into functional units to accurately estimate runoff rates.

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N and P fertilization on rangeland production in Midwest Argentina

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Abstract

Low soil nutrient status may be the major limiting factor to forage production in rangelands of the Mendoza plains 4 years out of 10. We studied vegetation responses to annual applications of N and P on such rangelands. Fertilizer application rates were 0 or 25 N and 0 or 11 P (kg ha^{-1}) in a factorial arrangement. Dry matter production of grasses and palatable shrubs and crude protein (CP) content of grasses were determined annually from 1996 to 1998. Experimental plots received rains of 189, 278, and 346 mm during the 3 study years compared to mean growing season rainfall of 258 mm. Forage production was increased by N+P fertilization only in 1998 (1,390 vs 980 kg ha^{-1}, $P < 0.05$), producing 16.5 kg forage kg^{-1} N applied. Crude protein concentration was increased by N fertilization in 1997 (6.3 vs 5.3%, $P < 0.05$) and N+P application increased in 1998 (6.8 vs 5.7%, $P < 0.05$). Nitrogen and P application increased seasonal rain-use efficiency when the rainfall exceeded 300 mm. In 1998, the increase of grass production per kg N applied with and without P was 18.4 and 12.4 kg, respectively. The break-even point between rain and nutrients as the main primary production determinant on sandy soils in the central Mendoza plains is around 400 mm year^{-1} instead of 300 mm in other arid lands of the world. The value of meat increment derived from the N fertilization, with and without P application (US$ 0.07 ha^{-1} year^{-1} kg^{-1} N) was lower than the fertilizer cost (US$ 0.87 kg^{-1} N). A 5-fold increase in forage yields would be required to offset the cost of fertilizer. Fertilizer application did not increase forage production enough to be profitable for cattle production at present fertilizer and meat prices.

Key Words: crude protein, seasonal rain-use efficiency, nutrient use efficiency, range fertilization economics

As aridity increases, the importance of rainfall as a limiting factor to primary production increases (Le Houérou 1983, Le Houérou et al. 1988). The break-even point between nutrients and rainfall as being the focal point and major determinant in arid land primary production is around a mean annual rainfall of 300 mm on coarse sandy soils, as was demonstrated by Tadmor et al. (1972) and Van Keulen (1975) for the Northern Negev and by Penning de Vries and Djiteye (1982) for the Sahel of Mali. This rainfall has a 40% probability of occurrence in the central Mendoza plains (Guevara et al. 1997).

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Resumen

El contenido bajo de nutrientes del suelo puede ser el factor limitante principal de la producción de forraje en las pasturas naturales de la llanura de Mendoza en 4 años de 10. Se estudió la respuesta de la vegetación de esas pasturas a aplicaciones anuales de N y P. Las dosis aplicadas de fertilizantes fueron (kg ha^{-1}): 0 o 25 N y 0 u 11 P en un diseño factorial. Se determinó anualmente la producción de materia seca de las gramíneas y leñosas forrajeras y el contenido de proteína bruta (PB) de las primeras, desde 1996 a 1998. La lluvia media anual durante la estación de crecimiento en el sitio de estudio fue de 258 mm, mientras que las parcelas experimentales recibieron 189, 278 y 346 mm durante los tres años de estudio. La producción de forraje se incrementó como consecuencia de la aplicación de N+P sólo en 1998 (1.390 vs 980 kg ha^{-1}, $P < 0,05$), lo que correspondió a 16,5 kg de forraje por kg de N aplicado. La fertilización con N incrementó el contenido de PB de las gramíneas en 1997 (6,3 vs 5,3%, $P < 0,05$) y la aplicación de N+P la aumentó en 1998 (6,8 vs 5,7%, $P < 0,05$). La aplicación de N+P incrementó la eficiencia estacional de uso de las lluvias cuando éstas fueron mayores que 300 mm. En 1998, el incremento de la producción de gramíneas por kg de N aplicado, con y sin agregado de P, fue de 18,4 y 12,4 kg, respectivamente. El punto de quiebre entre la lluvia y los nutrientes, como determinante principal de la producción primaria en suelos arenosos de las llanuras centrales de Mendoza, está alrededor de 400 mm por año, en vez de 300 mm en otras zonas áridas del mundo. El valor del incremento de carne que derivaría de la aplicación de N, con y sin adición de P (US$ 0,07 ha^{-1} año^{-1} kg^{-1} N) fue menor que el costo del fertilizante (US$ 0,87 kg^{-1} N). Se requeriría que la producción de forraje se incrementara 5 veces para compensar el costo del fertilizante. La aplicación de fertilizantes no aumentó suficientemente la producción de forraje para que esta práctica sea rentable en la producción de carne bovina, dados los precios de fertilizantes y carne actuales.

The rangelands of the Mendoza plains of Argentina occupy an area of 5.6 million ha. About two-thirds of the Mendoza cattle population (318 x 10^3 head) was concentrated in this area in 1998. Economic analyses for cow-calf operations of various size classes conclude that most operations are negative while a very small number are marginally positive (Guevara 1992, Guevara et al. 1996a). This suggests action is needed to increase the economic performance of animal production systems.

Range development programs designed to attain higher productivity include fertilization, among other practices (Le Houérou 1995, Guevara et al. 1997). In Argentina, fertilization experiments have been performed outside of the arid zones. Under arid conditions similar to the Mendoza plain, low levels of N+P fertilization (10–20 kg ha^{-1}) increased forage production by a factor of 3 to 5 in Israel and the Sahel of Mali (Van Keulen 1975, Penning de Vries and Djiteye 1982). In the Indian arid region, annual application of 20 kg N ha^{-1} more than doubled forage yields 7 years out of 10 (Rao et al. 1996).

The objective of this study was to determine the effects of annual, low-level N and P fertilization on forage production, crude protein content of grasses, seasonal rain use efficiency and nutrient use efficiency in mid-west Argentina. A brief economic analysis was also performed.

Materials and Methods

Study area

This study was conducted at El Divisadero Cattle and Range Experiment Station (33°45' S, 67° 41' W, elev. 520 m), in the north central Mendoza plain, mid-west Argentina. The climate is temperate-warm. Average maximum daily temperatures ranged from 32.4 in January to 14.9°C in July. Average minimum temperatures ranged from 16.0 in January to -0.9° C in July (Personal communication, Estrella et al.). Mean annual rainfall for 1987–98 was 303.4 mm (SD = 96.6) with nearly 85% occurring during the growing season.

Soils are Torripsamments with greater silt content in interdunal depressions. Some major soil characteristics include: pH, 6.4–7.6; organic matter (Walkley-Black method), 0.09–0.22 %; total N (Macro-Kjeldahl method), 360–420 ppm; extractable P (bicarbonate extraction, Arizona method), 9–20 ppm; extractable K (nitric acid extraction, Pratt method), 990–1,420 ppm; and EC of soil saturation extract, 0.17–0.38 mS cm^{-1} (Masotta and Berra 1994).

The vegetation is an open xerophytic savanna and shrubland of *Prosopis flexuosa* DC. (algarrobo dulce). Warm-season grasses dominate the herbaceous vegetation with *Panicum urvilleanum* Kunth (tupe) as the major species. The other grasses present include *Aristida mendocina* Phil. (flechilla crespa), *Aristida inversa* Haeck. (flechilla), *Chloris castilloniana* Lillo & Parodi (falso plumerito), *Digitaria californica* (Benth.) Henr. (pasto algodón), *Pappophorum philippianum* Roseng. (pasto blanco), *Setaria leucopila* (Scrib. & Merr.) Schum. (cola de zorro), and *Sporobolus cryptandrus* (Torr.) A. Gray (gramilla cuarentona). *Capparis atamisquea* Kuntze (atamisque) was the principal palatable woody species.

Experimental procedures

In October 1995 a 40 x 40-m study area was selected and treatments randomly assigned to 4 plots within each of 4 blocks. Each treatment plot was 7 x 7 m with a distance between plots of 1 meter. Treatments were repeated on the same plots for 3 years (1995, 1996, and 1997). Fertilizer application rates were 0 or 25 N and 0 or 11 P (kg ha^{-1}) in a factorial treatment arrangement. Ammonium nitrate (30% N) and triple superphosphate (39% P_2O_5, i.e. 17% P) were the N and P sources, respectively. Fertilizer was broadcast by hand and then buried by a rake without disturbing the vegetation. Half of the N and all of the P were applied at the beginning of the rainy season (mid-October). The remaining N was applied at the peak of the rains (January). The experimental area was excluded from grazing during the experiment.

Herbaceous vegetation was harvested annually within eight, 1.0-m^2 permanent quadrats located within each plot when grasses reached maturity. Vegetation was handclipped at ground level, separated into species, oven dried at 60°C, and weighed to determine dry matter production. Height, crown width and basal diameter of the stems of each woody species present in the plots were recorded at the beginning of the study and annually. Total dry biomass of woody species was calculated based on allometric relations between plant dimensions and dry weights as described by Braun et al. (1978). Aboveground annual productivity of palatable woody species was estimated via the assumption that biomass increment was equivalent to the deciduous production, which amounts to 14% of aboveground phytomass (Braun et al. 1978).

Crude protein (CP) of harvested grasses was determined using 1 composite sample of each species per single treatment plot by micro-Kjeldahl (N x 6.25), in 1997 and 1998.

Calculations and statistical analyses

Seasonal rain-use efficiency (S-RUE) was determined by dividing forage yield over total rainfall of the growing season. From data on fertilizer rate and forage production greater than the yield of no-fertilized plots, nutrient use efficiency was calculated as kg dry matter kg^{-1} fertilizer applied. The growing season rainfall probabilities at the study site were calculated assuming data were normally distributed.

Three-way Within-Subjects (Repeated Measures) ANOVA was performed for each response variable (forage production, crude protein content and seasonal rain use efficiency). The Tukey's HSD test was used to assess differences among treatment means ($P < 0.05$).

A brief economic analysis was conducted using April 1999 prices (US$ 0.87 kg^{-1} N, and US$ 0.8 kg^{-1} meat on the hoof). A conversion rate of 32 kg of consumable forage per kilogram of meat on the hoof in cow-calf operations (Guevara et al. 1996b) was assumed. It was also assumed that there were no residual effects of fertilizers applied.

Results and Discussion

Rainfall and forage production

The experimental plots received a total of 189 and 278 mm of rainfall during the 1995–1996 and 1996–1997 growing seasons, which were lower and slightly higher than normal, respectively (Table 1). In 1998 the growing season rainfall was greater than the long-term mean.

There was a significant yield response to N and years. Furthermore, there was a significant N by year interaction. Application of N, P, and N+P did not affect forage yields in 1996 and 1997 (Fig. 1). In 1998, yield from N+P application was higher than that from no-fertilization. If the average forage yield over the 3 study years are compared, the application of N, P, and N + P did not affect forage yields.

According to the rainfall probabilities in the growing season at the study site, rainfall of 335 mm, similar to that occurred in 1997–98, would occur 2 years out of 10. Thus we would expect rainfall adequate to obtain yield responses to N+P applications in at least 20% of the growing seasons. In this study, yield responses to N+P fertilization occurred 1 year out of 3. The difference is probably due to the limited sample size of this study.

Forage production from N+P application was around 40% above the yield from non-fertilized plots in 1998. The response to fertilization in this study was lower than that in the Sahel of Mali because the mean annual rainfall was 250 mm lower, while

Table 1. **Rainfall at El Divisadero Cattle and Range Experiment Station in 1995 to 1998, compared to the 11-year mean.**

Period	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Growing season total	Annual total (Aug–Jul)
	-----	-----	-----	-----	mm	-----	-----	-----
1995–96	6	76	28	42	17	20	189	281
1996–97	3	16	85	114	24	36	278	344
1997–98	7	23	62	107	90	57	346	414
Mean	24	42	55	64	42	31	258	303

Table 2. Mean annual aboveground primary productivity of palatable woody species on a Mendoza plain rangeland with different fertilizer application rates, 1995–98.

Fertilizer rate N–P	Year 1995	1996	1997	1998
(kg ha^{-1})	------ kg dry matter ha^{-1} -----			
0–0	140	160	160	180
25–0	100	100	100	100
0–11	50	50	50	50
25–11	150	140	150	130

the substrates and soils were almost identical in both sites. On the other hand, the probability of occurrence of 300 mm rains reaches 90% in the Sahel (Penning de Vries and Djiteye 1982, Le Houérou 1989) and, therefore, nutrients are more often the main limiting factor to primary production.

Forage production from N, P and N+P applications was higher in 1998 than those in the previous years. Average forage yield was different over years (380, 660, and 1,150 kg ha^{-1} during 1996, 1997, and 1998, respectively).

Fertilizer application or growing season rains did not affect aboveground primary production of palatable woody species (Table 2). The aboveground production estimated during the experiment strongly depended on the production levels that existed in 1995. The roots of atamisque, the main palatable woody species, usually reach water tables as deep as 20–30 m (Roig and Ruiz Leal 1959) and production, therefore, is little affected by rains. This result supports the role of browse species as stabilizers of the forage productivity in arid lands.

Crude protein content

Nitrogen fertilization affected the crude protein (CP) content of grasses. The CP content from N application in 1997 and from N + P application in 1998 was higher than that of the grasses from the plots without fertilization (Fig. 2). The CP content from each treatment did not differ between the 2 study years. If the average CP content over the 2 years is compared, the values from N and from N+P applications were higher than that from grasses without fertilization and did not differ from the P application. Increases of CP content due to N or N+P applications has been reported in numerous studies (Stephens and Whitford 1993, Rubio et al. 1996, Veneciano and Terenti 1997, Gillen and Berg 1998).

Seasonal rain-use efficiency

Nitrogen fertilization and years significantly affected seasonal rain-use efficiency (S-RUE). The S-RUE from N+P application was higher than P application in 1996, but fertilizers did not affect S-RUE in 1997 (Fig. 3). In 1998, S-RUE from N+P application was higher than that from no-fertilization and from P application.

In 1998, S-RUE from N application, with and without P, was higher than those in 1996 and 1997. Average S-RUE was higher in 1998 (3.3 kg ha^{-1} mm^{-1} year^{-1}) than in 1997 (2.4) and 1996 (2.0). This indicates that N application affected S-RUE only if rainfall through the growing season was higher than 300 mm.

The average efficiency over years from the control (2.4 kg ha^{-1} mm^{-1}) was lower than that previously estimated for the central Mendoza plain (Guevara et al. 1996b, 1997). The difference is probably due to the lower contribution of woody species at the current study site.

Nutrient use efficiency

Nutrient use efficiency increased as the growing season rainfall increased (Table 3). This agrees with the results of Rubio et al. (1996). In 1998 the ratio of kg herbage produced versus kg fertilizer applied was 18.4, and 12.4 kg for N applications with and without P, respectively. The N use

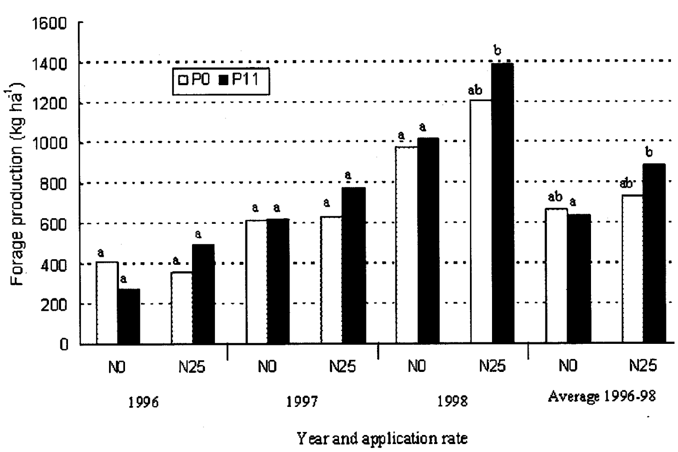

Fig. 1. Mean annual forage production on a Mendoza plain rangeland with different fertilizer application rates, 1996–98. Bars within years sharing a common letter are not significantly different (P > 0.05).

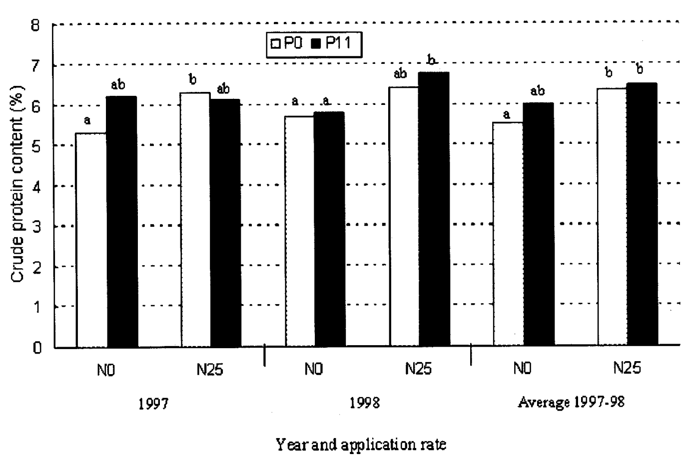

Fig. 2. Mean annual crude protein content of grasses on a Mendoza plain rangeland with different fertilizer application rates, 1997–98. Bars within years sharing a common letter are not significantly different (P > 0.05).

Table 3. Nutrient use efficiency on a Mendoza plain rangeland with different fertilizer applications, 1996–98.

Fertilizer	Nutrient use efficiency			Average
	1996	1997	1998	
(kg ha^{-1})-	- - - - - - - - - - - - - - - - kg dry matter kg^{-1} fertilizer -			
N 25 (without P)	–	0.9	9.2	2.7
N 25 (with P)	3.4	6.6	16.5	8.8
P 11	–	0.8	3.7	–

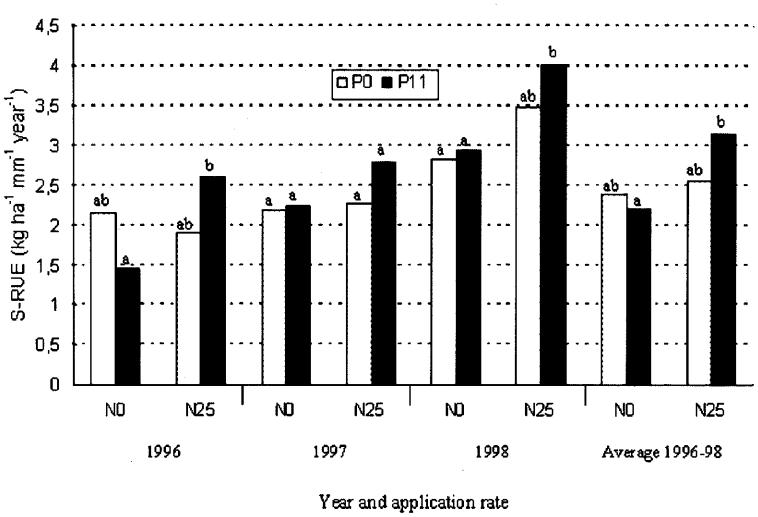

Fig. 3. Mean annual seasonal rain use efficiency (S-RUE) on a Mendoza plain rangeland with different fertilizer application rates, 1996–98. Bars within years sharing a common letter are not significantly different (P > 0.05).

efficiency without P application was lower than the range of 15 to 40 kg herbage production kg^{-1} N applied for warm-season grasses (Wilkinson and Langdale 1974, Tucker and Murdock 1984).

Economic analysis

Using the forage yields from 1998, the N fertilization yielded 322 kg (mean of production values from N fertilization with and without P application) above the non-fertilization treatment. This additional yield corresponds to about 73 kg of consumable forage ha^{-1} (Guevara et al. 1996b). This translates into meat production of 2.3 kg ha^{-1} year^{-1} or 0.09 kg meat ha^{-1} year^{-1} kg^{-1} N. The value of this meat increment was US$ 0.07, lower than the fertilizer cost (US$ 0.87 kg^{-1} N). A 5-fold increase in forage yields would be needed to offset the cost of fertilizers. This result agrees with findings in the Sahel, where the increase in primary production would have to be multiplied by a factor of almost 10 to make range fertilization economically feasible (Le Houérou 1983, 1989 p. 103). The ratio for the Sahel was estimated considering only the herbage yield while in this study the shrub production was also considered.

Conclusions

Application of N+P increased forage yield, crude protein content of grasses and seasonal rain-use efficiency when the growing season rains were higher than 300 mm. The break-even point between rain and nutrients as main primary production determinant on sandy soils in the central Mendoza plains is around 400 mm per year instead of 300 mm in other arid lands of the world. Rainfall greater than 400 mm has a 20% probability of occurrence and, therefore, rainfall is more often than nutrients the limiting factor to forage production. Our N+P fertilization rates did not increase forage production enough to be profitable for cattle production at present fertilizer and cattle prices.

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Supplemental barley and charcoal increase intake of sagebrush by lambs

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Abstract

We evaluated the influence of supplemental barley and activated charcoal on the intake of sagebrush by lambs in individual pens. In 3 experiments, lambs were fed sagebrush (harvested and chopped to 2–3 cm) during the morning; they were fed a basal diet of alfalfa pellets in the afternoon. In the first experiment, lambs supplemented with activated charcoal + barley ate more A. *tridentata* ssp. *vaseyana* than lambs supplemented with barley (304 vs. 248 g; P = .071). A second set of experiments, which consisted of 3 trials, determined the effects of activated charcoal, barley, and subspecies of sagebrush on intake of sagebrush. Lambs supplemented with activated charcoal + barley ate more *A. tridentata* ssp. *vaseyana* (Trial 1; 292 vs. 225 g; P = .086), and more *A. tridentata* ssp. *tridentata* (Trial 2; 371 vs. 255 g; P = .031) than lambs supplemented with barley. In Trial 3, lambs supplemented with barley ate more sagebrush than lambs that were not supplemented (480 vs. 318 g; P = .0002). A third set of experiments compared activated charcoal + barley, barley, and no supplement in 2 trials. In Trial 1, lambs supplemented with activated charcoal + barley or barley generally ate more A. *tridentata* ssp. *vaseyana* than lambs not supplemented (P = .017). In Trial 2, lambs supplemented with activated charcoal + barley ate slightly more *A. tridentata* ssp. *vaseyana* than lambs supplemented with barley, and they ate substantially more than lambs not supplemented (P = .032). Collectively, the results suggest that energy from supplemental barley increased intake of sagebrush by lambs fed a basal ration of alfalfa pellets which are high in protein, and that activated charcoal played a minor role in further increasing intake of sagebrush.

Key Words: sheep, macronutrients, terpenoids, rangeland

Resumen

Evaluamos la influencia de la suplementación de cebada y carbón activado en el consumo de "Sagebrush" por corderos confinados en corrales individuales. En 3 experimentos, los corderos se alimentaron con "Sagebrush" (cosechado y picado a 2-3 cm) durante la mañana y en la tarde se alimentaron con una dieta basal de pelets de alfalfa. En el primer experimento, los corderos suplementados con cebada + carbón activado comieron mas *A. tridentata* ssp. *vaseyana* que los corderos suplementados con cebada (304 vs. 248 g; P = 0.071). En un segundo grupo de experimentos, consistente de 3 ensayos, se determinaron los efectos del carbón activado, cebada y subespecies de "Sagebrush" en el consumo de "Sagebrush." Los corderos suplementados con carbón activado + cebada comieron mas *A. tridentata* ssp. *vaseyana* (ensayo 1; 292 vs. 225 g P = 0.086) y más *A. tridentata* ssp. *tridentata* (ensayo 2; 371 vs. 255 g; P = 0.031) que los corderos suplementados con cebada. En el experimento 3, los corderos suplementados con cebada comieron mas "Sagebrush" que los corderos sin suplementación (480 vs. 318 g; P = 0.0002). En un tercer grupo de experimentos, conformado de 2 ensayos, se comparo el carbón activado + cebada, cebada y sin suplemento. En el experimento 1, los corderos suplementados con carbón activado + cebada o cebada generalmente comieron más *A. tridentata* ssp. vaseyana que los corderos sin suplementación (P = 0.017). En el ensayo 2, los corderos suplementados con carbón activado + cebada comieron un poco mas *A. tridentata* ssp. *vaseyana* que los corderos suplementados con cebada, y ellos comieron substancialmente mas que los corderos no suplementados (P = 0.032). Los resultados colectivos de este grupo de experimentos sugieren que la energía proveniente de la cebada suplementaria aumenta el consumo de "Sagebrush" de los corderos alimentados con una ración basal de pelets alfalfa los cuales son altos en proteína, y que el carbón activado jugo un papel menor en incrementar el consumo de "Sagebrush."

Sagebrush (*Artemisia tridentata* Nutt.) refers to a diverse array of subspecies and ecotypes of shrubs that occur on approximately 39 million hectares of land in the western United States (Bastian et al. 1995). While accounts vary, there is evidence that sagebrush has increased in abundance in many areas due to grazing preferences of herbivores and lack of fire.

Sagebrush steppe ecosystems are used in various ways, and one of the more important is as habitat for domestic and wild animals. Many grasses and forbs that grow with sagebrush are valuable foods, but the merit of sagebrush as a forage varies. Although sagebrush is relatively high in nutrients for a rangeland shrub, some accessions of sagebrush are more digestible and nutritious than others (Welch and Pederson 1981, Welch and McArthur 1986). Different accessions also vary in kinds and amounts of potentially toxic compounds such as terpenes (Johnson et al. 1976, Personius et al. 1987), which can deter feeding by sheep, goats, cattle, mule deer, moose, hares, and voles (Picman 1986, Bray et al. 1991, Langenheim 1994). Thus, sagebrush is abundant and generally nutritious, but its forage value can be low because it contains a variety of terpenes, some of which deter feeding by herbivores.

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It may be possible to increase use of sagebrush with compounds like activated charcoal that adsorb terpenoids and other potentially harmful compounds that may occur in sagebrush, and with supplemental macronutrients that may facilitate detoxification. Activated charcoal is a safe, effective, and inexpensive gastrointestinal adsorbent recommended for use by virtually every textbook or handbook on the treatment of acute drug intoxications because it adsorbs a wide range of compounds such as alkaloids, phenols, salicylates, sulfanoamides, and inorganic compounds (Hayden and Comstock 1975, Levy 1982). Supplemental macronutrients may also increase use of sagebrush, as needs for energy and protein increase due to detoxification processes (Foley et al. 1995, Illius and Jessop 1995). Thus, we hypothesize that nutritious supplements containing macronutrients and adsorbents like activated charcoal, alleviate the adverse effects of the terpenoids in sagebrush, thereby allowing an increase in use of sagebrush by herbivores. Our objective was to evaluate the roles of supplemental barley and activated charcoal on the intake of sagebrush by lambs fed a basal diet of alfalfa pellets. We conducted 3 independent experiments over an 18-month period with different sets of animals.

Materials and Methods

Experiment 1

The objective of the first experiment was to determine the effects of activated charcoal + barley on intake of sagebrush by lambs. We fed sagebrush harvested in early May from the foothills west of Logan in northern Ut. Sagebrush leaves and twigs were clipped, placed in woven, polyethylene feed sacks, and frozen. Several days after freezing, the sagebrush was ground to 1 cm in length with a chipper, mixed for uniformity, placed in plastic bags in 8 to 10 kg amounts, and returned to a freezer. The night before each daily trial, a bag of sagebrush was removed from the freezer and placed in a refrigerator to thaw prior to the next day's feeding.

We accustomed 16 lambs (crossbreds; 4 mo age; 38 kg BW) from the Utah State University farm to eat a barley-activated charcoal mix and sagebrush prior to the trials. We determined the average intake of sagebrush for each lamb during hour-long trials when they were being fed a basal diet of alfalfa pellets, and ranked them from high to low based on their intake of sagebrush. We then assigned lambs at random to 2 treatments (n = 8 lambs $treatment^{-1}$), balanced for intake of sagebrush. Lambs in 1 group received activated charcoal + barley, whereas lambs in the other group received only a barley supplement.

At 0730 hours each morning on days 1 to 6, treatment lambs received 100 g of ground barley mixed with 10 g of commercial grade activated charcoal, whereas controls were offered 100 g barley; all lambs consumed all of their supplement throughout the trial. Neither activated charcoal + barley nor barley supplements were fed on days 7 and 8 to determine if intake of lambs would decline. From 0800 to 0900 hours each day, lambs had access to ground sagebrush (*A. tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle) ad libitum. Food refusals were collected and sagebrush intake was calculated. Lambs were then offered alfalfa pellets ad libitum until 1830 hours and held without food overnight. Lambs had free access to trace-mineral salt blocks and water throughout the 8-day study.

Experiment 2

The objective of Experiment 2 was to determine the effects of supplemental barley and activated charcoal, as well as food restriction, on the intake of sagebrush. We conducted three trials with 24 lambs (crossbreds about 3 mo age) obtained from the U.S. Sheep Experiment Station. Lambs weighed 26 kg at the beginning of the experiment just prior to Trial 1 and 31 kg at the end of Trial 3. We conditioned lambs to eat a barley-activated charcoal mix and sagebrush, as in Experiment 1, and we assigned lambs at random, balanced for intake of sagebrush, to 2 treatments (n = 12 $treatment^{-1}$), one that received the activated charcoal + barley supplement and the other that received only barley. Lambs remained in the same treatments in Trials 1 and 2 and were randomly re-assigned to treatments by pairs for Trial 3.

We used 2 subspecies of sagebrush. In Trial 1, we used *A. tridentata* ssp. *vaseyana* harvested in the foothills west of Logan in northern Utah. For Trial 2, we used *A. tridentata* Nutt. ssp. *tridentata* harvested in Tintic Valley in central Utah. For Trial 3, we used both subspecies of sagebrush. Sagebrush leaves and twigs were clipped, frozen, ground, and stored as in Experiment 1.

Trial 1. At 0800 hours daily, treatment lambs were fed 180 g of ground barley mixed with 20 g of activated charcoal, whereas controls were fed 180 g barley. From 0820 to 1200 hours, lambs were fed sagebrush (*A. tridentata* ssp. *vaseyana*) ad libitum. We determined intake of activated charcoal + barley and sagebrush for each lamb for 13 days; all lambs ate all of their supplement throughout the trial. At 1200 hours, lambs were fed alfalfa pellets at 80% of maintenance. Lambs had free access to trace-mineral blocks and water for the duration of the trial.

Trial 2. The procedures for this trial were the same as those described for Trial 1, except that lambs were offered a different subspecies of sagebrush (*A. tridentata* ssp. *tridentata*), and the trial lasted 7 days. Again, all lambs ate all of their supplement—activated charcoal + barley or barley— during the trial.

Trial 3. The methods for this trial were the same as those for Trial 1, except treatment lambs received 200 g of ground barley and controls received no barley. Lambs were ranked from high to low, based on sagebrush intake in Trials 1 and 2, and then assigned to treatments. Half of the lambs previously fed activated charcoal + barley in Trials 1 and 2 were fed barley in this trial, whereas the other half were not fed barley. Likewise, half of the lambs previously fed barley received barley, whereas the other half did not receive barley. Lambs ate all of the barley during the trial. On days 1 to 3 lambs had access to *A. tridentata* ssp. *tridentata*, whereas on days 4 to 11 they had access to *A. tridentata* ssp. *vaseyana*. Sagebrush was available ad libitum from 0820 to 1200 hours daily.

Experiment 3

Our objective was to compare 3 treatments—activated charcoal + barley vs. barley vs. no supplement—and to vary the level of food deprivation. Lambs (30 crossbreds, about 6 mo age; 45 kg BW) were adapted to supplements and sagebrush prior to the experiment, and they were ranked and assigned to treatments as in Experiments 1 and 2. Sagebrush (*A. tridentata* ssp. *vaseyana*) was harvested, ground, and stored as in Experiments 1 and 2.

Trial 1. The objective of this trial was to compare intake of sagebrush by lambs when they had ad libitum access to alfalfa pellets for an extended period of time during the afternoon. At 0700 hours for 6 days, lambs (n=10 $treatment^{-1}$) were offered activated charcoal + barley (25 g + 225 g), barley (225 g), or no supplement for 20 min. All lambs consumed all of the supplement. Lambs were then given access to sagebrush ad libitum from 0720 to 1200 hours. Lambs had access to alfalfa pellets ad libitum from 1200 to 1700 hours each afternoon.

Trial 2. The objective of Trial 2 was to determine if food restriction influenced the effect of supplementation on intake of sagebrush by lambs. For 2 days following Trial 1, lambs had access to alfalfa pellets until food boxes were removed at 1400 hours, and lambs were fasted overnight. At 0900 hours for the next 4 days, lambs were offered activated charcoal + barley (25 g + 225 g), barley (225 g), or no supplement for 20 min; lambs were in the same treatments as for Trial 1. All lambs ate all of the supplement offered. Lambs were then given access to sagebrush ad libitum from 0920 to 1300 hours. Lambs had access ad libitum to alfalfa pellets for 1 hour each afternoon, from 1300 to 1400 hours.

Statistical Analyses

The analyses of variance had 2 treatments (activated charcoal + barley, barley) in Experiment 1 and in Experiment 2, Trials 1 and 2. The analyses of variance had 2 treatments in Experiment 2, Trial 3 (barley, no supplement) and 3 treatments (activated charcoal + barley, barley, no supplement) in Experiment 3. Lambs within treatment was the error term for treatments. Day was the repeated measure. Lamb within treatment x day was the error term for day and its interaction with treatment.

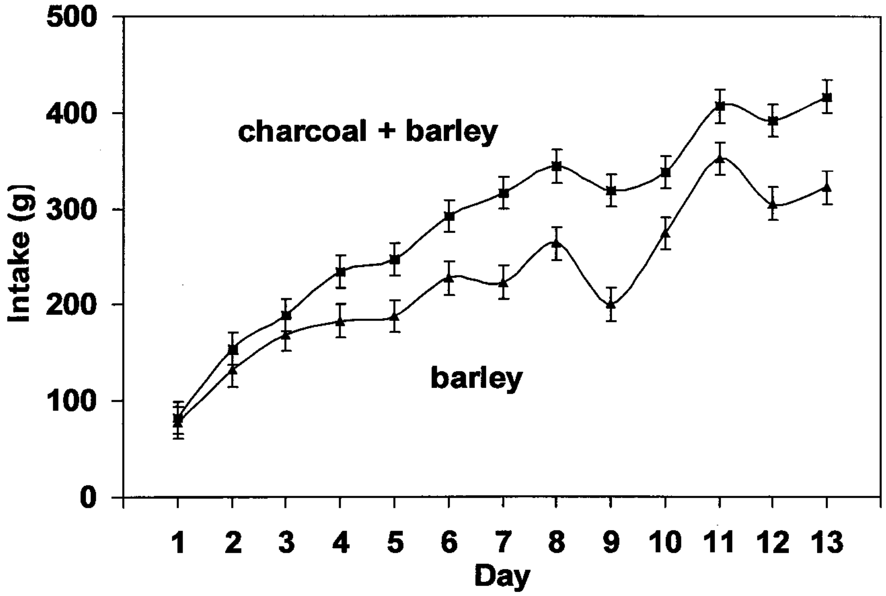

Fig. 2. Intake (means ± SE) of *Artemisia tridentata* ssp. *vaseyana* for 4 hours day^{-1} by lambs supplemented with activated charcoal + barley or barley alone (L.S.D.$_{.05}$ = 35).

Results

Experiment 1

Lambs supplemented with activated charcoal + barley ate more *A. tridentata* ssp. *vaseyana* than lambs supplemented with barley (304 vs. 248 g; P = .071; Fig. 1). Lambs increased intake of sagebrush during the trial (P = .0001). Treatment and day did not interact (P = .148).

When supplements were withheld on days 7 and 8, lambs accustomed to eating the activated charcoal + barley supplement did not continue to increase intake of sagebrush on day 7, as they had on days 1 to 6, and they decreased intake on day 8 (390 vs. 407 vs. 375 g for days 6, 7, 8; L.S.D$_{.05}$ = 29). Lambs accustomed to receiving the barley supplement did not increase intake of sagebrush on days 7 and 8, as they had on days 1 to 6 (324 vs. 320 vs. 299 g for days 6, 7, 8; L.S.D$_{.05}$ = 29).

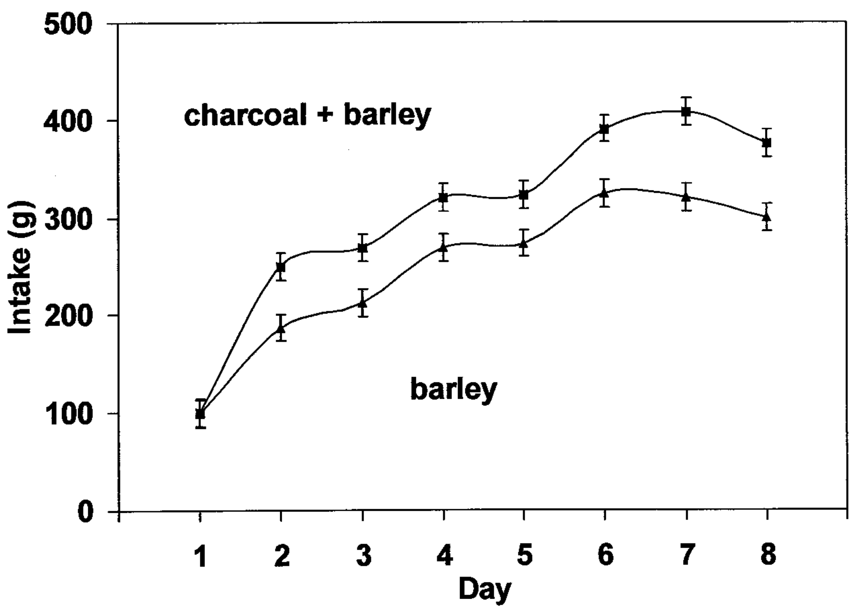

Fig. 1. Intake (means ± SE) of *Artemisia tridentata* ssp. *vaseyana* for 1 hour day^{-1} by lambs supplemented with activated charcoal + barley or barley alone (L.S.D.$_{.05}$ = 29). Barley and charcoal were fed from days 1 to 6, but not on days 7 or 8.

Experiment 2

Trial 1. Lambs supplemented with activated charcoal + barley ate more *A. tridentata* ssp. *vaseyana* than lambs supplemented with barley (292 vs. 225 g; P = .086; Fig. 2). Lambs increased intake of sagebrush throughout the trial (P = .0001), and treatment and day interacted (P = .038).

Trial 2. Lambs supplemented with activated charcoal + barley ate more *A. tridentata* ssp. *tridentata* than lambs supplemented with barley (371 vs. 255 g; P = .031; Fig. 3). Lambs increased intake of sagebrush during the trial (P = .0001). Treatment and day did not interact (P = .552).

Trial 3. Lambs supplemented with barley ate more sagebrush than lambs that were not supplemented (480 vs. 318 g; P = .0002; Fig. 4). Lambs generally increased intake of sagebrush throughout the trial (P = .0001), and there was a treatment x day interaction (P = .0001).

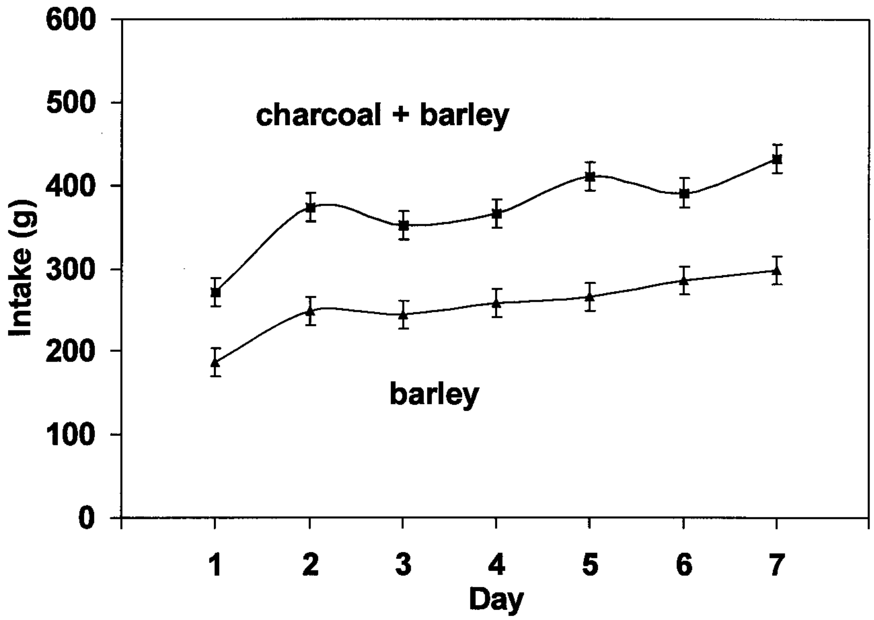

Fig. 3. Intake (means ± SE) of *Artemisia tridentata* ssp. *tridentata* for 4 hours day^{-1} by lambs supplemented with activated charcoal + barley or barley alone (L.S.D.$_{.05}$ = 33).

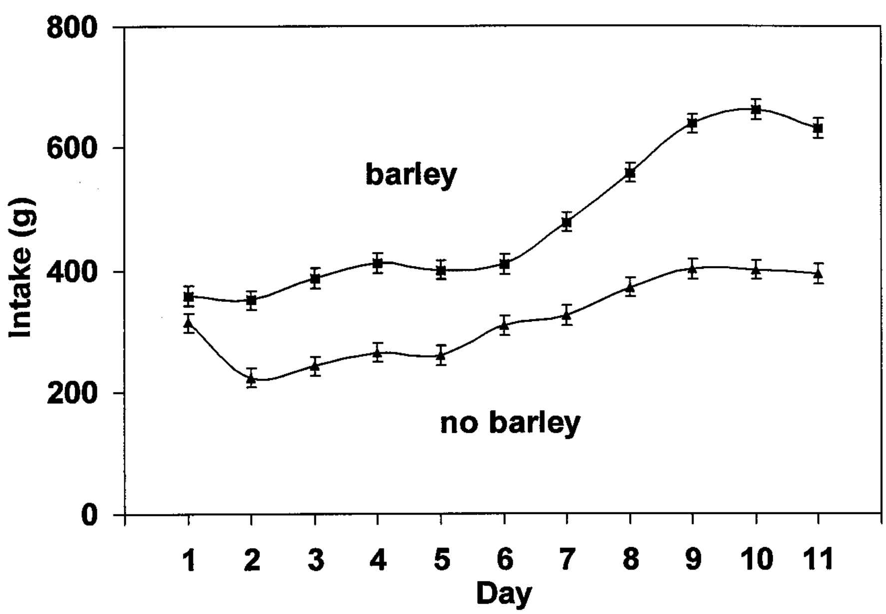

Fig. 4. Intake (means ± SE) of *Artemisia tridentata* ssp. *vaseyana* (days 1 to 3) or *tridentata* (days 4 to 11) for 4 hours day^{-1} by lambs supplemented with barley or not supplemented (L.S.D.$_{.05}$ = 31).

Experiment 3

Trial 1. Lambs supplemented with activated charcoal + barley or barley generally ate more *A. tridentata* ssp. *vaseyana* than lambs not supplemented, and treatment and day interacted (P=.017; Fig. 5). Lambs fed barley ate a large amount of sagebrush on day 4, and then decreased intake on days 5 and 6.

Trial 2. Lambs ate slightly more *A. tridentata* ssp. *vaseyana* when supplemented with activated charcoal + barley than with barley on days 2 to 4. Lambs supplemented with activated charcoal + barley or barley ate substantially more sagebrush during the trial than lambs not supplemented (treatment x day interaction, P = .032; Fig. 6). Lambs increased intake of sagebrush during the trial (P = .0001; Fig. 6).

Discussion

Influence of Supplements

Lambs supplemented with activated charcoal + barley ate slightly more sagebrush than lambs supplemented with barley, presumably because charcoal adsorbs terpenes in sagebrush. Adsorbents like activated charcoal may be useful for mitigating the aversive postingestive effects of terpenoids. Activated charcoal is used commonly to diminish the effects of poisons and drug overdoses at poison control centers. Administered promptly and in sufficient amounts, activated charcoal appreciably reduces gastrointestinal absorption of toxins, and it also increases clearance of drugs that have been absorbed and are in systemic circulation (Levy 1982).

The influence of supplemental barley was greater than that of charcoal. Most of the increase in intake in Experiment 3 (Trial 2) was accounted for by the addition of barley (Fig. 6). The same pattern is apparent when Trials 1 and 2 (Figs. 2, 3) are compared with Trial 3 (Fig. 4) in Experiment 2. Inadequate nutrition decreases availability of energy and protein, substrates vital in the process of detoxification (McArthur et al. 1991). It is likely that the maximum absorbed allelochemical dose, which will limit the amount of food ingested, depends on the supply of nutrients for detoxification and cosubstrate for conjugation (Glazenberg et al. 1983, Price et al. 1987, Foley et al. 1995, Illius and Jessop 1995, Jessop and Illius 1997, Wang and Provenza 1997). Protein sources high in sulfur-containing amino acids facilitate detoxification of sesquiterpene lactones in bitterweed (Ueckert and Calhoun 1988). Barley is a good source of energy (3.26 Mcal kg^{-1} DE) and alfalfa is a good source of protein (15 to 17% CP), and barley and alfalfa are both good sources of sulfur-containing amino acids (Nutrient Requirements of Sheep 1985).

Plane of Nutrition

Our data also suggest that the abundance of an alternative food influenced intake of sagebrush by lambs. During Experiment 3, lambs with access to alfalfa pellets throughout the afternoon (Fig. 5) ate considerably less sagebrush than lambs with only 1 hour access to alfalfa pellets each afternoon (Fig. 6). Lambs fed diets adequate in nutrients avoid foods high in toxins, even when they are supplemented with compounds that ameliorate their effects (e.g., polyethylene glycol and tan-

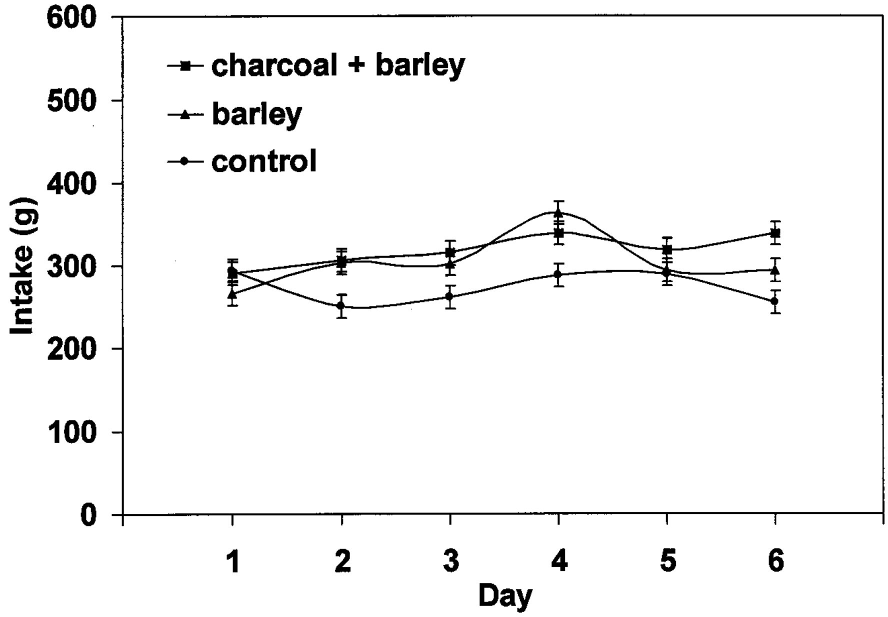

Fig. 5. Intake (means ± SE) of *Artemisia tridentata* ssp. *vaseyana* for 4 hours day[-1] by lambs supplemented with activated charcoal + barley, barley, or not supplemented. Lambs were fed alfalfa pellets ad libitum in the afternoon during this trial (L.S.D.$_{.05}$ = 28).

charcoal and barley in Experiment 1 (Fig. 1, days 7 and 8).

Terpenoids in sagebrush may act as feeding deterrents because they have a bitter flavor or because they are toxic. Sesquiterpene lactones in sagebrush, rubberweeds (*Hymenoxys* spp.), and orange sneezeweed (*Helenium* spp.) irritate the mucosa of the mouth and the gastrointestinal tract, which causes vomiting in ruminants (Cheeke and Shull 1985). Sheep limit intake of native hay-sagebrush rations in accord with the concentration of sagebrush (*Artemisia tridentata* ssp. *vaseyana*) in the mix (Ngugi et al. 1995). Their dry matter intake decreased from 93 to 23 g day^{-1} metabolic body weight^{-1} as sagebrush increased from 0 to 30% of the ration. These findings are consistent with the idea that the deterrent effects of terpenoids are dose-dependent (Langenheim 1994). The supplement-induced changes in intake in our study suggest that the decrease in intake is at least partially due to the postingestive effects of sagebrush (Provenza 1995).

nins, Titus et al. 1999). The data on food restriction are confounded with the influence of ongoing adaptation to the diet, but they nonetheless warrant further inquiry, particularly into how nutritional quality and abundance of alternative foods influences intake of sagebrush.

In another study, we reported that lambs fed supplemental energy or protein did not increase intake of sagebrush (Burritt et al. 1999). In that study, lambs fed a basal diet inadequate for growth (1.2 times maintenance) also ate more sagebrush than lambs fed a nutritionally adequate diet (2.7 times maintenance). However, both groups of lambs were fed ground sagebrush mixed with barley, and thus benefited from the additional energy provided by the barley. The protein provided by the basal diet of alfalfa pellets fed later in the day likely complemented the supplemental barley to improve sagebrush consumption (Villalba and Provenza 1999, Villalba, unpublished data).

Changes in Intake

Lambs typically increased intake of sagebrush throughout all three experiments, likely due to ongoing adaptation to the sagebrush diet. The interactions between treatment and day, which occurred in most of our trials, reflect the ongoing divergence in intakes between supplemented and control lambs as trials progressed (Figs. 1, 2, 5). In most cases, supplemented lambs increased intake at a more rapid rate and consistently ate more than lambs not supplemented. However, unsupplemented lambs in Experiment 3 (trial 1) showed a marked decrease in intake from days 1 to 2 (Fig. 5), evidently because they had been supplemented with barley and activated charcoal until day 1 of the trial. Rate of intake also declined when we no longer provided activated

Implications

Terpenoids occur in grasses, forbs, shrubs, and trees in all stages of succession from early to late (Picman 1986, Langenheim 1994). Conifers, mints, and euphorbs typically contain terpenoids, and all but one tribe of the family Asteraceae contain sesquiterpene lactones. These plants are often abundant, and could be

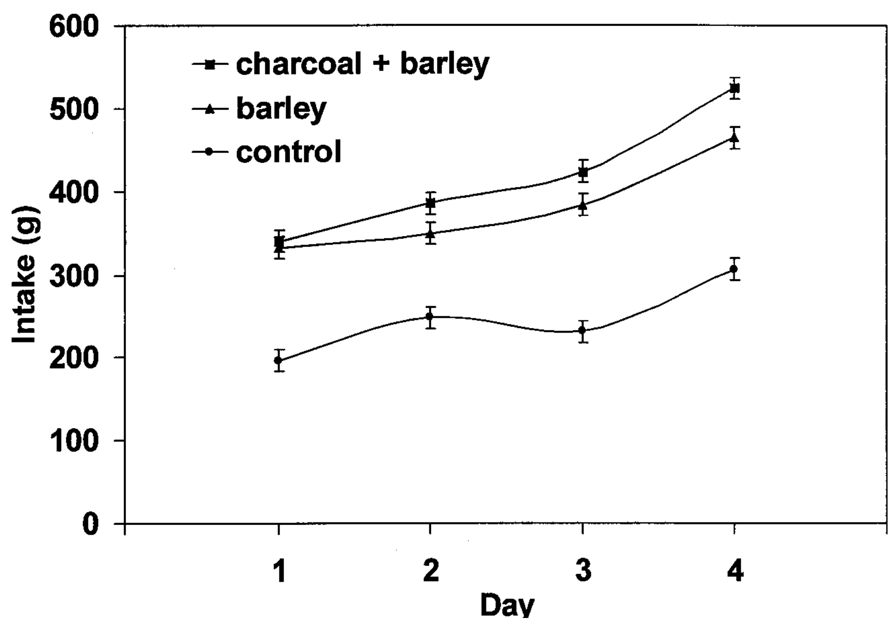

Fig. 6. Intake (means ± SE) of *Artemisia tridentata* ssp. *vaseyana* for 4 hours day[-1] by lambs supplemented with activated charcoal + barley, barley, or not supplemented. Lambs were fed alfalfa pellets for only 1 hour in the afternoon during this trial (L.S.D.$_{.05}$ = 26).

important sources of forage for animals in dry environments, but their use is limited by terpenoids.

Managers have used various techniques —herbicides, mechanical manipulations, fire—to reduce the abundance of sagebrush (Bastian et al. 1995). People are skeptical of herbicidal remedies and mechanical manipulations often are not justifiable economically. Fires can cause air quality and safety concerns, even in sparsely populated areas, and it often removes both desirable and undesirable vegetation. Herbivores can reduce the abundance of sagebrush, especially browsing during winter when concentrations of terpenoids are low and sagebrush is most acceptable (Gade and Provenza 1986).

Most accessions of sagebrush are nutritious, but their nutritive value may be offset by the deleterious effects of terpenoids (Ngugi et al. 1995). Sheep supplemented with adsorbents and macronutrients eat more sagebrush than non-supplemented sheep under confined conditions. Thus, it is important to determine if supplementation will also influence sheep to eat more sagebrush on rangelands during fall and winter. The coincidental timing of sagebrush acceptability and flushing ewes for reproduction may provide a practical opportunity to increase use of sagebrush by sheep. Supplementing ewes to improve conception during breeding and utilizing sagebrush when it is lower in terpenoids may be a practical management solution. Likewise, supplementing sheep and cattle with macronutrient-rich concentrates, as opposed to poorer quality roughages, may enhance intake of sagebrush during fall and winter.

Several benefits could be realized if herbivores used sagebrush more. For example, the abundance of sagebrush might be reduced because sagebrush does not tolerate grazing well (Bilbrough and Richards 1993). Increasing use of sagebrush, and decreasing use of alternate forages, would likely enhance production of grasses and forbs and create a more diverse mix of plants. In addition, the amount of forage in the western United States would increase substantially if domestic and wild herbivores used sagebrush. Herbivores might use sagebrush steppe uplands more, and riparian areas less, if their preference for sagebrush were to increase. Use of livestock browsing to reduce biomass of shrubs and trees in areas prone to fire also depends on how terpenoids affect preference. Finally, the results may apply broadly, as 15,000 to 20,000 terpenoids have been identified from plants worldwide. However, it is important to note that the effectiveness of macronutrient supplements and activated charcoal will likely vary with the chemical structure of the terpenoid.

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Vegetation response to late growing-season wildfire on Nebraska Sandhills rangeland

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Abstract

This study examined the effects of late growing-season (September) wildfire on the subsequent production and species composition of upland Nebraska Sandhills prairie vegetation. Three paired-plots (burn and control), 0.5 ha in size were established in 1995 on sands range sites on each of 3 replications in west-central Nebraska. Soil temperature data were collected the following growing season and herbage standing crop and species composition data were collected for 3 growing seasons following the burn. During March through May of the 1996 growing season, soil temperature in the burn treatment was an average of 1.6 ° C higher at both 15 and 30 cm depths compared to the control ($P < 0.05$). This small increase in spring soil temperature under the burn treatment did not appear to result in earlier growth or to increase herbage standing crop in May. Total herbage standing crop in August averaged 143, 142, and 185 g m^{-2} in 1996, 1997, and 1998, respectively, and did not differ between the burn treatment and control ($P > 0.05$). Little bluestem [*Schizchyrium scoparium* (Michx.) Nash] was the species most adversely affected by burning. Percentage composition by weight of little bluestem in August 1996 averaged 8% under the burn treatment compared to 47% in the control. Other species and species groups, however, were more abundant in burned plots, thus offsetting the lesser amounts of little bluestem. Little bluestem exhibited a marked recovery during the second and third growing seasons after the burn. During the third growing season, percent composition of little bluestem averaged 46% and was not different between treatments ($P > 0.05$). Forbs were more abundant under the burn treatment compared to the control only during the first growing season following the burn ($P < 0.05$).

Key Words: burning, species composition, herbage standing crop, soil temperature

Resumen

En este estudio se examinaron los efectos del fuego a fines de la estación de crecimiento (Septiembre) en la producción subsecuente y composición de especies de la vegetación de pradera de las mesetas de los pastizales "Sandhills"de Nebraska. En 1995, en sitios de pastizal "sand", se establecieron tres pares de parcelas (quema y control) de 0.5 ha en cada una de las 3 repeticiones localizadas en la región central-oeste de Nebraska. En la siguiente estación de crecimiento se colectaron datos de temperatura del suelo y durante las 3 estaciones de crecimiento posteriores a la quema se tomaron datos de producción forraje en pie y composición de especies. En el periodo de Marzo a Mayo de la estación de crecimiento de 1996, la temperatura del suelo a las profundidades de 15 y 30 cm fue en promedio 1.6°C mayor en el tratamiento con quema que en el control ($P < 0.05$). Este pequeño incremento de la temperatura del suelo durante la primavera no pareció resultar en un carecimiento mas temprano de la vegetación o en un incremento en la producción de forraje en pie de Mayo. La producción total de forraje en pie de Agosto promedio 143, 142 y 185 g m^{-2} en 1996, 1997 y 1998 respectivamente y no difirió entre los tratamientos con y sin quema ($P > 0.05$). La especie mas severamente afectada por el fuego fue "Little bluestem" [*Schizchyrium scoparium* (Michx.) Nash]. En Agosto de 1996 el porcentaje de composición por peso del "Little bluestem" promedio 8% en el tratamiento con quema y 47% en el control. Sin embargo, otras especies y grupos de especies fueron mas abundantes en las parcelas con quema, compensando así las menor producción de "Little bluestem". Durante la segunda y tercera estaciones de crecimiento después de la quema el "Little bluestem"mostro una marcada recuperación. Durante la tercer estación de crecimiento, el porcentaje de composición de "Little bluestem" promedio 46% y no hubo diferencia entre tratamientos ($P > 0.05$). Las hierbas fueron mas abundantes en las parcelas con quema que en las parcelas control, pero esta diferencia solo se dio en la primer estación de carecimiento después de la quema ($P < 0.05$).

Many early observers in the Nebraska Sandhills noted the frequent occurrence of prairie fires, from spring through fall (Wolfe 1973). There have, however, been few studies conducted to evaluate the effect of fire on the Nebraska Sandhills grasslands. Wildfires, as well as prescribed burning, have the potential to cause changes in plant cover or species composition on grasslands (Daubenmire 1968). While prescribed burning is not typically used to manage upland Sandhills range, wildfires caused by lightning or accidental means still occur. Immediate and obvious effects of late growing-season or dormant-season wildfires are loss of the forage resource as well as increased exposure of the soil surface to potential wind and water erosion for up to 8

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months until the next growing season. Pool (1914) observed that wildfires that removed protective plant cover for extended periods of time increased the frequency of blowout formation or at least some level of soil erosion, particularly on the choppy sands range sites. While this effect is only anecdotal, wind erosion is among concerns expressed with fire application in the Sandhills (Burzlaff 1962, Bragg and Steuter 1996).

Fires started by lightning in the Nebraska Sandhills may occur in the spring but the majority occur during late summer (Westover 1977). Fires started accidentally, however, can occur anytime when there is adequate dry fuel, primarily from fall through early spring. High winds often dramatically increase the extent of these fires. Variables such as season or date of the burn, fuel load, wind speed, humidity, soil moisture, range condition prior to the burn, and rainfall and management after the burn will influence the response of grasslands (Wright and Bailey 1982). Vegetation characteristics that are affected may include production, species composition, habitat structure, density, plant size, root development, nutrient content, and seed survival and germination. Soil characteristics that may also be affected include soil temperature, moisture, pH, nutrients, and erosion.

The reported effects of burning on individual plant species in the Sandhills has been variable. This is not unexpected given the spatial variability of fire conditions, fire behavior, and date of burning. Following spring burns, Wolfe (1973) for example, reported reductions in the amount of sand bluestem (*Andropogon hallii* Hack.) and sand dropseed [*Sporobolus cryptandrus* (Torr.) Gray] and an increase in prairie sandreed [*Calamovilfa longifolia* (Hook.) Scribn.] and needleandthread (*Stipa comata* Trin. & Rupr.). Bragg, (1978) however, reported that prairie sandreed and needleandthread declined with burning. Pfeiffer and Steuter (1994) reported that prescribed spring burning increased end-of-year standing crop of both rhizomatous grasses and bunchgrasses; however, summer burning (late July) reduced bunchgrass standing crop but did not affect rhizomatous grasses.

Late growing-season (August–September) wildfires occur at a time when warm-season species are near, or at full maturity. The impact of fire on Sandhills vegetation at this time of year has not been fully evaluated. Thus, the objective of this study was to compare soil temperatures, herbage production, and species composition of late-growing season burned and control plots on upland Sandhills range.

Materials and Methods

This study was conducted on Sandhills rangeland in west-central Nebraska. Three replicate study sites were selected in cooperation with landowners that had areas affected by individual wildfires that occurred within a 2-week period from late August to early September 1995. One of the study sites was located in Thomas County (41° 46' 30" N, 100° 45' 45" W) and the other 2 were in McPherson County (41° 28' 45" N, 101° 24' 00" W and 41° 25' 00" N, 100° 59' 30" W). The study sites ranged from 50 to 90 km from North Platte, Nebr. The long-term average annual precipitation for the general area is 484 mm (NOAA 1998). Precipitation was 106, 100, 86, and 117 % of the average during 1995, 1996, 1997, and 1998, respectively.

Study plots were established on sands range sites, the most abundant of upland Sandhills range sites. Soils were Valentine fine sand (mixed, mesic Typic Ustipsamments). Vegetation of sands range sites in west-central Nebraska is dominated by a mix of mid- and tall-grasses. Common warm-season grasses include prairie sandreed, little bluestem [*Schizchyrium scoparium* (Michx.) Nash], sand bluestem, switchgrass (*Panicum virgatum* L.), and sand dropseed. Hairy grama (*Bouteloua hirsuta* Lag.) and blue grama [*Bouteloua gracilis* (H.B.K.) lag. Ex Steud.] are also present. Common cool-season grasses include needleandthread, prairie junegrass [*Koeleria pyramidata* (Lam.) Beauv.], and Scribner panicum [*Dicanthelium oligosanthes* (Schult.) Gould var. *scribnerianum* (Nash) Gould]. Several species of sedges (*Carex* spp.) and forbs also occur on sands range sites.

During the 10 years before this study, grazing management of the pastures containing the study plots was similar for the 3 cooperating ranches. Pastures were generally grazed once per year with scheduled variation in the season or period of use each year. Stocking rates varied from 35 to 50 AUD ha^{-1} depending on annual growing conditions.

Three paired-plots (0.5 ha) were established at each study site. Paired-plots included adjacent 0.25 ha burned and 0.25 ha control (unburned) areas. To minimize confounding of pre-fire fuel-load and species composition with burn and control treatment response, plot locations were restricted to areas where fire-fighting efforts had suppressed the fire and created the burn line. These locations were burned by a flank fire. Additional selection criteria for paired-plot location included similarity of slope, aspect, and density of little bluestem plants. Fences were constructed to exclude cattle grazing during the subsequent 3 growing seasons.

Fuel load, estimated in September 1995 by clipping 10 quadrats (25 x 100 cm) per plot, was 212 g m^{-2}. Each of the wildfires at the 3 study locations began in the mid to late afternoon as a result of lightning associated with developing thunderstorms. Air temperatures ranged from 26 to 32° C with low relative humidity (22 to 40%). Wind speeds ranged from 20 to 35 km hr^{-1} with higher gusts closer to the thunderstorms. The fires consumed all fuel within the plot areas.

Soil temperatures (15 and 30 cm depth) were obtained at monthly intervals beginning in March 1996 and continued through July 1996. Soil temperature readings were taken at 5 random locations in each burn and control plot using a thermometer fitted with a thermocouple probe.

During 1996, the first post-burn growing season, vegetation sampling was conducted in May, June, July, and August. Additional sampling was conducted in June and August of 1997 and in August of 1998. Sampling occurred within the first or second weeks of these months. Peak standing crop of herbage typically occurs in August on this Sandhills vegetation type (Nosal 1983). Standing crop of herbage was determined at each sampling date by hand-clipping ten, 0.25 m^2 quadrats per treatment plot. All current-year growth of herbage in the quadrat area was clipped to ground level, bagged, and later dried and weighed.

Composition of dominant species and groups of minor species in the current-year herbage was determined in each treatment by using a dry-weight-rank method (Jones and Hargreaves 1979). With this method, the 3 most abundant species in each quadrat (25 x 100 cm) were given a rank of 1, 2, or 3 with 1 indicating the most abundant. If any species accounted for more than 85% of the total, it was given both the ranking 1 and 2. If a quadrat did not contain 3 species, the dominant species received rank 1 and the second species received ranks 2 and 3. Multiplication factors of 70, 21, and 9 were then used to calculate the percent composition from the rankings (Gillen and Smith 1986). A single, trained observer collected all dry-weight-rank data. On each sampling date, 100 randomly located

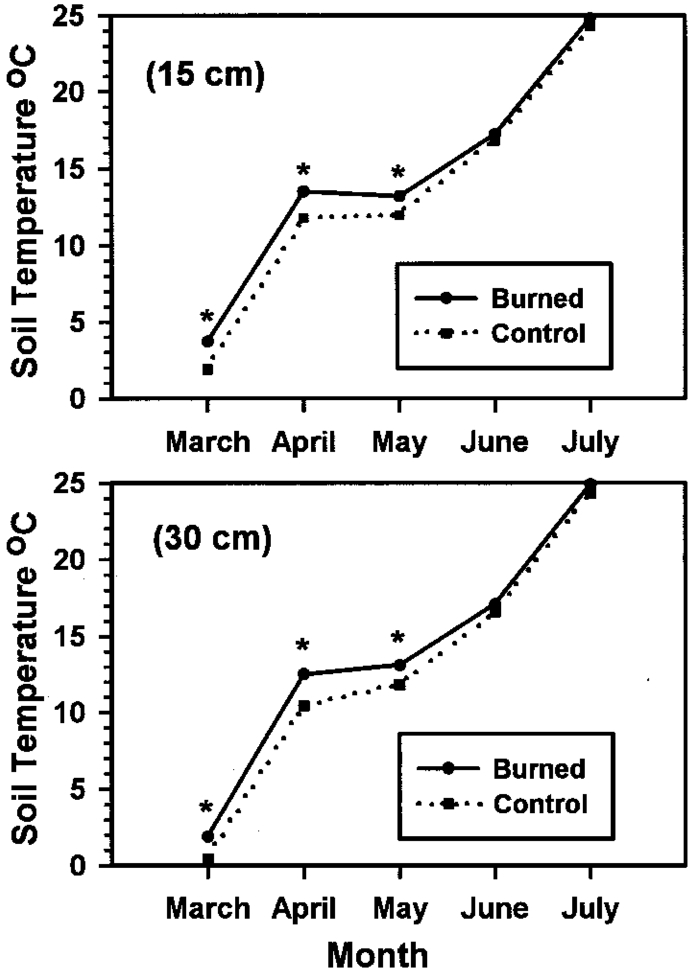

Fig. 1. Spring and early summer soil temperatures during 1996 at 15 and 30 cm depths for the burn treatment (previous fall) and control. * Within months, treatment means differ significantly (P < 0.05).

quadrats were ranked in each of the burn and control plots. Because there was minimal or no warm-season species growth at the time of the May sampling, dry-weight-rankings in May 1996 were based on dominant individual cool-season grass species. Sampling that occurred in June through August ranked dominant warm-season grass species individually and minor warm-season and all cool-season grasses as groups. Forbs and sedges also were ranked as groups.

Analysis of variance procedures (SAS Institute Inc. 1985) were used to evaluate treatment effects on soil temperature, herbage standing crop, and percent composition for each individual species or species group. The 3 cooperating-ranch study sites were considered replications and the 3 burn and control paired-plots at each replication were designated as the experimental units. Soil temperature data were collected only in 1996 and model components for that analysis included treatment and replication. Weight of herbage standing crop components (cool- and warm-season grasses, sedges and forbs) was determined by multiplying percent composition for those components by total herbage weight. Analysis of herbage standing crop and percent composition was conducted by year and sampling month and model components included treatment and replication. All differences discussed are significant at the $P \leq 0.05$ level unless otherwise noted.

Results and Discussion

Soil Temperature

Through the beginning of the 1996 growing season (March through May), soil temperatures under the burn treatment were an average of 1.6°C higher at both 15 and 30 cm depths compared to the control (Fig. 1). By June, however, these differences were no longer significant. The small increase in spring soil temperature apparently had no effect on standing crop production up to the May sampling date (Table 3). Wright and Bailey (1982) reported soil temperatures on several grassland types to average about 5^0 C higher following spring burns. Our observed increase in soil temperature was less, probably because in the 7 months since the burn had occurred, wind and water erosion and leaching had nearly removed all blackened ash from the soil surface.

Species Composition

Species composition sampling conducted in May 1996 (first growing season after the fires) ranked dominant cool-season grass species individually and other herbage components as groups. Needleandthread, prairie junegrass, and sedges were the 3 species having the highest percentage composition (Table 1). Percentage composition of sedges was significantly higher under the burn treatment

Table 1. Percentage composition for species and species groups for the burn treatment and control, May 1996.

Species/species group	Burn	Control
	- - - - - - - - - - - - (%)	- - - - - - - - - - - -
Cool-season grasses		
Prairie junegrass	15	20
Needleandthread	33	34
Scribner panicum	5	7
Western wheatgrass	2	2
Other cool-season grasses	1	1
Total cool-season grasses	56	64
Warm-season grasses	5	8
Sedges	33[a]	20[b]
Forbs	6	8

[ab]Treatment means for each species or group with unlike letters differ significantly (P < 0.05).

Table 2. Percentage composition for species and species groups for the burn treatment and control in August 1996, 1997, and 1998.

Species/species group	1996 Burn	1996 Control	1997 Burn	1997 Control	1998 Burn	1998 Control
	(%)					
Warm-season grasses						
Blue and hairy grama	2	1	2	1	2	3
Little bluestem	8[a]	47[b]	20[a]	51[b]	42	49
Prairie sandreed	19	14	15[a]	8[b]	7	7
Sand bluestem	6	4	8	4	5	4
Switchgrass	8	5	8	7	9	6
Other warm-season grasses	1	1	1	2	2	1
Total warm-season grasses	44[a]	72[b]	54[a]	73[b]	67	70
Cool-season grasses	33[a]	19[b]	32[a]	16[b]	25	23
Sedges	5[a]	1[b]	4[a]	2[b]	3	2
Forbs	18[a]	8[b]	10	9	5	5

[ab]Within years, treatment means for each species or group with unlike letters differ significantly ($P < 0.05$).

(33%) compared to the control (20%). Treatment plots did not differ in composition for any of the other species or groups in May 1996. Bragg (1998) reported that sedge response in the growing season following a September burn was variable depending on the site aspect. However, during the second and third growing seasons following the burn, sedges declined, indicating that they may be adversely affected by burning (Bragg 1998). Wright (1971), in a burning mortality comparison between needleandthread and squirreltail [*Sitanion hytstrix* (Nutt.) J.G. Smith], reported that needleandthread mortality was higher because of a greater density of dead plant material within the bunch. This caused burn temperatures to be higher for a longer period of time. At the time of the fire in our study, spring growth of needleandthread was mature and dry, but some new fall growth (4 to 6 cm) was present. This may have reduced heat within needleandthread bunches.

Percentage composition data of the peak standing crop (August) during the first (1996), second (1997) and third (1998) growing seasons after the fires are shown in Table 2. Percentage composition of several individual species or species groups differed between the burn treatment and control during 1996 and 1997.

The percentage composition of little bluestem was significantly less under the burn treatment compared to the control in 1996 (39 units) and 1997 (31 units), but not in 1998 (Table 2). The percentage composition of blue and hairy grama, prairie sandreed, sand bluestem, and switchgrass did not differ between treatments in August 1996. The percentage composition of prairie sandreed was higher under the burn treatment in 1997 but similar to the control in 1998. Because of less little bluestem, percentage composition for the total warm-season grass group also was less in the burn treatment compared to the control in 1996 and 1997. Our visual observations that were made on little bluestem tussocks indicated that there were relatively few tussocks that were completely killed and had no new tillers emerging. In most cases, the burned tussocks had from 5 to 20 new tillers emerging compared to unburned tussocks that contained from 75 to as many as 140 tillers. Over time, little bluestem produces a dense canopy of dead tillers that also limits availability of current-year's growth to grazing animals. This canopy produces an intense fire around the growing points of a bunchgrass when it burns (Wright 1971). The extent of little bluestem mortality is likely related to fuel load and heat, both of which can vary between tussocks. Anderson et al. (1970) also reported a decrease in little bluestem basal cover with 20 March burning compared to 1 May and hypothesized that with the drier conditions in March, little bluestem was more susceptible to injury. Pfeiffer and Steuter (1994) reported a 90% reduction in bunchgrass standing crop (primarily little bluestem) in the growing season following a late-July burn. On hilltops and sites with a south aspect, Bragg (1998) reported less canopy cover of little bluestem on plots burned the previous September compared to an unburned control. During the second and third growing seasons following the burn, canopy cover of little bluestem increased on hilltop sites but not south aspect sites. Our observed increase of little bluestem in burned plots during 1997 and 1998 appeared to be the result of recruitment of new tillers within the partially thinned tussocks. Although no measurements were made, an increase in individual tiller size also would contribute to the overall increase.

The percentage composition of cool-season grasses and sedges was significantly greater under the burn treatment compared to the control in August 1996 and 1997, but not in 1998 (Table 2). This difference was present for sedges when sampling was conducted in early May 1996, but not for the cool-season grass group (Table 1). On this range type, the majority of cool-season grass growth occurs from May through June. With removal of dormant and dead plant material in the burn treatment, cool-season species would have had full access to sunlight and possibly, less competition for soil water in 1996 and 1997 as a result of the mortality of little bluestem.

The percentage composition of forbs was greater under the burn treatment (18%) compared to the control (7%) during 1996, but no differences were detected in 1997 or 1998 (Table 2). Of the forb species, visual observations indicated that annual sunflower (*Helianthus annuus* L.), plains sunflower (*H. petiolaris* Nutt.), and to a lesser extent, stiff sunflower [*H. rigidus* (Cass.) Desf.] were more abundant under the burn treatment compared to the control. Spotted spurge (*Euphorbia maculata* L.) and Missouri spurge (*E. missurica* Raf.) were 2 other annual species that also

Table 3. Current-year herbage standing crop for the burn treatment and control in the first growing season (1996) following the fall wildfires.

Component	May Burn	May Control	June Burn	June Control	July Burn	July Control	August Burn	August Control
	($g\ m^{-2}$)							
Cool-season grasses	10	13	28	29	51[a]	33[b]	48[a]	27[b]
Warm-season grasses	1	1	9[a]	31[b]	35[a]	82[b]	64[a]	101[b]
Sedges	6	4	12[a]	6[b]	6[a]	1[b]	8[a]	2[b]
Forbs	1	2	6	4	22[a]	9[b]	26[a]	10[b]
Total	18	20	55	70	114	125	146	140

[ab]Within months, treatment means with unlike letters differ significantly ($P < 0.05$).

were observed to be more abundant under the burn treatment. Bragg (1998) reported an average 36% canopy cover of forbs on plots burned the previous September compared to an average 25% canopy cover of forbs in control plots. Stiff sunflower, Missouri spurge, and western fleabane (*Erigeron bellidiastrum* Nutt.) were forb species that Bragg (1998) described as exhibiting a fire-positive response during either first or second growing season following a September burn.

Herbage Standing Crop

During 1996, the first growing season after the burn, there were no significant treatment differences in total current-year herbage standing crop on any of the sampling dates (Table 3). Total standing crop averaged 19, 63, 120, and 143 g m^{-2} in May, June, July, and August, respectively. However, differences were present for 2 of the herbage components in June and for all 4 herbage components in July and August. In June, standing crop of sedges was greater and standing crop of warm-season grasses was less under the burn treatment compared to the control. During July and August, standing crop of cool-season grasses, sedges, and forbs was greater and standing crop of warm-season grasses less under the burn treatment compared to the control. The lower standing crop for the warm-season grass group was primarily attributable to less little bluestem under the burn treatment (Table 2). Pfeiffer and Steuter (1994), also working on sands range sites, found no difference in total August standing crop between burn (previous late July) and control treatments. They observed a decline in the bunchgrass component and an increase of forbs. Morrison et al. (1986) reported 16% greater August standing crop on a burn treatment compared to a control.

Total herbage standing crop during 1997 averaged 92 g m^{-2} in June and 142 g m^{-2} in August with no significant difference between the burn treatment and control (Table 4). Similar to 1996, there were standing crop differences for the herbage components with greater yield of cool-season grasses and sedges and less yield of warm-season grasses under the burn treatment compared to the control. Forb standing crop was greater under the burn treatment during June but similar between treatments during August.

Total herbage standing crop averaged 185 g m^{-2} in August 1998 with no difference between treatments (Table 4). There also were no treatment differences for any of the herbage components. The warm-season grass component of the August standing crop under the burn treatment increased each year with 64, 78, and 123 g m^{-2} being present in 1996, 1997, and 1998, respectively. This increase is attributable to the recovery and increase in percent composition of little bluestem (Table 2).

Management Implications

A late growing-season burn did not reduce August standing crop of total herbage the following growing season on sands range sites. Cool-season grasses, sedges, and forbs increased with fire to offset a decline in little bluestem. Little bluestem exhibited a marked recovery during the second and third growing seasons after the burn. The positive response of forbs to burning was generally evident for only the first growing season following the burn.

A primary question posed by Sandhills ranchers and land managers is to what extent their grazing management should change following wildfires that occur in the late growing-season or when vegetation is completely dormant. Because of the loss of residual plant cover and litter, wind and water erosion are possible. Grazing management that includes reductions in stocking rate along with a delay in the start of grazing should enhance the accumulation of residual plant material and litter formation. Although our study found no reduction in standing crop on sand range sites, productivity of choppy sands range sites following a burn is reduced (Bragg 1978, 1998). Thus, because most Sandhills pastures contain a mosaic of sandy, sands, and choppy sands range sites, it is likely that the overall livestock carrying capacity of a pasture will be reduced. Additionally, increases in unpalatable forbs would likely increase grazing pressure on more desirable species.

Burning may also result in changes in grazing behavior that could complicate grazing management decisions. Patterns of grazing distribution, for example, may be different in burned than in unburned areas. Preference and relative palatability of individual plant species and corresponding degree of plant use also may change following a burn. Pfeiffer and Steuter (1994), for example, reported heavy use and further reduction of little bluestem when bison grazed the growing season following a burn.

Further studies are needed to completely address the effects of burning on the vegetation, soil, and animal components of Sandhills rangeland. Specifically, the evaluation of burning and grazing interaction effects is an area of study where additional information is needed.

Table 4. Current-year herbage standing crop for the burn treatment and control in the second (1997) and third (1998) growing season following the fall wildfires.

	June[1]		August	
Component	Burn	Control	Burn	Control
	(g m^{-2})			
1997				
Cool-season grasses	52[a]	33[b]	48[a]	23[b]
Warm-season grasses	21[a]	45[b]	78[a]	101[b]
Sedges	6[a]	2[b]	5[a]	3[b]
Forbs	17[a]	8[b]	15	12
Total	96	88	146	139
1998				
Cool-season grasses	—	—	46	42
Warm-season grasses	—	—	123	133
Sedges	—	—	5	4
Forbs	—	—	9	9
Total	—	—	183	188

[1] Sampling did not occur in June 1998.
[a b] Within months, treatment means with unlike letters differ significantly ($P < 0.05$).

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Cattle prefer endophyte-free robust needlegrass

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Abstract

Robust needlegrass (*Achnatherum robustum* [Vasey] Barkw. = *Stipa robusta* [Vasey] Scribn.) is a high-biomass rangeland species that is adapted to warmer temperatures and matures later than most cool-season grasses. However, it has been associated with negative animal effects including avoidance. We compared populations of *Neotyphodium* and *P*-endophyte-infected endophyte-infected (E+) and endophyte-free (E-) robust needlegrass for animal preference. Leaf blades were fed to yearling heifers in 3 trials of 8-min cafeteria sessions for 4 to 5 days each. Trial 1 (27–30 May) compared E+, E-, basin wildrye (*Leymus cinereus* [Scribn. & Merr.] A. Löve), and tall wheatgrass (*Thinopyrum ponticum* [Podp.] Barkw. & D.R. Dewey). Basin wildrye consumption (425 g) did not differ from tall wheatgrass (342 g), but basin wildrye consumption exceeded E- (258 g), which in turn exceeded E+ (117 g) (16 animal-sessions). Basin wildrye was dropped from Trial 2 because its consumption exceeded that of both E- and E+. In Trial 2 (1–5 June), consumption of E-, E+, and tall wheatgrass did not differ. Tall wheatgrass was dropped from Trial 3 to allow direct comparison of E- and E+. In Trial 3 (13–17 July), consumption of E- (585 g) exceeded E+ (145 g) (15 animal-sessions). In Trial 3, animals often rejected E+ forage before tasting. Discrimination against E+ was greater at the end of Trial 3 than at the beginning. The reputation of robust needlegrass for animal avoidance may be more related to its endophyte infection status than to the grass itself. Differences in forage-quality parameters were not large enough to account for the observed differences in preference. Ergot and loline alkaloids were not found in either E- or E+, therefore they cannot be responsible for the observed avoidance of E+. Non-trace amounts of ergot alkaloids were found only in seed collected in the Sacramento Mountains of New Mexico and not at other locations in New Mexico, Arizona, or Colorado.

Key Words: *Achnatherum robustum, Acremonium,* ergonovine, lysergic acid amide, narcosis, *Neotyphodium,* sleepygrass, *Stipa robusta*

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Resumen

"Robust needlegrass"(*Achnatherum robustum* [Vasey] Barkw. = *Stipa robusta* [Vasey] Scribn.) es una especie de pastizal de alta producción de biomasa adaptada a temperaturas calientes y que madura mas tarde que la mayoría de los zacates de época fría. Sin embargo, esta especie se ha asociado con efectos negativos del animal incluyendo el rechazo. Comparamos la preferencia animal en poblaciones de "Robust needlegrass" libres de endófitos (E-) e infectadas con endófitos (*Neotyphodium* y *Phialophora*) (E+). Vaquillas de año se alimentaron con láminas de la hoja del zacate en tres experimentos tipo cafetería de 8 minutos de duración durante un período de 4 a 5 días cada ensayo. En el ensayo 1 (27 al 30 de Mayo) comparamos E+, E-, "basin wildrye" (*Leymus cinerus* [Scribn. & Merr.] A. L`ve) y "Tall wheatgrass" (*Thinopyrum ponticum* [Podp.] Barkw. & D.R. Dewey). El consumo de "Basin wildrye" (425 g) no difirió del de "Tall wheatgrass" (342 g), pero el consumo de "Basin wildrye" superó al de E- (258 g) el cual a su vez fue mayor que el de E+ (117 g) (16 sesiones-animal). El "Basin wildrye" se elimino del ensayo 2 porque su consumo superó el de E- y E+. En el ensayo 2 (1–5 de Junio), el consumo de E-, E+ y "Tall wheatgrass" no difirió. "Tall wheatgrass" se elimino en el ensayo 3 para permitir una comparación directa del consumo de E- y E+. En el experimento 3 (13-17 Julio), el consumo de E- (585 g) fue mayor que el de E+ (145 g) (15 sesiones-animal). En el ensayo 3, los animales a menudo rechazaron el forraje de E+ antes de probarlo. La discriminación contra E+ fue mayor al final del ensayo 3 que al principio. La reputación del "Robust needlegrass" de ser evitado por el ganado puede estar mas relacionado a su estado de infección endófita que al zacate por si mismo. Las diferencias en los parámetros de calidad de forraje no fueron lo suficientemente grandes para atribuirles la diferencias de preferencia observadas durante los experimentos. Los alcaloides Ergot y Leolina no se encontraron ni en E- ni en E+, por lo tanto ellos no pueden ser responsables del rechazo observado hacia el E+. Solo en la semilla colectada en Sacramento se encontraron cantidades no traza del alcaloides Ergot.

Robust needlegrass (*Achnatherum robustum* [Vasey] Barkw.) has long been known to deleteriously affect horses by inducing a narcosis characterized by deep sleep (Bailey 1903). Although this grass is notorious for its narcotic properties, this effect appears to be occasional. Narcosis has only been reported in Lincoln and Otero counties (Sacramento Mountains) in southern New Mexico and not in other parts of the state (Wooton and Standley 1912). Neither has narcosis of horses been reported in Arizona, Colorado, Montana, or Wyoming, all states where the grass is found.

When fed robust needlegrass from Otero County, sheep exhibited elevated body temperature, depression, weakness in the legs, and mucous intestinal discharge, but not narcosis (Marsh and Clawson 1929). No symptoms were detected in cattle in this study, but later workers reported cattle grazing in Otero County assumed a recumbent position, urinated frequently, and slobbered excessively (Smalley and Crookshank 1976). Grass from 3 northern New Mexico locations did not induce symptoms in horses, sheep, or cattle.

Cattle familiar with robust needlegrass sites have been reported as avoiding this grass assiduously (Bailey 1903), though this may not be true on all sites. This avoidance is the primary economic impact, not infrequent narcosis.

White (1987) was first to report the *Neotyphodium* endophyte, formerly *Acremonium* (Glenn et al. 1996), in robust needlegrass. Lysergic acid amide was the dominant alkaloid in *Neotyphodium*-infected robust needlegrass forage collected in Otero County (Petroski et al. 1992). Other alkaloids detected were isolysergic acid amide, 8-hydroxylysergic acid amide, ergonovine, chanoclavine-1, and N-formylloline. We suspect that the endophyte or its associated alkaloids may be responsible for avoidance of robust needlegrass, based on findings with other grasses (Garner and Cornell 1987, Fribourg et al. 1991, Miles et al. 1996).

Kaiser et al. (1996) isolated *Neotyphodium* from robust needlegrass seed collected from 10 New Mexico and Colorado populations. Fungal isolates were notable for their diversity of spore morphology. Serological diversity, as determined by western blot analysis, was greater than expected for a single host species. Diversity was more similar to that seen among endophytes from a wide variety of hosts. The observation of diversity within the A. *robustum* endophyte, the general presence of the endophyte throughout the host's range (Kaiser et al. 1996), and the restriction of somnolence symptomology to Lincoln and Otero counties (Wooten and Standley 1912) imply that most endophyte strains are not associated with narcosis.

Our objective was to determine if cattle preferred robust needlegrass accession T-953 (Cokedale, Colo.) relative to T-961 (Center, Colo.). We previously determined that T-953 is naturally endophyte-free (E-) while T-961 is endophyte-infected (E+). We also wished to determine if ergot or loline alkaloids were associated with avoidance of E+ robust needlegrass and how widespread ergot alkaloids were in accessions collected in Arizona, Colorado, and New Mexico.

Materials and Methods

E- (T-953) and E+ (T-961) robust needlegrasses were harvested from seed fields near Richmond, Utah. The T-953 accession was originally collected in a floodplain near the confluence of Burro Creek and the Purgatoire River near Cokedale, Colo. (Las Animas Co.). Associated native species were rabbitbrush (*Chrysothamnus* sp.), juniper (*Juniperus* sp.), snakeweed (*Gutierrezia sarothrae* [Pursh] Britt. & Rusby), Indian ricegrass (*Achnatherum hymenoides* [Roem. & Schult.] Barkw.), and western wheatgrass (*Pascopyrum smithii* [Rydb.] A. Löve). The T-961 accession was originally collected near Center, Colo. (Saguache Co.). Associated native species were inland saltgrass (*Distichlis stricta* [Torr.] Rydb.), sand dropseed (*Sporobolus cryptandrus* [Torr.] A. Gray), Indian ricegrass, and slender wheatgrass (*Elymus trachycaulus* [Link] Gould ex Shinners). Tall wheatgrass was harvested from wild stands in Benson, Utah. Basin wildrye originating from eastern Washington and northeastern Oregon was harvested from research plots at Evans Farm near Millville, Utah. To condition the test animals, freshly harvested leaf blades were fed for 4 days before the beginning of Trial 1 (27–30 May, 1998). Trial 2 (1–3 and 5 June, 1998) followed the week after Trial 1. Feeding freshly harvested leaf blades was repeated for 2 days prior to the beginning of Trial 3 (13–17 July, 1998), 6 weeks after the beginning of Trial 2.

In Trial 1, 600 g of freshly cut leaf blades of basin wildrye, tall wheatgrass, E-, and E+ were weighed and offered to each of 4 red angus heifers about age 2 in 4 adjacent feeding stations. Forages were rotated among feeding stations daily. Feeding trials were conducted for 4 days. Two heifers evaluated the forages simultaneously in adjacent pens for 8 min. Time spent by each animal consuming each forage was recorded. Orts were weighed and consumption was determined by subtraction. Then the 2 remaining heifers were offered the forages. Heifers were fed a daily ration of alfalfa hay *ad lib*. immediately following each late morning trial and then fasted overnight until the succeeding trial the following morning.

Forages were offered for 4 days in Trial 2 similarly to Trial 1 except basin wildrye was not included. Forages offered for Trial 3 did not include basin wildrye or tall wheatgrass; only E+ and E- robust needlegrasses were offered. In Trial 3, 500 g of each forage was offered at each of 2 feeding stations for 5 days. One animal used in Trials 1 and 2 refused to eat in Trial 3; thus data could only be obtained from 3 animals.

Data for each trial were analyzed as a split-plot design with animals as replicates (random effect), days as whole-plots (fixed effect), and forages as split-plots (fixed effect). The day effect was tested with the animal X day interaction term. The forage and day X forage effects were tested with error b (animal X forage and animal X day X forage interaction terms combined) when these terms were homogeneous (Trial 1). When these 2 interaction terms were nonhomogeneous (Trials 2 and 3), the forage effect was tested by the animal X forage interaction term and the day X forage interaction was tested by the animal X day X forage interaction term. In Trial 3 the day effect was partitioned into linear and residual components. The day (linear) X forage and residual (lack-of-fit) X forage effects were tested with the animal X day X forage term to assess changes in preference over the course of the trial. Forage means in Trials 1 and 2 were separated with the Waller-Duncan k-ratio t test at k-ratio=100.

E- and E+ robust needlegrasses were checked for presence of the *Neotyphodium* and *P*-endophytes in 27 plants each (Siegel et al. 1995). Flowering stems were removed and split lengthwise with a razor blade. Pith tissue was removed from the center of the stem, placed on a microscope slide, and stained with aniline blue lactic acid (Bacon et al. 1977). Individual stems were scored for presence or absence of each of the 2 endophytes (Figs. 1, 2).

Samples of each forage were taken at time of feeding and dried at 60°C to determine dry-matter (Trials 1, 2, and 3), acid-detergent fiber, soluble sugars, total nonstructural carbohydrates (TNC), ergot alkaloid (ergonovine and lysergic acid amide), and loline alkaloid (loline, *N*-methylloline, *N*-acetylloline, and *N*-formylloline) concentrations (Trial 3). Trial 3 samples were ground through a 1-mm screen following drying. Acid-detergent fiber was determined according to Goering and Van Soest (1970). Crude protein was calculated as Kjeldahl N X 6.25. Each acid-detergent fiber and crude protein sample was evaluated in duplicate. For soluble sugars, about 20 mg of tissue was extracted for 15 min at 85 to 90°C in

Fig. 1. The *Neotyphodium* endophyte among pith parenchyma cells in tissue teased from a stem of T-961 robust needlegrass (320X).

3 changes of 2 ml deionized water each. Sugar determination was with the anthrone color reaction method adapted from Pollock (1982). Assays were performed in test tubes at 85°C for 1 hour. At this temperature, both furanoses, e.g., fructose, and pyranoses, e.g., glucose, react. Aliquots of the finished reaction were transferred to a microplate and read at 620 nm. For TNC determination, an additional 20 mg of tissue was heated with 2 ml deionized water for 15 min. After cooling, 4 ml of 0.2% Clarase[1] (amylase) was added to each sample and enzymatic digestion was allowed to proceed for 24 hours to digest starch. Anthrone assay was then performed as on the water extract for soluble sugar determination. Soluble sugar and TNC determinations were not duplicated. Dry-matter, acid-detergent fiber, crude protein, soluble sugars, and TNC concentrations of grasses were compared using a randomized complete block design with days as replications (random effect). Means in Trials 1 and 2 were separated with the Waller-Duncan k-ratio t test at k-ratio = 100.

Samples for ergot alkaloid analysis were prepared by adding 4 ml alkaline methanol and 1 ml internal standard (20 µg ergotamine tartrate in 1.0 ml methanol) to 100 mg ground plant tissue. The samples were rotated overnight and filtered. The filtrate was dried at 60°C over a stream of N_2 and reconstituted with 1 ml methanol. Reversed-phase high-performance liquid chromatography was performed using an HP[1] 1090 HPLC equipped with a Beckman[1] C18 silica (ultrasphere) column (4.6 x 250 mm) and HP[1] 1040 fluorescence detector. Fluorescence emission was measured at 420 nm with excitation at 310 nm. Chromatographic conditions were as follows: mobile phase; (A) water + 0.1% ammonium acetate, and (B) acetonitrile. Flow rate was 1 ml min^{-1} in a linear gradient from 10% B to 40% B, 0-15 min; 40% B to 100% B, 15–25 min. For loline alkaloid detection, a 100 mg aliquot of the dry ground plant material was extracted with a mixture of 4 ml $CHCl_3$ and 4 ml 1% H_2SO_4 for 1 hour. The sample was centrifuged to aid layer separation and the aqueous portion was removed and saved. The sample was extracted a second time with 2 ml of 1% H_2SO_4 for 5 min and centrifuged. The acidic aqueous portion was removed and combined with the first acid extract. The acid solution was made basic (pH = 9) by the addition of concentrated NH_4OH and the sample extracted twice with $CHCl_3$ (4 ml, 2 ml). The $CHCl_3$ extracts were combined and filtered through anhydrous Na_2SO_4 and concentrated to 1 ml.

Loline alkaloids were analzyed by gas chromatography/mass spectrometry using

Fig. 2. The *P*-endophyte in T-961 robust needlegrass (80X). Branching hyphae distinguish the *P*-endophyte from *Neotyphodium* (upper right).

[1]Mention of a proprietary product does not constitute a guarantee or warranty by USDA or the Utah Agric. Exp. Stn. and does not imply its approval to the exclusion of other products that may also be suitable.

a Finnigan[1] GCQ. The GC conditions were as follows: column was a DB-5ms (30 m x 0.25 mm i.d., J&W Scientific[1]); injector temperature = 225°C; oven temperature = initial 80°C for 1.0 min, 80–250 @ 10°C/min, final 250°C for 5 min. The heated transfer line was 275°C and the ion source was 150°C. Electron impact (70eV) spectra were recorded for the mass range 60–400 m/z at a scan rate rate of 0.5 sec/scan. Positive loline detection was confirmed by the analysis of a standard sample of 'Kentucky 31' tall fescue seed.

Table 2. Dry-matter concentrations of basin wildrye, tall wheatgrass, and T-953 (E-) and T-961 (E+) robust needlegrass leaf blades fed to cattle in 3 trials.

Forage	Trial 1	Trial 2	Trial 3
		Dry matter	
	------------------------------ ($g\ kg^{-1}$ fresh weight) --------------------------		
basin wildrye	290a[1]	—	—
tall wheatgrass	271a	284a	—
E– robust needlegrass	405b	410b	461
E+ robust needlegrass	389b	394b	435**
SE $\overline{x}$	7	6	2

[1]Means followed by different letters within a column are different according to the Waller-Duncan k-ratio t test (k-ratio = 100).
**Significantly different (P < 0.01).

Results and Discussion

E- and E+ robust needlegrass populations were collected as seed in 1993 and established as transplants near Richmond, Utah in April 1996, after an initial seed increase. Cytological examination for the endophytes in the fields near Richmond revealed a small amount of infection with the *Neotyphodium* endophyte in 1 stem of E-, while the 26 remaining stems were *Neotyphodium*-free. No *P*-endophyte mycelium was found in E-. In contrast, the *Neotyphodium* endophyte was found in 26 of 27 stems of E+, with 25 of the 26 also infected with the *P*-endophyte. No infection of either endophyte was found in 1 stem. The *P*-endophyte mycelium was considerably less concentrated in the pith tissue than the *Neotyphodium* endophyte in E+. This is the first report of the *P*-endophyte in robust needlegrass.

In Trial 1, consumption and time spent feeding were greater for basin wildrye than either robust needlegrass (Table 1). Cattle use of tall wheatgrass was similar to E- for these variables but greater than E+. Consumption and time spent feeding of E- was about twice that of E+. To provide a more succinct comparison of the robust needlegrasses and tall wheatgrass, basin wildrye was not included in Trial 2 the following week. Basin wildrye was deleted from Trial 2 because it differed from E- for both consumption and time spent feeding, while tall wheatgrass and E+ did not. However, no differences (P>0.10) among grasses were found for either variable in Trial 2.

Trial 3 was conducted to directly compare E- and E+. Ranchers we interviewed reported that animals accept robust needlegrass early in the growing season but reject it as it matures. Therefore, we delayed Trial 3 for 6 weeks to augment any differences that might be present. Consumption and time spent feeding E- were 4 times greater than E+, a difference (P < 0.10) much greater than in Trials 1 or 2. Total or near-total rejection of E+ was exhibited by animal 32 on the first day of Trial 3 and animals 18 and 32 on the third, fourth, and fifth days of Trial 3. In Trial 3, feeding pans containing E+ were often passed over without tasting.

The day X forage effect was not significant (P > 0.10) for consumption or time spent feeding in Trials 1 and 2. This indicates animals did not demonstrate changes in discrimination among the forages over the 4-day feeding periods. However, this interaction was significant (P < 0.05) in Trial 3 for both variables. A significant day (linear) X forage effect (P < 0.05) showed that the cows increasingly discriminated in favor of E- over E+ over the course of the 5-day trial. The residual (lack-of-fit) X forage effect was not significant for either variable (P > 0.10).

Differences in dry-matter concentration among forages (Table 2) did not explain preference differences. Animals did not appear to be primarily selecting forages based on succulence. Dry-matter concentrations of basin wildrye and tall wheatgrass were similar in Trial 1, but both these forages were about 117 $g\ kg^{-1}$ lower in dry-matter concentration than the robust needlegrasses, which were similar to each other. At the same time, consumption of tall wheatgrass was similar to E-, but E- consumption was greater than E+. Dry-matter concentration in Trial 2 was similar to that of Trial 1 the preceding week. In Trial 3, dry-matter concentration was 41-51 $g\ kg^{-1}$ greater than Trial 2, 6 weeks before. The preferred forage, E-, was higher in dry-matter concentration than E+.

We found no difference (P > 0.10) in leaf blade acid-detergent fiber between E- (343 $g\ kg^{-1}$) and E+ (344 $g\ kg^{-1}$) robust needlegrasses or among the 5 days of Trial 3. We found a small difference (P<0.10) in crude protein between E- (143 $g\ kg^{-1}$) and E+ (133 $g\ kg^{-1}$) robust needlegrasses, but no difference among the 5 days of Trial 3. We found a small difference (P < 0.05) in soluble sugars between E- (45 g

Table 1. Consumption and time (s = seconds) spent feeding by cattle of leaf blades of basin wildrye, tall wheatgrass, and T-953 (E-) and T-961 (E+) robust needlegrasses in 3 trials.

Forage	Consumption	Time
	----------- ($g\ day^{-1}$) -----------	----------- (s) -----------
Trial 1		
basin wildrye	425 a[1]	187 a
tall wheatgrass	342 ab	121 b
E- robust needlegrass	258 b	99 bc
E+ robust needlegrass	117 c	47 c
SE $\overline{x}$	48	21
Trial 2		
tall wheatgrass	384	148
E- robust needlegrass	400	175
E+ robust needlegrass	272 NS	135 NS
SE $\overline{x}$	70	31
Trial 3		
E- robust needlegrass	585	366
E+ robust needlegrass	145†	91†
SE $\overline{x}$	103	57

[1]Means followed by different letters within a column and trial are different according to the Waller-Duncan k-ratio t test (k-ratio=100).
† Significantly different (P<0.10).

kg^{-1}) and E+ (43 g kg^{-1}), with a 7 g kg^{-1} difference between the highest (day 1) and lowest (day 2) days of Trial 3. Concentrations of TNC were slightly different ($P < 0.10$) between E- (45 g/kg) and E+ (42 g kg^{-1}) with no differences among the 5 days of Trial 3. The similarity of soluble sugars and TNC indicates that starch concentration was negligible.

The 4-fold preference of E- in Trial 3 could not be attributed to any measure of forage quality. Ergonovine and lysergic acid amide were not detected in E- or E+ robust needlegrasses in Trial 3. Therefore, the ergot alkaloids are not primarily responsible for avoidance of E+, as has been proposed for narcosis (Petroski et al. 1992). Neither were loline alkaloids found in E- or E+ robust needlegrasses. Some other chemical constituent or physical property associated with the endophytes must be responsible for differences in preference.

Although narcotic potential beyond the Sacramento Mountain area is probable, it is likely infrequent. Of 54 accessions of seed collected during 1995 in Colorado, New Mexico, and Arizona, we found measurable quantities of ergonovine and lysergic acid present at only 6 sites, all in Otero County, N.M. Trace levels were found in 1 collection from Apache Co., Ariz. between Springerville, Ariz. and Luna, N.M. Because lysergic acid amide has a sedative effect and is the dominant alkaloid in whole-plant samples, Petroski et al. (1992) suggested that it is the causative agent for narcosis. Our biogeographical data lend support to their hypothesis.

The *Neotyphodium* endophyte in tall fescue has also been associated with avoidance in cattle. Steers preferred clover in mixed E+ tall fescue (*Festuca arundinacea* Schreb.)/white clover (*Trifolium repens* L.) pastures, but they preferred E- tall fescue in mixed E- tall fescue/white clover pastures (Fribourg et al. 1991). Eleven of 12 heifers avoided diets with 60% E+ tall fescue seed in favor of diets with 60% E- tall fescue seed (Garner and Cornell 1987).

Management Implications

Based on our results, E- robust needlegrass may provide desirable forage, particularly in areas in the transition zone between cool- and warm-season grasslands. The grass produces abundant forage later in the growing season than other cool-season grasses. Because of its very late maturity, robust needlegrass leaf-to-stem ratio remains high during June, July, and early August. Thus, robust needlegrass may provide palatable forage at the time of year when other cool-season grasses are heading and senescing. Robust needlegrass produces coarse stems with few leaves once it begins to head, but grazing may delay the appearance of heads. We have observed rapid leaf regrowth from cut tillers in the field.

Concomitantly, E+ robust needlegrass may provide a deterrent to grazing where it is not desired, e.g., in riparian areas and along roadsides. Height may limit the use of this grass along roadsides. We are currently evaluating accessions for shortness and late heading for such an application. Robust needlegrass may be particularly effective in deterring roadkill of deer because of its late green-up in spring. Early spring is the only time of year when deer utilize significant amounts of grass. If green grass is not present at this time of year along roadsides, vehicular collisions with deer could be reduced.

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Rearing conditions for lambs may increase tansy ragwort grazing

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Abstract

Grazing by sheep is an accepted method of controlling tansy ragwort (*Senecio jacobaea* L.), but some flock members seldom eat it. Our objectives were to determine if pre-weaning exposure to tansy ragwort increases later consumption of the plant by lambs, and if confinement with ragwort-eating ewes after weaning facilitates ragwort eating. The sampling periods were Weeks 1, 3, and 12 following weaning. During each period grazing behavior was observed for 1-hour each day and the 24-hour reduction in ragwort volume measured on each of 4 or 5 consecutive days. Lambs exposed to ragwort before weaning removed more ragwort than ragwort-naïve lambs during the first 2 sampling periods (P < 0.05). Lambs that grazed with ewes for 11 weeks following weaning ate ragwort more frequently during direct observation, than lambs without ewes during Weeks 3 and 12 (P < 0.05). The ragwort-eating of all lamb groups increased markedly between Weeks 1 and 12 (P < 0.05). This may indicate an increased ability of lambs to consume ragwort with increasing age or an acclimation period during which most lambs come to accept ragwort. Behavioral interventions aimed at increasing the consumption of weeds by lambs may need to take into account age-related differences in toxin tolerances. Exposing lambs to ragwort before weaning and grazing newly-weaned lambs with older ragwort-eating sheep after weaning may increase later ragwort-eating by lambs.

Key Words: *Senecio jacobaea*, training, social facilitation

Resumen

El apacentamiento con ovinos es un método aceptado para controlar el "Tansy ragwort" (*Senecio jacobea* L.), sin embargo, algunos miembros del rebaño raramente lo consumen. Nuestros objetivos fueron determinar si el exponer los corderos en la etapa de pre-destete al "Tansy ragwort" incrementa el consumo posterior de esta planta por parte de los corderos, y determinar si el confinamiento de los corderos con borregas que comen "Tansy ragwort" facilita el consumo de "Tansy ragwort" por los corderos. Los periodos de muestreo fueron 1, 3, y 12 semanas después del destete. En cada periodo de muestro se observo durante 1 hora el comportamiento de apacentamiento y cada 24 horas durante 4 o 5 días se midió la reducción de volumen del "Tansy ragwort". En los primeros dos periodos de muestreo, los corderos expuestos al "Tansy ragwort" antes del destete consumieron mas "Tansy ragwort" que los corderos no expuestos (P < 0.05). En el tiempo de observación directa de los periodos de muestreo de 1 y 12 semanas, los corderos que apacentaron con borregas durante 11 semanas después del destete comieron ‘Tansy ragwort" mas frecuentemente que los corderos sin borregas. (P < 0.05). El consumo de "Tansy ragwort" de todos los grupos de corderos se incremento marcadamente durante las semanas 3 y 12 (P < 0.05). Esto puede indicar un aumento en la capacidad de los corderos para consumir "Tansy ragwort" al aumentar la edad o un periodo de aclimatación durante el cual la mayoría de los corderos vienen a aceptar el "Tansy ragwort". Las modificaciones de comportamiento encaminadas a incrementar el consumo de malezas por corderos puede necesitar tomar en cuenta las diferencias en tolerancia a las toxinas relacionadas con la edad del animal. El exponer los corderos al "Tansy ragwort" antes del destete y el que los corderos recién destetados apacienten con ovinos más viejos que consumen "Tansy ragwort" puede incrementar el consumo posterior de "Tansy ragwort" por los corderos.

Tansy ragwort (*Senecio jacobaea* L.) is a biennial, broadleaf weed of cattle pastures found in Europe, North Western areas of the United States, New Zealand, and elsewhere (Wardle 1987). Cattle and horses tend to avoid grazing ragwort which contains pyrrolizidine alkaloids that are highly toxic to them (Cheeke 1994). Despite this natural avoidance, accidental or forced ingestion can occur, and stock losses often result (Sharrow and Mosher 1982).

Grazing by sheep is an effective ragwort-control method (Poole and Cairns 1940, Sharrow and Mosher 1982, Amor et al. 1983, Betteridge et al. 1994). Unlike cattle, sheep can tolerate, and often readily include, large amounts (up to 50%) of ragwort in their diet (Cheeke 1994).

In New Zealand, a trend towards all-cattle farming has seen the subsequent removal of sheep from previously integrated sheep and cattle systems. This has resulted in dense stands of ragwort in areas where previously it was not a problem. Re-introducing a minimum number of sheep to control ragwort infestations could be a suitable compromise. However, quantifying the minimum number of sheep relies on all individuals having similar ragwort-

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eating behavior. In practice this appears not to be the case and a small percentage of sheep may avoid eating ragwort altogether (Betteridge et al. 1994).

The grazing experiences of lambs during weaning influence their food preferences as adult sheep (Ramos and Tennessen 1992). Grazing with mothers (Nolte et al. 1990), older sheep (Chapple and Lynch 1986), or conspecifics (Scott et al. 1996), can also modify food preferences of lambs. The objectives of the present study were to examine the effect of pre-weaning ragwort exposure on the subsequent grazing of ragwort by lambs; to see if the presence of older, ragwort-eating ewes would enhance acceptance of ragwort by weaned lambs; and to assess the usefulness of any induced behavioral differences in improving ragwort biological control by sheep.

Materials and Methods

Study Area

The experiment lasted 3 months on hill country farmland at the AgResearch *Ballantrae* Research Station (36°S) near Palmerston North, New Zealand. Pastures, on slopes ranging between 20% and 60%, comprised of *Agrostis capillaris* L., *Holcus lanatus* L., *Lolium perenne* L. and *Anthoxanthum odoratum* L. as the major grasses and *Trifolium repens* L. as the dominant legume. Tansy ragwort, *Cirsium vulgare* (Savi) Tenore and C. *arvense* (L.) Scop.were common weeds. The Aquic Eutrocepts soils were of sedimentary origin and had a low phosphorus status. Stocking rate at this fertility level is typically 10 adult sheep stock units/ha/year. Annual rainfall is 1,200 mm yr^{-1}.

Formation of treatment groups

Sixty pregnant Romney ewes with a history of grazing on ragwort infested pastures were obtained from *Ballantrae*. Thirty ewes were randomly selected and transported to Flock House, a ragwort-free farm, in mid-August (early spring) 1995. The remaining 30 ewes continued to graze on ragwort-present pasture at *Ballantrae*. Lambing began in early September and lambs were reared with their mothers on their respective background pasture types.

On 14 November 1995 the ewes and lambs on ragwort-free pasture were returned to *Ballantrae* and retained on pasture cleared of ragwort. After 24-hours the lambs from both background pasture types were weaned. Each group of lambs was split into 2 groups using a weight-restricted randomization. Experimental groups comprised only the 15 heaviest lambs from each of the 4 randomized groups. During the experiment, 1 group of lambs from each of the 2 pasture backgrounds was confined with 6 ewes from the opposite pasture background. Thus, 15 lambs from ragwort-present pasture were confined with ewes that had not grazed ragwort-present pasture from lambing, and 15 lambs from ragwort-free pasture were confined with ewes that had recently grazed ragwort infested pasture. The ewes in both lamb + ewe groups were selected because they each displayed a similarly high propensity for eating ragwort when cut plants were offered to each ewe flock in sheep-yards. The 2 remaining lamb groups grazed without ewes.

All lambs were individually identified with numbered ear-tags, color-coded for each of the 4 groups. In addition to ear-tags, all lambs were spray-painted with a number (1–15) on each shoulder, side, and rump, with a group-specific color-code. The 12 ewes were similarly marked.

The weaned lambs born on ragwort-free pasture were retained on ragwort-free pasture at *Ballantrae* for 2 weeks before post-weaning observations on ragwort-present pasture began on 27 November 1995.

Experiment Design

Four, 10-m wide pasture lanes were created with electric sheep netting in a paddock infested with ragwort. Care was taken to ensure that ragwort content and plant size distribution, both between and within lanes, was similar. Each of the 4 sheep groups were randomly assigned a fresh lane of pasture during each observation week. The lanes used during Weeks 3 and 12 were set up in a separate area of the farm to that used in Week 1 to ensure fresh ragwort was available on each observation day. Each lane was divided into daily grazing areas sufficient for 24-hour feeding to provide moderate animal growth, but less than *ad libitum* feeding. Lambs with ewes present were given larger areas (~130-m^2 day^{-1}) than lambs grazed alone (~100-m^2 day^{-1}). Sheep were introduced into a new pasture area immediately prior to observational recording each day. Lamb weaning weight was 20-kg and this increased to 29.7-kg at the conclusion of Week 12.

Plant measurements and animal observations were made during 3 separate observation periods; Week 1 (first exposure of ragwort-naïve lambs to ragwort), Week 3, and Week 12. Five consecutive days of observation were made during Week 1, and 4 consecutive days during Weeks 3 and 12.

The ewes grazed with their respective treatment groups for 11 weeks but were removed from their respective lamb groups immediately prior to the first observation day of Week 12. All 4 groups were grazed separately from Week 1 through Week 12, both during and between observation periods on pastures containing ragwort.

Animal Measurements

Each of the 4 groups was observed for 1-hour on each observation day. Because of a limited number of observers (n = 5), only 2 groups could be observed at the same time. For each observation day the order for observing the groups was randomized to allow for possible time-of-day effects.

At 0900 hours (or 1030) 2 observers collectively scan-sampled (Altmann 1974) 1 group of lambs at 2-min intervals. One observer made the observations while the other recorded them. This provided 30 scan-samples of the group for each observation day. During a scan each lamb was categorized as (1) eating ragwort, (2) eating a plant other than ragwort, or (3) not eating. A third observer recorded the same activities for the ewes (if present).

The percentage of total grazing scans in which ragwort was consumed was used as the dependent variable for analysis. As there was no significant day-within-week effect, the percentages of total grazing scans on ragwort were averaged over the 4 or 5 days to create the Week factor for each animal. The main effects of sampling period (Week), presence of a ewe, and background pasture type were assessed using the GLM procedures of SAS (SAS Institute 1990) in a split plot design using individual lambs within each group as the error term. Any interactions between the independent variables were also examined.

For the ewes, the mean percentage of total feeding scans in which ragwort was consumed was determined for each of the 2 groups for each day and again averaged over the week. Sampling period (Week) and background pasture type were the independent variables. Where necessary, lamb scan data were square root transformed and ewe data arcsine transformed to stabilise variances before analysis with the GLM procedures of SAS (SAS Institute 1990).

Plant Measurements

Within each daily grazing area, 20 ragwort plants were identified with a numbered peg, and the height and 2 width dimensions at ground level (taken at right-angles to each other) were recorded. The growth stage of each plant was also noted and categorised as either rosette or elongated. These initial plant measurements were completed before the sheep were allowed into the grazing area for 24-hours. Plant volumes were estimated on the assumption that plants were cylindrical in shape and that reduction in volume equated to ragwort consumption. These measurements were repeated once animals were removed from the plot after a 24-hour confinement. The mean volume of ragwort material removed per day by each ewe-absent group during Weeks 1 and 3 and all 4 lamb-only groups in Week 12 was analysed using the GLM procedures of SAS (SAS Institute 1990). As there were no days-within-week effects, ragwort volume removed per day was averaged for each week. Sampling period (Week), grazing with ewes, and background pasture type were the independent variables.

Mean pasture height was determined from 50 'first hit on green plant tissue' sward stick (Barthram 1986) measurements made daily in each lane. Pasture mass was estimated from *Ballantrae* calibrations of height against pasture dry matter (DM) following the method used by Webby and Pengelly (1986).

Results

Pasture Measurements

Mean (SD) ragwort plant heights measured during Weeks 1, 3, and 12, were 25 (±13), 29 (±13), and 48 (±23) cm respectively; and mean volumes were 0.28 (±0.40), 0.22 (± 0.26), and 0.39 (± 0.46) m^3. Ragwort heights and volumes were similar between lanes within each week (week x group interaction; P = 0.35). Mean grass height before grazing was 16 (±6), 13 (±7), and 11 (±5) cm (estimated mass was 3,100, 2,500 and 2,100 kg DM ha^{-1}) in Weeks 1, 3 and 12 respectively. This decline represented usual seasonal growth patterns during spring and mid summer. Post-24-hour grazing height reduction was always between 46 and 48%. Each lane contained an average of 6 mature ragwort plants m^{-2}.

Scan-sampling of Lambs

For all lamb groups, the mean percentage of ragwort-feeding-scans increased from 0.5 to 1.2% from Week 1 to 3 and then to 6.5% for Week 12 (P < 0.05). In Week 1, all 4 lamb groups grazed ragwort with a similar frequency. However, in Weeks 3 and 12 both lamb groups with ewes grazed ragwort more frequently (1.89 and 7.7 for Weeks 3 and 12 respectively; P < 0.05) than those without ewes (.84 and 6.5 for Week 3 and 12 respectively) (Table 1). There was no main effect (P = 0.22) of background pasture type on subsequent ragwort grazing by lambs (Table 1). There was also no interaction between background pasture type and ewe presence (P = 0.89).

Table 1. Mean percentage (±SE) of feeding scans spent eating ragwort by lambs from ragwort-free (naïve) or ragwort-present (ragwort-exposed) pasture backgrounds pre-weaning, grazing with or without ewes during Weeks 1, 3, and 12 from first introduction of naïve lambs to ragwort.

	Ragwort-exposed		Naïve	
Week	Ewes present	Ewes absent	Ewes Present	Ewes absent
	(%)			
1	0.8 ± 0.4 a*	0.8 ± 0.2 a	0.5 ± 0.2 a	0.1 ± 0.1 a
3	2.5 ± 0.5 a	0.5 ± 0.3 b	1.3 ± 0.3 a	0.3 ± 0.2 b
12	7.1 ± 0.9 a	6.2 ± 1.2 b	8.3 ± 1.3 a	6.8 ± 1.2 b

*Means within rows with similar letters are not significantly different (P < 0.05)

Plant Volume Reduction

The mean percentage of ragwort removed from the plots after 24-hours by the 2 lamb groups without ewes increased from Week 1 to 3, from 16 to 30%, and then to 60% during Week 12 (P < 0.05). Table 2 shows that during Weeks 1 and 3 the lambs reared on ragwort-present pasture removed more ragwort on a daily basis (33% of original volume), than the lambs reared on ragwort-absent pasture (13%), averaged over both weeks (P < 0.05). A comparison of daily ragwort consumption by the lambs that grazed with ewes during Weeks 1 and 3 was not possible because of the inseparable contributions of ewes and lambs to the reduction of ragwort volume.

When all 4 lamb groups grazed alone during Week 12 there was no effect of either background pasture type (P = 0.16) or ewe presence (P = 0.59) on 24-hour ragwort volume reduction (Table 2). There was also no interaction between background pasture type and ewe presence (P = 0.12).

Ewe Behavior

The scan-sampling data shows that the ewes deprived of access to ragwort during lactation spent more time eating ragwort than those ewes which were exposed to ragwort continuously (P < 0.05), during Weeks 1 and 3 (Table 3). There was also an interaction between week and ewe group (P < 0.01), with the non-exposed ewes spending more time grazing ragwort during Week 1 than Week 3, compared with no difference between Week 1 and Week 3 for the other ewe group.

Discussion

Ragwort Exposure

The animal measurements did not detect the increase in ragwort grazing from Weeks 1 to 3 shown by the plant volume reduction data for both groups of lambs that grazed alone. This suggests that the 1-hour animal grazing observations and the 24-hour plant volume reduction measurements were not equivalent measures of ragwort grazing by the lambs. Either lamb group rarely grazed ragwort plants during each 1-hour period during Weeks 1 and 3. Instead, as soon as the lambs were released onto a new grazing area they immediately began to graze other pasture

Table 2. Mean percentage (±SE) of ragwort volume reduced after 24-hour grazing periods by lambs from ragwort-free (naïve) or ragwort-present (ragwort-exposed) pasture, grazing with or without ewes during Weeks 1, 3, and 12 from first introduction of naïve lambs to ragwort.

	Ragwort-exposed		Naïve	
Week	Ewes present	Ewes absent	Ewes Present	Ewes absent
	(%)			
1	—	27.1 ± 6.4 a*	—	4.4 ± 1.5 b
3	—	38.7 ± 9.2 a	—	21.0 ± 3.5 b
12	50.8 ± 9.5 a	60.6 ± 10.2 a	64.7 ± 6.3 a	59.7 ± 5.3 a

*Means within rows with similar letters are not significantly different (P < 0.05)

Table 3. Mean percentage (±SE) of feeding scans spent eating ragwort by ewes that grazed with lambs from ragwort-free (naïve) or ragwort-present (ragwort-exposed) pasture background during Weeks 1 and 3 from first introduction of naïve lambs to ragwort.

Week	Ewes - non-exposed for 3 months during lactation (Lambs - ragwort-exposed)	Ewes - ragwort-exposed continuously (Lambs - naïve)
	(%)	
1	20.4 ± 2.0 a	3.5 ± 0.7 b
3	11.8 ± 2.2 a	6.2 ± 1.1 b

*Means within rows with similar letters are not significantly different ($P < 0.05$)

species. During Weeks 1 and 3 the lambs from the ragwort-present pasture usually grazed ragwort in quantity sometime after the observation period had finished, as did the lambs from ragwort-free pasture during Week 3. Lambs from ragwort-free pasture grazed very little ragwort at any time during Week 1. This finding, that short-term observations of grazing behavior, made at a single time of day, may not represent longer-term grazing patterns, has been found by Parsons et al. (1994) with Scottish halfbred ewes that exhibited changing preferences for clover and ryegrass.

There are at least 2 alternative explanations for the apparent increase in ragwort eating by the ragwort-exposed lambs during the remaining 23-hours after introduction to new pasture. The first is that ragwort may not have been a preferred food for the lambs and therefore remained relatively untouched until more preferred species were depleted, and/or rendered inedible through trampling. Walker et al. (1992) found that lambs avoided grazing leafy spurge when other pasture species were readily accessible, but switched to grazing leafy spurge when its biomass was high relative to other pasture species. A second possibility is that ragwort was not preferred by ragwort-exposed lambs in the morning, but was taken at some time later in the day. This type of regular diurnal preference pattern, for reasons other than the depletion of a previously preferred species, could indicate a determined strategy of ingestion (Sibley 1981). Both possibilities are equally likely, and distinguishing between them would involve observing lambs grazing on large areas of pasture, to ensure the maintenance of free-choice grazing throughout each 24-hour period of confinement (Parsons et al. 1994). Further, both possibilities require the ragwort-exposed lambs to have sampled ragwort before weaning, and to have developed a learned response that persisted after weaning in a familiar grazing environment (Scott et al. 1996). In contrast, lambs reared on ragwort-free pasture probably grazed only familiar species when first exposed to ragwort (a novel plant) in an environment that was initially unfamiliar to them (Scott et al. 1996); and ragwort remained relatively untouched as a consequence.

Social Facilitation

Social facilitation occurs when a learned behavior is performed at a greater rate when animals co-act with other individuals, than when the behavior is emitted in the absence of others (Thorhallsdottir et al. 1990). During Week 3, the presence of ewes facilitated the sampling of ragwort by lambs from both grazing backgrounds. It is unclear whether this resulted from social facilitation (physical presence of ewes eating ragwort) or changes in ragwort preferences learned by the lambs between Weeks 1 and 3 because the relative contributions of the 2 factors were inseparable. However, the effect persisted into Week 12 when the ewes were removed, suggesting that previous grazing with ewes had changed the ragwort preferences of the lambs. There was no difference in the Week 12 percentage of ragwort volume removed over 24-hours by any of the groups. This suggests that the ewes may have facilitated a change in the pattern of ragwort ingestion without increasing its percentage in the diet. However, the size of the pastures may have placed limits on the amount of ragwort available or acceptable for grazing. The greater incidence of ragwort sampling in Week 3 by the lambs reared on ragwort-free pasture and confined with ewes, compared with lambs without ewes, suggests that the ewes may have facilitated the lambs' initial consumption of ragwort. The small number of observed grazings must, however, limit the confidence of this finding.

Ewe Behavior

The ewes that had returned from a ragwort-free environment, where they were grazed from lambing until weaning, were observed eating ragwort 4 times as often as their counterparts from the ragwort-present background during Weeks 1 and 3. Sheep often prefer pasture species different to those grazed most recently (Newman et al. 1992), although this preference disappears over time (Parsons et al. 1994). In the case of the ewes deprived of ragwort from lambing until weaning, increased ragwort-eating following reintroduction to ragwort-dense pasture may indicate a short-lived preference for a familiar food type that had not been recently encountered. The reduction of time spent eating ragwort from Week 1 through Week 3 by ewes deprived of ragwort from lambing to weaning suggests learning from negative post-ingestive consequences (Provenza 1995). It is not known what effect this differential ragwort eating by the 2 ewe groups may have had on the lambs that they grazed with. One possibility is that the ewe group that grazed ragwort more frequently provided the lambs that grazed with them increased opportunities to co-act in ragwort grazing. However, the possible effect of differential social facilitation may not be directly proportional to the ragwort-grazing of the ewes.

Persistence of Training

Ragwort-eating, in comparison to other feeding, increased substantially between Weeks 3 and 12 for all 4 lamb groups. This pattern of initial low intake of a food type by lambs, followed increasing consumption as the feed becomes familiar is a regularly reported finding; eg Chapple and Lynch (1986) with wheat; and Ralphs et al. (1990) and Pfister and Price (1996) with locoweed, a plant which, like ragwort, also contains toxic alkaloids. The gradual process of habituation to a novel food is one possible interpretation of the increase in consumption over time (Ralphs et al. 1990). This, however, fails to explain why lambs exposed to ragwort from birth underwent an increase similar in magnitude to the lambs that remained ragwort-naïve until after weaning. Because of the data gap between weeks 3 and 12 we do not know: when the marked increase in ragwort-eating during this period occurred; whether the transition was sudden or gradual; and whether the pattern was the same for each group.

Thus it is unclear if the lambs in all 4 groups independently reached an experience threshold after which ragwort grazing increased markedly. For example, once sheep eat more than 10-grams of wheat during daily, 15-min feeding sessions, wheat-eating increases very rapidly

(Chapple and Lynch 1986). The difference in volume of ragwort removed (consumed) between the lambs from ragwort-free and ragwort-present backgrounds that grazed without ewes did not persist into Week 12. This suggests that 12 weeks of exposure to ragwort may have allowed the lambs from the ragwort-free background to develop similar ragwort grazing skills to those reared with their mothers on ragwort-present pastures. However, a second variable that may determine the amount of ragwort included in the diet of lambs is age. Unfortunately, age is confounded with experience so the relative effects of the 2 variables can only be speculated.

Young calves are generally more susceptible to ragwort pyrrolizidine alkaloid (PA) toxicosis than older cows, because of increased cellular activity and higher levels of PA bioactivating enzymes in the liver (Johnson et al. 1985). Lambs also are more susceptible than older sheep to the toxic effects of excess ragwort ingestion (Cameron 1935, Olson and Lacey 1994). Possibly the lambs used in the present study developed an increased tolerance for the alkaloids that came with age, between Weeks 3 and 12, that enabled them to eat more ragwort. This could have occurred through a combination of factors, including a decline in PA bioactivating enzymes, an increase in PA detoxifying enzymes in the liver (Cheeke 1994) and/or development of de-toxifying rumen microflora (Wachenheim et al. 1992).

Physiological changes that allow the ingestion of toxic foods may not only occur as a result of developmental processes; but may also occur as an adaptive response to a major change in forage type (Olson and Lacey 1994). Such adaptations could also involve changes in rumen microflora and/or the relative concentrations of enzymes in the liver (Olson and Lacey 1994). This may help to explain the observation by Poole and Cairns (1940) that adult sheep with no ragwort experience tend to eat very little of the plant initially, but after continued sampling, a taste for the plant rapidly develops; and it eventually becomes a large component of the diet.

Clearly, further research should aim to separate the relative effects of age, physiology, and learning, on the level of ragwort-eating by sheep. This could involve identifying the sheep in different aged flocks that may lack the physiological plasticity to consume ragwort. The greater toxicity of ragwort to lambs compared with ewes suggests that sheep may not develop a stable pattern of ragwort ingestion until they can eat it ‘safely’. Perhaps a greater preference for ragwort could be induced if lambs were denied access to the plant until they were old enough to detoxify the alkaloids effectively. Poole and Cairns (1940) reported that sheep from “non-ragwort country” developed a clear “preference” for the plant “once they had acquired a taste for it”. A comparison between adult ewes that have never experienced ragwort, with a group retained on ragwort-present pasture since birth, could be used to investigate this possibility.

Conclusions

Lambs may graze very little ragwort immediately following weaning, regardless of background pasture type. From a practical perspective, freshly weaned lambs may not provide immediate ragwort control, although their ragwort-grazing will probably increase within 14 weeks (viz. Week 12). Also, farmers may not need to ensure that lambs destined for ragwort-control experience ragwort-present pastures before weaning, because simply confining lambs to such pastures immediately after weaning may have a similar effect on subsequent ragwort grazing. Further, allowing lambs to graze with ragwort-eating ewes after weaning may increase subsequent ragwort grazing by lambs.

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Grass response to seasonal burns in experimental plantings

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Abstract

A 6-year experiment examined the effects of spring and summer fires on grasses in southern Wisconsin. Synthetic communities of C_3 and C_4 grasses were seeded (100 seeds m^{-2} species^{-1}) in 1992 and subjected to prescribed burns in May and August of 1995 and 1997, or left unburned. By 1994 all plots were virtual monocultures of the C_3 reed canary grass (*Phalaris arundinacea* L.). By the second post-season sample in 1998, total productivity of plots burned in May was higher (781 ± 212 se g m^{-2} year^{-1}) than those burned in August (362 ± 28 g m^{-2} year^{-1}) or left unburned (262 ± 43 g m^{-2} year^{-1}) due to the incursions of either the C_4 grasses big bluestem (*Andropogon gerardii* Vitman), switichgrass (*Panicum virgatum* L), or both. These large late-season grasses are much more productive per area covered than *P. arundinacea* or the other two C_3 grasses present, *Elymus virginicus* L. and *Poa pratensis* L. Even at this early stage of succession, C_4 production in plots burned in May was 5 to 6 times that in the other 2 treatments. August burns produced a mix of C_3 and C_4 grasses but did not strongly favor the pre-treatment C_3 dominant *P. arundinacea*. Unburned plots most resembled those burned in August in species composition, but differed in having 4 times the accumulated litter, perhaps foretelling divergence in C_3 and C_4 composition as succession proceeds.

Key Words: C_3 grass, C_4 grass, fire season, ecological restoration, tallgrass prairie

Resumen

Un experimento de 6 anos examino los efectos del fuego en pastos durante la primavera y verano en el sur de Wisconsin. Comunidades sintéticas de pastos C_3 y C_4 fueron creadas al sur de Wisconsin en 1992 y se les aplicó fuegos prescritos en Mayo y Agosto de 1995 y 1997, o fueron dejados sin quemar. Para 1994 todos las parcelas fueron monocultivos del pasto C_3 *Phalaris arundinacea* L. En la segunda muestra despues de la quema de 1998, la productividad total de las parcelas quemadas en Mayo fue más grande (781 ± 212 se g m^{-2} año^{-1}) que aquellas quemadas en Agosto (362 ± 28 se g m^{-2} año^{-1}) o las que no fueron quemadas (262 ± 43 se g m^{-2} año^{-1}), debido a la entrada del pasto C_4 *Andropogon gerardii* Vitman, *Panicum virgatum* L., o los dos. Estos dos grandes pastos tardíos son mucho más productivos por área que *P. arundinacea* o los otros dos pastos C_3 presentes, *Elymus virginicus* L. y *Poa pratensis* L. Incluso para este joven estado de sucesión, la producción de los pastos C_4 en parcelas quemadas en Mayo es de 5 a 6 veces más alta que en los otros 2 tratamientos. La quema de Agosto produjo una mezcla de pastos C_3 y C_4 pero no favorecio fuertemente la dominancia de *P. arundinacea.* Las parcelas que no fueron quemadas son parecidas a aquellas que fueron quemadas en Agosto en terminos de la identidad de las especies, pero difieren en que las parcelas no quemadas tienen 4 veces más hojarasca acumulada, quizas pronosticando divergencias en la composición de C_3 y C_4 a estados más avanzados de la sucesión.

Fire slows or precludes woody succession into tallgrass vegetation in the central United States (e.g. Saur 1950, Curtis 1959, Daubenmire 1968, Risser et al. 1981, Collins and Wallace 1990), justifying the well-established practice of using prescribed fire to maintain tallgrass prairie and related communities (e.g. Hulbert 1973, 1986, Rock 1981, McCain 1986). Prescribed fire maintains tallgrass prairie structure, productivity, and diversity as compared to unburned remnants (Leach and Givnish 1996), but the seasonal effects of fire on structure of herbaceous plant communities are less understood (Bragg 1982, Higgins 1984, Towne and Owensby 1984). For instance, spring fires may favor dominance by later-emerging species, such as large C_4 grasses, while fires during the middle of the growing season could suppress such "warm-season" species in favor of dominant earlier-emerging C_3 grasses (Higgins 1984, Hulbert 1988, Howe 1994a, 1994b, 1995). Any fire may maintain grassland structure by precluding woody succession, but the season of fire may largely determine which herbaceous communities persist.

This paper reports on the effects of fire season on synthetic grass communities established on plowed land in 1992 in southwestern Wisconsin. The preliminary objective after 2 alternate-year burn cycles is to test the hypotheses: (1) summer fire favors early-season C_3 grasses, and (2) spring fire favors late-season C_4 grasses. Because C_3 grasses are less productive than C_4 grasses, one expects lower productivity after summer than spring fires. After 2 additional burn cycles these questions will be revisited for both aggregate and species-specific variables.

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Methods

Three early cool-season (C_3) and 3 late warm-season (C_4) grass species were sown at equal densities of 100 seeds m^{-2} species^{-1} on 14 June 1992 in eighteen, 7 x 7 m plots in a 3 x 6 grid in a wet-mesic sandy loam near Viola, Vernon County, Wisc. with procedures adapted from Rock (1981). In 1991 pre-existing pasture vegetation of Eurasian grasses was sprayed with contact herbicide (glyphosate) on 18 May, plowed and disced on 20 June, sprayed again on 22 June to kill surviving quackgrass (*Agropyron repens* L), and disced on 28 July 1991 and 6 June 1992.

Seeds mixed with damp sand were broadcast on 14 June 1992 in each 7 x 7 m plot from 1 of 18 individually measured and weighed bags of C_3 wheatgrass (*Agropyron trachycaulum* [Link] Malte), Virginia rye (*Elymus virginicus* L.), reed canary-grass (*Phalaris arundinacea* L.), and C_4 grasses big bluestem (*Andropogon gerardii*) Vitman, switchgrass (*Panicum virgatum* L.) and prairie dropseed (*Sporobolus heterolepis* [Gray] Gray). Plots were raked and rolled. Cover of annual oats (*Avena sativa* L.) at 100–150 seeds m^{-2} suppressed invasive weeds while perennial plantings established the first growing season (see Rock 1981). Future fire lanes 1.5 m wide were broadcast-seeded, raked and rolled with the same seed mix between the plots. A uniform burn on 24 April 1994 reduced weeds and litter and permitted establishment of C_4 grasses. The growing season for C_3 grasses in this valley is April to October when not heavily shaded by other herbaceous or woody species. The growing season for C_4 grasses is May to late September.

Seasonal fire treatments commenced in 1995 and were repeated in 1997. On 18 May 1995, 6 plots were burned, 1 randomly picked from each of 6 north-south rows; on 12 August 1995, 6 similarly selected plots were burned. The third plot in each north-south row remained unburned. Plots burned in May 1995 were again burned on 4 May 1997, those burned in August 1995 were again burned on 1 August 1997. Fuel load was estimated using dry mass of clippings of live foliage of the year and dead litter in 2 randomly selected 25 x 25cm samples from each plot to be burned 1–4 days before each fire; in August 1997 clippings were repeated after burns. Ring fires were set on the first nearly windless late afternoon (after 4 pm) of May or August on plots that had been spared rain (≥ 1 cm) for 2 days. In 1995 a representative flame length was recorded > 1 m from the edge for each plot; in 1997 flame lengths at random locations were measured 4–6 times at 20 second intervals in each plot, and the mean values for the plots were analyzed. In 1997 the time required to engulf each 7 x 7 m plot was recorded after the perimeter was ignited with a drip torch, which took about 1 minute. The proportion of area in which herbaceous shoots were killed was recorded both years. A shorthand calculation of fire intensity $I = 259.83\ L^{2.174}$ (Johnson 1992), where L is flame length in m allows comparison of potential for fire effects independent of measured plant responses.

Response variables measured were estimates of above-ground primary production, litter, and canopy cover taken ≥ 1 m from the edge of each plot. Dry mass of live vegetation was estimated with clippings from 5 randomly located 25 x 25cm samples (exclusive of permanent cover plots, below) in late August or early September 1993, 1996, and 1998. Shoots of the year were dried to constant mass; in 1996 and 1998 dry litter was also evaluated, and in 1998 dry shoots of the year were separated by species. Values reported are converted to g m^{-2} (g/sample x 16). Canopy cover was determined in 5 randomly-located permanent m^2 plotlets. A map was drawn to scale of relative cover of all vegetation occupying ≥ 10x10 cm of continuous space within a plotlet; area per species was determined with a Lasico digital planimeter (Howe 1994b).

In this experiment burns are carried out in May and August of the same year, and this sequence is repeated in alternate years. Responses are evaluated in non-burn years. This means that spring burns are evaluated about 1.75 growing seasons after the burn, and August burns about 1.25 growing seasons after the burn, assuming either that C_3 or C_4 grasses, or both, grow from April through September. Because differences in productivity are due to inherent differences in productivity of species responding to the month of burn, the one half season difference in growth does not appear to be important; C_3 species present are always a fraction of the biomass m^{-2} of the C_4 species used in these plantings. An alternative, to burn in August of 1 year, in May of the next, and to evaluate productivity in autumn of the second year, would leave a similar but reversed one half season disparity in growing time (for August burns, evaluation after 1.25 growing seasons, for May burns after 0.75 season). The additional burden for interpretation of different year burns would be confounded by differences in growing times with unshared winter effects and unshared growing season effects in the critical early weeks of recovery from burns. Either burn regime could have consequences for conspecific comparisons, but neither would appear to make much difference in a system where differences in productivity are due to interspecific responses, not subtle variations in intraspecific recovery.

Dicot weeds were sprayed with 2-4 dichlorophenoloxyacetic acid in May and June after 1993; in July and August they were clipped (large roots) or pulled (small roots) on sight. Invasive graminoids were not weeded (the *Avena* cover crop disappeared by 1993).

The experiment was set up in a split-plot design, with burn treatments randomly assigned within each of 6 rows of 3 plots. Because no row effect materialized, data are analysed as a straightforward multivariate anova to make maximum use of degrees of freedom (Wilkinson 1993).

Results

Succession. The plots changed dramatically between the 1992 planting and 1998 census. In 1992, most canopy cover was of graminoid weeds (41 ± 5%) and the *Avena* cover crop (27 ± 4%). All 6 experimental grasses appeared by 1993, but *S. heterolepis* was only present in trace numbers before disappearing, while *A. trachycaulum* was common in 1992 (canopy cover of 24 ± 3%) but disappeared by 1994. *P. arundinacea* appeared in 1992 (3 ± 1 %), was a virtual monoculture by 1994 (97 ± 1%), and diminished in 1996 (82 ± 4%) and 1998 (41 ± 7%). The large C_3 species *E. virginicus* became abundant in 1996 (8 ± 3%) and 1998 (6 ± 2%). Large C_4 species *A. gerardii* and *P. virgatum* first gained prominence in 1996 (3 ± 2 and 5 ± 2%) and appeared to increase overall in 1998 (10 ± 4 and 13 ± 5%, respectively). By 1996, *E. virginicus* and the smaller volunteer *P. pratensis* partially displaced *P. arundinacea* in unburned and summer-burn plots. *Andropogon gerardii* and *P. virgatum* now occur in all plots, have virtually eliminated *P. arundinacea* from 2 spring-burn plots, and are gaining ground in the other spring-burn plots. Twenty-four dicot and 4 graminoid weeds dominated the plots during the first growing season ("other" in Fig. 1). Dicots swamp aster (*Aster simplex* Willd.) and tall goldenrod (*Solidago altissima* L.) required persistent control in all plots, and fleabane (*Erigeron* spp.) and chickweed (*Stellaria media* [L.] Vill.) required control in unburned and summer-burn plots. Of the graminoid weeds present, only the C_3 grass *Poa pratensis* L. became at all common, and then primarily in summer-burn plots.

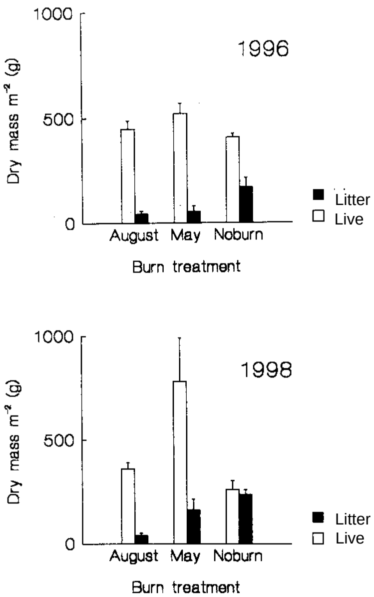

Fig. 1. Above-ground production and litter per square meter in 1996 after 1995 burns, and in 1998 after 1997 burns (mean ± se g).

Fuel loads. May and August burns in 1995 removed all litter and left negligible standing-dead vegetation; a low-intensity burn in August 1997 left nearly 30% standing dead (132 ± 39 g m^{-2}). May burns occurred when green vegetation averaged 25–40 cm tall, and accounted for much less of the above-ground biomass than August burns. By August green vegetation averaged 100–120 cm tall and accounted for most biomass above ground (Table 1), enough to reduce fire intensity when significant rain (≥ 1 cm) fell within 3 days of the burns (e.g. 1997).

Fire behavior. Fire behavior differed among treatments and years (Table 1). Flame length ranged from 0.25 to 0.78 m with a mean of 0.60 ± 0.10 m (mean ± 1se) in the May 1995 burns, but 1.25 to 1.50 m with a mean of 1.29 ± 0.04 m in August. Two years later the May 1997 burns ranged from 0.75 to1.62 m with a mean of 1.19 ± 0.15 m, while the August burns resembled the May 1995 burns with flame lengths of 0.44 to 0.85 m, averaging 0.67 ± 0.6 m. In 1997 plots burned in May were engulfed in 2.7 ± 0.3 minutes, while the less intense August fires took 4.2 ± 0.4 minutes. Fire intensities were greater in August than May fires in 1995, but higher in May than August in 1997. The policy of burning on windless late afternoons undoubtedly reduced fire intensities over those that might have been recorded earlier on same days.

Above-ground productivity. Above-ground productivity in August 1993, then *P. arundinacea* L. and some *E. virginicus*, averaged 495 ± 66 g m^{-2}, with no differences among plots later assigned to different burn treatments (Tukey tests, $P > 0.5$). Following the 1995 burns, 1996 samples were not different in overall productivity by burn treatment ($F_{2,15} = 2.475$, $P = 0.1$), although unburned treatments accumulated more litter ($F_{2,15} = 5.744$, $P < 0.025$; Fig. 1 top). Wilks' lambda (0.447, $F_{4,28} = 3.466$, $P = 0.02$) and the multivariate exact probability theta (0.498 S=2, M=-.5, N = 6.0, P = 0.027; Wilkinson 1993) indicate a significant combined response of productivity and litter to burn season. A year after the second burn (Fig. 1 bottom), productivity and litter deposition differed among burn treatments (univariate tests: $F_{2,15}$= 4.797 and 9.953, $P < 0.025$ and $P = 0.002$, respectively). Again there is a combined multivariate response of both annual productivity and litter with treatment (Wilks' lambda 0.159, $F_{4,28} = 10.582$, $P < 0.001$ and theta = 0.765 S = 2 m=-.05, N = 6.0, $P < 0.001$).

Table 1. Fuel conditions, fire intensities, and immediate effects on above-ground vegetation. Fuel and litter are reported as means (± se) from two, 25 x 25 cm samples from each plot the day before burns in May or August (transformed to green shoots or litter m^{-2}); fire intensities (mean ± se) are derived from 4–6 flame lengths from each plot.[1,2,3] Percent kill indicates the area (m^2 of total m^2 per plot x 100) in each plot for which 100% of the above-ground vegetation was killed.[4]

		Vegetation			Fire	
Year	Plots	Green mass	Litter mass	Percent green	Intensity	Percent kill
	(N)	(g)	(g)	(%)	(kW m^{-2})	(%)
1995 May	6	72 ± 4[a]	296 ± 29[a]	20 ± 2[a]	98 ± 25[a]	100
August	6	536 ± 106[b]	198 ± 19[b]	71 ± 4[b]	456 ± 34[b]	97
1997 May	6	19 ± 3[a]	299 ± 31[a]	6 ± 1[b]	421 ± 107[b]	100
August	6	310 ± 39[c]	234 ± 19[b]	56 ± 3[d]	116 ± 22[a]	100

[1]Intensity is $I = 259.83\ L^{2.174}$, where L is flame length in m (Johnson 1992).
[2]Means accompanied by different superscripts differ by Tukey tests at least at P < 0.05.
[3]Fuel conditions were not assessed for unburned plots.
[4]Grasses regularly resprouted from live underground buds.

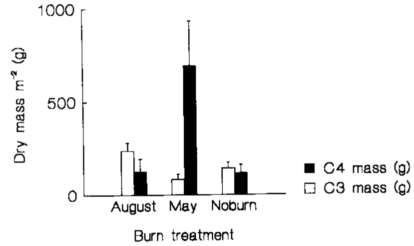

Fig. 2. Annual production of C_3 and C_4 grasses per square meter in 1998 after 1997 burns (mean ± se g).

The C_4 grasses were more productive than C_3 grasses. Pooling all treatments, in 1998 C_4 grasses *A. gerardii* and *P. virgatum* accounted for 10% and 14% of the area covered, but 22% and 26% of the biomass, respectively. The C_3 grasses *E. virginicus, P. arundinacea*, and *P. pratensis* accounted for 6%, 41% and 21% of the area covered, but 3%, 30%, and 19% of the biomass, respectively. Over all treatments, C_4 grasses accounted for 23% of the cover and 48% of the biomass, while C_3 grasses accounted for 71% of the cover and 52% of the biomass.

C_3 and C_4 grasses. By 1998 burn treatments affected biomasses of C_3 and C_4 grasses (Fig. 2; $F_{2,15}$ = 4.962 and 5.199, respectively, $P < 0.025$), and the combined response of both variables (Wilks' lambda 0.414, $F_{4,28} = 3.873$, $P < 0.025$; theta = 0.428 S = 2 m= –.05, N = 6.0, P = 0.063). Tukey tests show less green biomass of C_3 grasses the season following May than August burns ($P < 0.02$), and more biomass of C_4 grasses 1.75 growing seasons after May than 1.25 growing seasons after August burns or in unburned plots ($P < 0.05$).

At this stage of succession, high variance within and between treatments preclude significant effects of burn times for individual species. In some May-burn plots, for instance, *P. virgatum* is present in samples but *A. gerardii* is absent, while in other plots the opposite is true. One significant effect of treatment is the greater biomass of the invasive C_3 grass *P. pratensis* in plots burned the previous year in August (84.8 ± 20.8 g m^{-2}) than in May (24.0 ± 9.6 g m^{-2} ; Tukey test, $P < 0.05$).

Discussion

This study improves understanding of seasonal fire effects on tallgrass vegetation planted in a wet-mesic field. As expected, spring fires strongly promote overall productivity through enhanced establishment and growth of C_4 at the expense of C_3

grasses (e.g. Hulbert 1988, Howe 1995). However, summer fires do not increase the representation of dominant C_3 grasses nearly as much as expected. Instead of favoring dominant *P. arundinacea*, 2 cycles of summer burns have admitted 2 additional C_3 and 2 additional C_4 grasses, but the individual species responses are not clearly different from unburned plots.

Response to fire season

The imposition of fire, and to some degree fire frequency, is often perceived as "the treatment" in grassland management (Howe 1994a). In this study in a wet-mesic planting, fire season appears to promote very different communities out of identical seedings in as little as 6 years.

The most decisive response in the first 6 years of this experiment is the continuing replacement of a virtual monoculture of the C_3 grass *Phalaris arundinacea L*. with 1 or both of the 2 C_4 grasses present, *Agropyron gerardii* and *Panicum virgatum* L. This reversal of dominance is consistent with the general prediction that fires that damage plants during the peak of their growth favor competitors not so affected (Howe 1994a; see Neiland and Curtis 1956). While it is widely understood that spring fires favor C_4 grasses (e.g. Hulbert 1986, 1988, Steuter 1987, Anderson 1990, Howe 1994b), the rapid and continuing increases in productivity of C_4 grasses, leading to a sharp increase in total productivity in plots burned in May as compared with those burned in August or left unburned, is unexpected after only 2 alternate-year burns. *P. arundinacea* is a quickly establishing and extremely vigorous competitor on wet or wet-mesic sites such as this, often forming virtual monocultures (Galatowitsch and van der Valk 1996, Mergliano and Lesica 1998), as it has in a large experiment planted in 1990 at this site (Howe 1999). Early displacement of this species in May-burn plots is particularly interesting because wet soils often favor *P. arundinacea*. Total productivity, reaching 1,379 g m^{-2} $year^{-1}$ and averaging 781 ± 212 g m^{-2} $year^{-1}$, may ultimately approach the mean of > 1,100 g m^{-2} $year^{-1}$ on spring-burn treatments in a 1986 planting in which *A. gerardii* was seeded and established in overwhelming dominance (Howe 1994b, 1995).

August-burn plots present a more complex picture. One might expect that summer burns which occur after a dominant C_3 grass completes flowering, seeding, and seasonal growth would strongly favor that dominant through suppression of later-maturing C_4 grasses (Howe 1994a). Alternatively one might expect a general promotion of C_3 species, as has occurred in native short-grass prairies (Steuter 1987, Biondini et al. 1989). Here 2 cycles of August fires over 3 years favor C_3 grasses (Fig. 2) by breaking the hegemony of *P. arundinacea* in favor of a mixture of this species and 2 other C_3 grasses (*E. virginicus* and *P. pratensis*). Despite intrusion of some much more productive C_4 experimentals after August burns, overall productivity of August-burn plots may be declining from the *P. arundinacea* monoculture high of 495 ± 66 g m^{-2} $year^{-1}$ to a 1998 mean of 362 ± 28 g m^{-2} $year^{-1}$ ($t_{6.8}$ = 1.833, P = 0.1). Mid-summer fires favor C_3 grasses more than spring fires, but the net result seems to be a mixture of C_3 and C_4 grasses instead of the anticipated encouragement of continued dominance of *P. arundinacea*.

Unburned plots are least productive in this experiment. Despite incursions of heavy C_4 species and the pre-treatment monoculture of *P. arundinacea*, unburned plots have a low and at present declining productivity of 262 ± 43 g m^{-2} $year^{-1}$. The statistical picture is not yet definitive because vegetation in unburned plots does not differ dramatically from August-burn plots. However declining productivity, lower numerical if not statistical species-specific variables of C_3 grasses, and accumulation of four times as much litter in unburned as August-burn plots suggest that these treatments are diverging, if only because deep litter is known to preclude seedling establishment and ultimately eliminate some species (Hulbert 1969, Knapp and Seastedt 1986). The eventual differences between unburned and August-burn plots will depend on whether summer fires continue to favor small and relatively unproductive C_3 species, while unburned plots favor established C_3 dominance of *P. arundinacea* or eventually allow vigorous competition from larger and much more productive C_4 *A. gerardii* and *P. virgatum.*

Implications of summer fires

Summer fires have important implications for evolutionary history, ecology, and variability of grasslands in central North America. If they consistently favor different properties and species compositions than dormant-season or early spring fires usually prescribed, summer fires may offer important insights into the management and restoration of tallgrass habitats, which are among the "most endangered" ecosystems in North America (Noss et al. 1995).

The vast majority of non-anthropogenic fires in the Northern Great Plains occur in June, July, and August, with rare but sometimes widespread fires occurring when fire is usually prescribed in late fall, winter or spring (Nelson and England 1971, Higgins 1984). Storm patterns suggest that summer lightning fires were once common throughout central North America (Komarek 1968), and macrofossils of flowering individual plants indicate that tallgrass prairies were repeatedly burned during the growing season at least millenia ago (Baker et al. 1996). Emphasis on promotion and study of dominance of C_4 grasses by prescribed dormant-season fire may lead us to overlook the quite different attributes of grasslands left unburned or burned by summer lightning fires (Howe 1994a).

Secondly, I infer from Higgins' (1984) observation that C_3 grasses are shorter than C_4 grasses and that changes in species composition introduced by seasonal fire should influence overall productivity. Such a shift in the C_3/C_4 ratio of biomass appears to be underway in this study, where cool-season C_3 grasses *E. virginicus*, *P. arundinacea L*. and *P. pratensis* favored by August fires are substantially lighter than *A. gerardii* and *P. virgatum* favored by May fires. Plots burned in May are more than twice as productive as those burned in August or left unburned.

Thirdly, summer fires may encourage subdominants by temporarily suppressing the dominant species at a time when opportunistic species can establish (Howe 1999). Even temporary suppression of dominant vegetation often increases biodiversity as competitively "saturated" communities admit species that can take advantage of space or resources once occupied by dominants (see Huston 1979, Cornell and Lawton 1992). The present study uses too few species for a definitive test of this prediction, but invasion of summer-burn plots by *P. pratensis* and other weeds which had occupied mowed fire lanes offers anecdotal support. In a natural community with native opportunists, one would expect a similar response with native species.

Finally, summer fire intensity is more variable than spring fire intensity. Methods used in this study (burning from the perimeter on windless days) preclude dissection of subtle effects of fire behavior on vegetation (Bidwell et al. 1990, Bidwell and Engle 1992), but differences in variability of intensity and effect were clear. One set of spring burns averaged one fourth of the intensity of summer burns, in the second set the opposite was true (Table 1). However, both spring fires and a higher-intensity summer fire removed all vegetation, while the low-intensity summer fires in 1997 left enough green vegetation standing dead to provide shade, a common occurrence in highly variable summer fires (Howe 1995, 1999). For instance, a few days following the 1997 summer fires reported here (Table 1), a series of 24 burns in an experiment in the same field ranged from half to 30 times the average intensity shown here, leaving some plots covered with dead vegetation and others entirely bare (Howe 1999). If subdominant species or other potential dominants were to take advantage of dominants suppressed by summer fires, a wide variety of microhabitats were accessible to them. Given that fire behavior (Bidwell and Engle 1992) as well as vegetative responses are likely to be multivariate, it appears likely that summer fires in heavy green vegetation introduce more variability in physical behavior and effects than spring burns.

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Plant establishment on angle of repose mine waste dumps

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Abstract

Angle of repose slopes associated with mine waste dumps are difficult to revegetate due to steep slope angle, poor soil properties, and potential for extensive soil erosion. We examined the extent that seed movement, seedling establishment, soil characteristics, nutrient availability, and water availability were responsible for limiting plant establishment or survival on steep (average slope ~80%), south-facing angle of repose slopes at a gold mine north of Elko, Nev. Four treatments were established: 1) unaltered mine waste soil; 2) mine waste soil with fertilizer; 3) mine waste soil draped with at least 0.3 m of a fine-textured coversoil; and 4) treatments 2 and 3 combined. All treatments had study plots that received either broadcast seeds or containerized transplants. Seedlings from broadcast seeds only emerged on plots that were coversoiled, but transplants survived in all treatments. Thus, coversoiling was necessary at this site for seedling germination and establishment, but survival of transplants in unaltered mine waste soil indicated that nutrient availability, soil-root contact, and water availability were sufficient for plant survival. In addition, long distance transport of seeds down stable, angle of repose slopes was not detected during the first growing season after seeding, indicating that the lack of seedlings on angle of repose slopes was not due to movement of seeds downslope. However, coversoiling resulted in unstable slope surfaces; both erosion and soil mass wastage were observed on coversoiled treatments. Thus, although coversoiling increased establishment and survival of plants on angle of repose slopes, slope stabilization is necessary to ensure the success of revegetation efforts and to prevent the coversoil from eroding and moving downslope.

Key Words: seed fate and transport; seedling transplants; nutrient and water availability; growth medium; mine reclamation; revegetation

Resumen

El ángulo de reposo de las laderas asociadas con el depósito de deshecho de minas hace dificil la revegetación debido a lo pronunciado del ángulo de la ladera, las propiedades pobres del suelo, y su potencial extensivo para la erosión. Nosotros examinamos hasta qué punto el movimiento de la semilla, el establecimiento de la plántula, las características del suelo, la disponibilidad de los nutrientes y la disponibilidad de agua fueron responsables de limitar el establecimiento o sobrevivencia de las plantas en laderas con ángulo de reposo pronunciado (promedio de inclinación de ~80%) con exposición sur en una mina de oro al norte de Elko, Nev. Cuatro tratamientos fueron establecidos: 1) suelo de deshecho de mina inalterado; 2) suelo de deshecho de mina con fertilizante; 3) suelo de deshecho de mina con una cubierta de al menos 0.3 m de suelo de textura fina; y 4) los tratamientos 2 y 3 combinados. En todos los tratamientos se establecieron parcelas de estudio donde se dispersaron semillas o se trasplantó en recipientes cónicos. Las plántulas de las semillas dispersadas emergieron únicamente en las parcelas que fueron cubiertas con suelo, pero los transplantes sobrevivieron en todos los tratamientos. Por lo tanto, el cubir el suelo en este sitio fué necesaria para la germinación y el establecimiento de las plántulas, pero la sobrevivencia de los transplantes en el suelo de deshecho de mina sin alterar indicó que la disponibilidad de nutrientes, el contacto suelo-raiz, y la disponibilidad de agua fueron suficientes para la sobrevivencia de las plantas. En adición, no se detectó transporte a larga distancia, ladera abajo, de las semillas en ángulos de reposo de laderas estables durante la primera estación de crecimiento posterior al sembrado, indicando que la falta de plántulas sobre el ángulo de reposo de las laderas no se debió al movimiento de semillas ladera abajo. Sin embargo, cubrir el suelo dió por resultado superficies de laderas inestables; ambos erosión y desgaste de suelo en masa fueron observados en los tratamientos de cobertura de suelo. Por lo tanto, aunque cubrir el suelo incrementó considerablemente el establecimiento y la sobrevivencia de las plantas sobre el angulo de reposo de las laderas, es necesario estabilizar las laderas para asegurar el éxito en los esfuerzos de revegetación y para prevenir la erosion y el movimiento ladera abajo de la cubierta del suelo.

Our ability to return surface-mined areas to productive use has increased greatly over the last 3 decades as our knowledge of successful techniques and ecological processes has grown. Although site specific characteristics need to be carefully assessed, recent reclamation handbooks and manuals (e.g. Ferris et al. 1997, Harris et al. 1996, Munshower 1994) provide sound guidance on techniques that work in most cases. Typically, mine reclamation includes recontouring to reduce erosion, topsoilng to provide a plant growth medium, seedbed preparation to maximize germination and plant establishment, soil amendments (e.g. fertilizer or

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mulch) to enhance plant growth, and seeding or transplanting suitable plant species. Although each step of the process is needed to ensure success, the importance of topsoiling cannot be overemphasized (DePuit and Redente 1988). In fact, many reclamation laws require topsoiling, either with true topsoil (i.e. soil taken from near the surface of vegetated areas) or with a coversoil (i.e. material that exhibits good plant-growth supporting characteristics) (Munshower 1994).

Unfortunately, not all sites are amenable to typical reclamation approaches. For example, topsoiling steep (>50% slope), angle of repose slopes in mine waste dumps is especially problematic because of the high erosion potential. Angle of repose slopes are formed when waste rock is dumped and left to form its own slope due to gravity. Although once a common practice throughout historic mining districts in western North America, few angle of repose dumps are now constructed. However, steep topography and limited space sometimes require angle of repose slopes (Young and Ross 1993). The existence of old barren mine dumps indicates the difficulty of establishing vegetation on these slopes. Field trials have demonstrated some successful revegetation practices (e.g. Golder 1994), but the mechanisms that explain these limited successes are unclear. Thus, studies that better identify factors that limit plant establishment on angle of repose slopes are needed.

Occasionally, angle of repose dumps are not completely barren. Observations of naturally vegetated mine slopes have shown higher plant cover and species richness at the bases of slopes in comparison with upper and mid slopes (Russell 1985). Four mechanisms may explain the observed differential pattern of vegetation establishment. The first mechanism is seed transport (Archibold 1980). Once seeds reach the soil surface, they may remain trapped where they land, move horizontally over the soil surface, or move vertically through the soil column (Chambers and MacMahon 1994). If seeds are transported down slope by wind, water, or gravity, then a seed gradient should exist on the slope with few seeds at the top of the slope and many at the bottom. In addition, coarse-textured soils capture a greater range of seed sizes in comparison with fine-textured soils, but more seeds move vertically through the soil column (Chambers 1995). If seeds move too deep into the soil, they may not germinate or may not have sufficient resources to grow to the soil surface. A second mechanism is the movement of fine soil particles to the base of the slope (Molyneux 1962). Soil texture influences seed germination and plant growth by its direct effect on soil aeration, water infiltration, water retention, cation exchange capacity and erodibility (Munshower 1994). The accumulation of fine soil particles near the base of the slope may create sites that are more favorable for seed germination and seedling establishment because fine materials often facilitate seed-soil and root-soil contact. A third mechanism is nutrient transport down slope. The leaching of water-soluble nutrients from the top of the angle of repose face may result in a gradient of nutrient availability, from fewer available nutrients at the top of the face to higher amounts at the base. Finally, water accumulation down slope is a fourth possible mechanism. Water runoff increases with slope steepness and length (Gray and Leiser 1982). The steepness of angle of repose slopes increases the runoff velocity whereas terraced benches decrease runoff. Snow may also preferentially accumulate near the base of the slope. These factors likely interact; for example, fine soil materials that accumulate down slope likely increase nutrient availability and water holding capacity.

The overall goal of this study was to determine the relative importance of these 4 mechanisms for revegetation of angle of repose slopes. To determine if seed movement was the critical factor influencing plant establishemt, measurements of seed bank at different locations along the slope face and of differentially-dyed seeds placed at specific locations along the slope face were made on unaltered mine waste and coversoiled plots. If gradients in seed density occur and if seeds dyed a specific color are found outside the area that they were placed, then long distance transport of seed likely would be an important influence on revegetation. If seed germination and seedling survival are greater on fine-textured coversoil but survival of transplants are similar on mine waste and coversoil, then the more favorable sites for seed germination and plant establishment provided by fine-textured coversoil likely would limit revegetation. Similarly, if survival of transplants is greater on fertilized plots but seedling density is similar among plots, then nutrient deficiencies likely would limit plant establishment. Finally, we assessed the extent that water limited revegetation of angle of repose slopes by measurements of plant water potential.

Materials and Methods

Experimental Design

The overall experimental design was a split-strip-split plot design with 2 replicates. Plots were established on 2 replicate waste rock dumps: North Generator (41°24'19"N 115°59'02"W, 2,286 m) and Burns Basin (41°20'06"N 116°00'52"W, 2,195 m) dumps at the Jerritt Canyon Mine located 64 kilometers north of Elko, Nev. Slopes used in the experiments had south aspects and steepness that averaged 80%. At each dump, 2 sets of plots, each consisting of 4 main plots, were located along the face of the dump. A random draw without replacement method was used to assign 1 of 4 treatments to each main plot within a set of plots. Main plots were oriented along the face of each dump, and 2 study plots were then placed on each main plot (Fig. 1). The upper plot was located near the top of the slope and the lower plot was 5 m below the bottom of the upper plot. Each study plot was 10 x 10 m a 2.5 m buffer area around the study plot.

The 4 main plot treatments consisted of untreated mine waste, coversoil, fertilizer, and fertilizer plus coversoil. The coversoil treatment was a layer of at least 0.30 m of fine-textured pit material. North Generator Dump plots were draped with a clay loam coversoil from the Winters Creek Pit, whereas Burns Basin Dump plots were draped with silt loam coversoil from the Burns Basin Pit. To apply the coversoil. the coversoil was end dumped by haul trucks at the top of each of the respective plots. The coversoil piles were then pushed over the edge of the dump face with bulldozers, and the coversoil slid down to cover the mine waste. Although this method was the only practical way to place the coversoil over a large area on steep slopes, this method resulted in portions of the plots having up to 1.5 m of coversoil. We did not systematically measure variation in coversoil thickness because of worker safety and slope stability concerns. Although variation in coversoil thickness may eventually influence plant productivity (DePuit and Redente 1988) and diversity (Munshower 1994), we believe that variation in coversoil thickness did not seriously confound our studies, especially studies of seed movement and initial plant establishment. The fertilizer treatment was 45 kg ha^{-1} each of N, P, and K. To apply the fertilizer, 300 bulk kg ha^{-1} of 15:15:15 Plant Food (Simplot™, Lanthrop, Calif.) was hand broadcast on 5–7 February 1995 on the respective plots and their buffer areas.

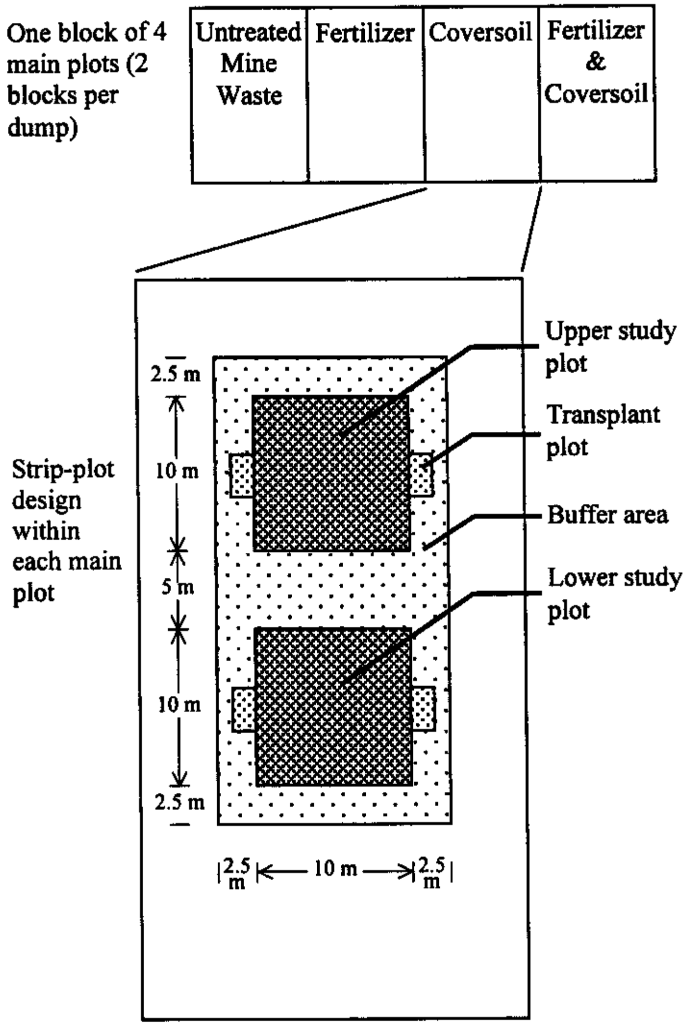

Fig. 1. Schematic representation of the split-strip portion of the experimental design; each block had 4 main plots that were split into 2 study plots. Not shown are the 2 waste rock dumps, with 2 blocks of main plots at each dump.

Seeding and Planting Techniques

Seeding viable seeds—Upper study plots, lower study plots, and the buffer area around study plots were seeded by hand broadcasting at a total rate of 323 pure live seeds (PLS) rn^{-2} (30 PLS ft^{-2}) on 5–7 February 1995. The seed mix contained equal numbers of PLS for each of 10 species: 1) *Elymus hispidus* (Opiz) Melderis (intermediate wheatgrass; previously known as *Agropyron intermedium*); 2) *Bromus inermis* Leyss. (smooth bromegrass); 3) *Elymus elymoides* (Raf.) Swezey (bottlebrush squirreltail; previously known as *Sitanion hystrix*); 4) *Linum lewisii* Pursh (Lewis' blue flax); 5) *Penstemon palmeri* A. Gray (Palmer's penstemon); 6) *Sanguisorba minor* L. (small burnet); 7) *Artemisia tridentata* Nutt. subspecies *vaseyana* (mountain big sagebrush); 8) *Atriplex canescens* (Pursh) Nutt. (fourwing saltbush); 9) *Chrysothamnus nauseosus* (Pall. In Pursh) Britton in Britton and A. Br. (rubber rabbitbrush); and 10) *Purshia tridentata* (Pursh) DC. (antelope bitterbrush). Seeds were purchased from Granite Seed Company (Lehi, Utah). Seeds for each species were from the same seed lot, except for *Sanguisorba minor*, *Linum lewisii*, and *Elymus hispidus*. For these 3 species with different seed lots, the 2 lots for an individual species were mixed together to ensure a uniform seed mix throughout the experiment.

Sterilized dyed seeds—Sterilized, dyed seeds were used to track seed movement and changes in seed density through time. Because we did not expect the fertilizer treatment to influence movement or density of dyed seeds, only untreated mine waste and coversoiled plots were used for this portion of the study. Seeds were soaked in concentrated dye for 24 hours. Seeds for the upper plots were dyed neon pink and seeds for the lower plots were dyed neon green. The dye solution was drained off, then seeds were baked at 177°C until dry. Baking also sterilized the seeds and eliminated the possibility of dyed seeds germinating. Although we planned to use all 10 species used in the revegetation seeding, 2 species were not used; *Penstemon palmeri* seeds did not absorb the dye, and exposure to water activated the mucilaginous coat of *Linum lewisii*. Dyed seeds were prepared to attain 32 seeds m^{-2} for each of the 8 species for individual sample plots, and then combined with pure live seed mixes for each upper and lower study plot. Dyed seeds were hand broadcast with viable seeds on 5–7 February 1995.

Transplants—To determine if plants were capable of growth on angle of repose slopes. 6-month-old seedlings of *Bromus inermis, Elymus elymoides, Penstemon palmeri, Sanguisorba minor, Chrysothamnus nauseosus*, and *Purshia tridentata* plants were transplanted into the buffer areas. All 6 species were grown from the same seed lots used for the seeding portion of the experiment. Two species, *Penstemon palmeri* and *Purshia tridentata*, required a stratification treatment before germination. *Purshia tridentata* was soaked in water for 24 hours (Meyer and Monsen 1989). Then both *Purshia tridentata* and *Penstemon palmeri* seeds were sealed in individual tea bags, buried in moist sterilized sand, and placed in a 3°C walk-in cooler for 7 weeks. Cold-stratified seeds from these 2 species as well as seeds from the other 4 species were germinated at room temperature on moist filter paper in petri dishes, then planted into 164 ml Cone-tainers™ (Stuewe and Sons, Inc., Corvallis, Ore.) that were filled with a 65:10:25 mixture of topsoil, humus, and coarse sand.

Seedlings were cultured in a glasshouse for 4 months, during which time they were supplied with ample amounts of water and NPK fertilizer. Day length was also increased to 18 hours day^{-1} using 1 kW metal halide lamps (Ruud Lighting, Racine, Virg.). Starting in the fifth month, plants were hardened by gradually decreasing watering and fertilization frequencies and by decreasing greenhouse temperatures. During the second week of the fifth month, transplants were placed outside under a shade shelter and covered at night with a tarp to prevent frost damage. After 1 week outside, plants were moved to full sunlight but were still covered with a tarp at night. The plants were transported to the mine site on 28 April

1995, when they were approximately 6 months old. Over the next 10 days, containerized stock were planted into transplant plots within the buffer area on both sides of the upper and lower study plots (Fig. 1). Each transplant plot contained 60 individual plants. Ten individuals of each species were planted in a vertical row at 0.3 m apart; horizontal placement of the 6 species rows within each transplant plot was randomly assigned. "Dibbles" were used to make holes in the soil for the plants. Plants were gently removed from the Cone-tainers™, placed into the dibble-holes, and soil was gently placed around the individual plants.

Vegetation Sampling

Seedling establishment—Seedling density in each study plot was measured once a month from June through September 1995 and from May through September 1996. We counted the number of seedlings in 23 sample plots by systematically placing 0.09 m^2 plots across a study plot.

Transplant survival—Survival of transplants was evaluated once a month from June to September 1995, from May to September 1996. and once during May 1998. A plant was considered alive if it still had green leaves.

Plant water potential—Plant water potential measurements were collected at predawn and midday once every month from June to September 1995. Because it was unsafe to traverse slopes before first light, predawn measurements were collected after sunrise but before plots received direct sunlight. Water potential was measured on transplants of 3 species: *Elymus elymoides*, *Penstemon palmeri*, and *Chrysothamnus nauseosus*. These species were selected because they were representative grass, forb and shrub species plus they had plant characteristics that facilitated measurement of water potential. One transplant plot associated with each study plot (right or left) was randomly selected (Fig. 1). Within the sampled transplant plot, 3 independent water potential samples were collected from each of the 3 species sampled. A pressure chamber was used to determine leaf water potential (Waring and Cleary 1967, Holbrook et al. 1995) for *Elymus elymoides* and *Penstemon palmeri* and stem water potential for *Chrysothamnus nauseosus.* Leaves and stems were enclosed by plastic bags before excision to minimize measurement errors (Turner and Long 1980).

Plant nitrogen content and biomass — In order to measure plant nitrogen pools, samples were collected 27–30 July 1995. One transplant was harvested per study plot for the same species used for water potential measurements: *Elymus elymoides, Penstemon palmeri,* and *Chrysothamnus nauseosus*. Transplants were cut at ground level, placed in paper sacks, and air-dried. Once dry, samples were separated into stem, leaf, and reproductive components.

Prior to analysis of total nitrogen content, plant tissues were dried in a 60°C oven for 24 hours. Samples were weighed, then coarsely ground with a Wiley mill and finely ground with a MSD model dental amalgamator (Crescent Dental Manufacturing Company). A portion of the sample was then analyzed for percent total nitrogen with a Perkin-Elmer model 2400 CHN analyzer. Total aboveground plant nitrogen pools were calculated by multiplying the dry weight of each biomass component (stem. leaf, and reproduction) by its percent nitrogen content, then summing the products for each individual plant.

Plant canopy volume was measured on 24 May 1998 from 2 transplants per study plot for the same species used for water potential and plant nitrogen measurements. Maximum canopy width and the width perpendicular to the maximum were measured for *Chrysothamnus nauseosus* and *Penstemon palmeri*. Maximum basal width and the basal width perpendicular to the maximum were measured for *Elymus elymoides*. Maximum canopy height exclusive of seed stalks was measured from ground level. The mathematical formula for an ellipsoid was then used to calculate canopy volume.

Seed Bank and Soil Sampling

Seed bank—Soil cores to assess the seed bank were collected from unaltered mine waste and coversoil treatments. Samples were collected on 3 February 1995 (2 days prior to the seeding treatment), on 18 June 1995 (4.5 months after seeding), and on 4 November l995 (9 months after seeding). Prior to sampling, each upper and lower study plot was divided into nine, 3.33 m^2 sections and 4 of the 9 sections were randomly selected for sampling. In addition, the 5 x 10 m area between the study plots and an area of equal size below the lower study plots were each divided into 4 equal sections. One sample was collected from each of the 4 sections. A 10-cm diameter by 5-cm deep soil core (0.5 liter) was collected from all of the selected sections. Areas with stable, finer textured soils were preferentially sampled (as opposed to rocky areas or areas that were within erosion rills). These areas were chosen because they represent areas that are most conducive to seed germination and plant establishment, but note that they are not necessarily representative of the entire plot. After each soil core was collected, a pin flag was used to mark the sampled area to prevent repetitive sampling of the same area, but the holes were not backfilled.

Soil cores were air-dried and processed through a series of 4 soil sieves, which broke up dirt clods and allowed rocks to be retrieved and discarded. Seeds and other organic matter were then retrieved from the sieved soil using a water flotation method (Keeley 1978). Once dry, samples were examined under a microscope, and seeds were collected and identified. Seed recovery was calculated as the number of seeds extracted from the 0.5 liter soil cores divided by the total number of seeds expected given the cross sectional area of the soil core and the initial seeding rate; values are expressed as a percentage of the expected number of seeds.

Soil nutrient status—Soil samples were collected twice during the experiment to determine available soil nutrients. The first samples were collected 14–15 October 1994 prior to fertilization and seeding. The purpose of the initial soil samples was to determine if heavy metals within the soil might inhibit or prevent plant growth and to determine a fertilization rate. Two sets of soil samples were collected: 1 set for general nutrient status and the other set for the heavy metals arsenic and mercury. For general nutrient status, four, 0.5 liter soil cores were collected in a manner similar to that for seed bank analysis, then composited. Soil samples were allowed to air dry and then sent to Utah State University Analytical Laboratories for standardized soil analyses (pH, electrical conductivity, phosphorus (Olson method), potassium, texture, lime, total nitrogen, nitrate, organic carbon, particle size, and percent coarse figments). To reduce cost, only 16 of the 32 composited samples were analyzed: 1 composited sample from either the upper or lower study plot within each main plot was randomly selected for analysis. Eight of the 16 samples were randomly selected and also tested for cation exchange capacity.

For heavy metal analysis one, 0.5 liter soil core was collected from 2 slope locations in each main plot. The upper and lower study plot samples were then composited into 1 sample for each main plot. The samples were composited again by main plot treatment type. A total of eight, 2-liter soil samples (4 per dump) were sent to Chemex labs (Sparks, Nev.) and analyzed for arsenic and mercury. Because we had no indication of soil properties that might inhibit or prevent plant establishment or growth in the initial soil sample results, we did not conduct additional soil sampling prior to the beginning of the experiment.

A second set of soil samples was collected for nutrient analysis after 1 field season on 4–5 November 1995. Four, 0.5 liter soil cores were collected from each study plot. As in the initial sampling, the samples were composited and a pin flag was used to mark the sample location (to prevent repetitive sampling). Soil samples were allowed to air dry, then sent to Utah State University for analysis. All samples collected (32) were analyzed for pH, electrical conductivity, phosphorus (Olson), potassium, texture, lime, and total nitrogen.

Precipitation

One rain gauge was placed at each dump location on 3 February 1995. Antifreeze and oil were added to the rain gauge to prevent freezing and evaporation of precipitation. Measurements were collected every month during the 1995 and 1996 field seasons. Data for the beginning of the 1995 water year were estimated from precipitation at the closest National Climate Data Center weather station (Tuscarora, Nev.) with a simple proportional correction.

Statistical Analysis

Analysis of Variance (ANOVA) with General Linear Models procedures (GLM) were used to examine all data sets (SAS Institute Inc. 1987). Assumptions of normality, additivity, and variance homogeneity for ANOVA were checked. The Shapiro-Wilk statistic for normality ($P < 0.1$), normal probability plots, and stem leaf plots in the PROC UNIVARIATE procedure were used to determine if the data sets were normally distributed. Residual plots were used to examine the additivity and variance homogeneity of each data set. Data sets were checked for outliers by plotting standardized residuals against predicted values; no outliers were observed, therefore no observations were removed. When necessary, data were transformed to: 1) make error variances more homogenous; 2) improve additivity; and 3) improve normality. The Box and Cox test (Box and Cox 1964) was used to determine the appropriate power transformation.

In general, data sets with 1 or 2 measurement dates were initially analyzed using a split-strip-split plot model appropriate for the data set, whereas data with more than 2 measurement dates were analyzed as a repeated measures analysis. For all ANOVA's, $P \leq 0.05$ was considered statistically significant. The most common treatment factors for each data set were: dump location at 2 levels (North Generator and Burns Basin); either soil type at 2 levels (mine waste and coversoil) or treatment type at 4 levels (untreated mine waste, fertilizer, coversoil, and fertilizer plus coversoil); location on the slope at 2 levels (upper and lower study plots); species at 6 levels (*Bromus inermis, Elymus elymoides, Penstemon palmeri, Sanguisorba minor, Chrysothamnus nauseosus,* and *Purshia tridentata*); and time at varying levels. The general split-strip-split plot design was a split plot with respect to dump location, a strip plot with respect to treatment type and slope location, and a split-split plot with respect to species or time (Table 1). If dump and all dump interaction terms were not significant in the initial full model analysis, then the dump factor was removed from the model and the analysis was repeated on the simplified model (Table 1).

Three exceptions to this general pattern of statistical analyses occurred. First, insufficient computer memory was available to run a repeated measures analysis with all treatment factors for the transplant survival data set. Thus, time was removed from the initial analysis of the transplant survival data by averaging data over all sample dates. Data were then analyzed with a split-strip-split-split plot design. Because dump and all dump interaction terms were not significant in this ANOVA, dump was removed from the model, time was added back in, and transplant survival data were reanalyzed with a repeated measures analysis. Second, for seed density, measurements were collected at 4 locations on the slope rather than 2: in addition to the upper and lower study plots, the area between the upper and lower study plots and the area below the lower plot was sampled. Finally, plant nitrogen, transplant biomass, and water potential data sets had 3 levels of plant species (*Elymus elymoides, Penstemon palmeri,* and *Chrysothamnus nauseosus*) rather than 6.

To simplify presentation of the results, we have not included complete ANOVA tables. Instead, we only discuss those factors and interaction terms that were significant.

Results

Seed Densities

Very few seeds were present in the pretreatment seed bank. Five seeds of 2 genera used in our revegetation experiment, *Bromus* and *Chrysothamnus*, were recovered from 64 seed cores, which equates to an average of 0.5 and 2 seed m^{-2} for *Bromus* and *Chrysothamnus*, respectively. Unfortunately, identification of seeds to the species level was not possible because seeds of these 2 genera lack diagnostic characteristics. In addition, the pretreatment seed bank contained 1 or more seeds from the following taxa: *Argumone munita*, *Astragalus* spp., *Carex nebrascensis*, *Chenopodium* spp., *Cirsium* spp., *Cryptantha gracilis, Marrubium vulgare,*

Table 1. Summary of experimental design used for each type of data set. "N/A" indicates the treatment factor was not applicable to the data set; "N" indicates the number of treatment levels within a factor. "*" indicates this main effect and all of its interaction terms were not significant; statistical model was then simplfied by the removal of this factor.**

Data Set	Factor A	Factor B	Factor C	Factor D	Factor E	Final ANOVA Model
Seed Density	***Dump (N=2)	Soil Type (N=2)	Slope Location (N=4)	Species (N=10/8)	Time (N=2)	Strip-split-split-split plot
Seedling Density	Dump (N=2)	Main Plot Trt. (N=4)	Slope Location (N=2)	Time (N=10)	N/A	Repeated measures
Transplant Survival	***Dump (N=2)	Main Plot Trt. (N=4)	Slope Location (N=2)	Species (N=6)	Time (N=10)	Repeated measures
Pre-Treatment Soil	Dump (N=2)	Soil Type (N=2)	Slope Location (N=2)	N/A	N/A	Split-strip plot
Post Treatment Soil	Dump (N=2)	Main Plot Trt. (N=4)	Slope Location (N=2)	N/A	N/A	Split-strip plot
Plant Nitrogen	***Dump (N=2)	Main Plot Trt. (N=4)	Slope Location (N=2)	Speices (N=3)	N/A	Strip-split-split plot
Transplant Biomass	***Dump (N=2)	Main Plot Trt. (N=4)	Slope Location (N=2)	Species (N=3)	N/A	Strip-split-split plot
Plant ψ	Dump (N=2)	Main Plot Trt. (N=4)	Slope Location (N=2)	Time (N=3)	Time (N=4)	Repeated measures

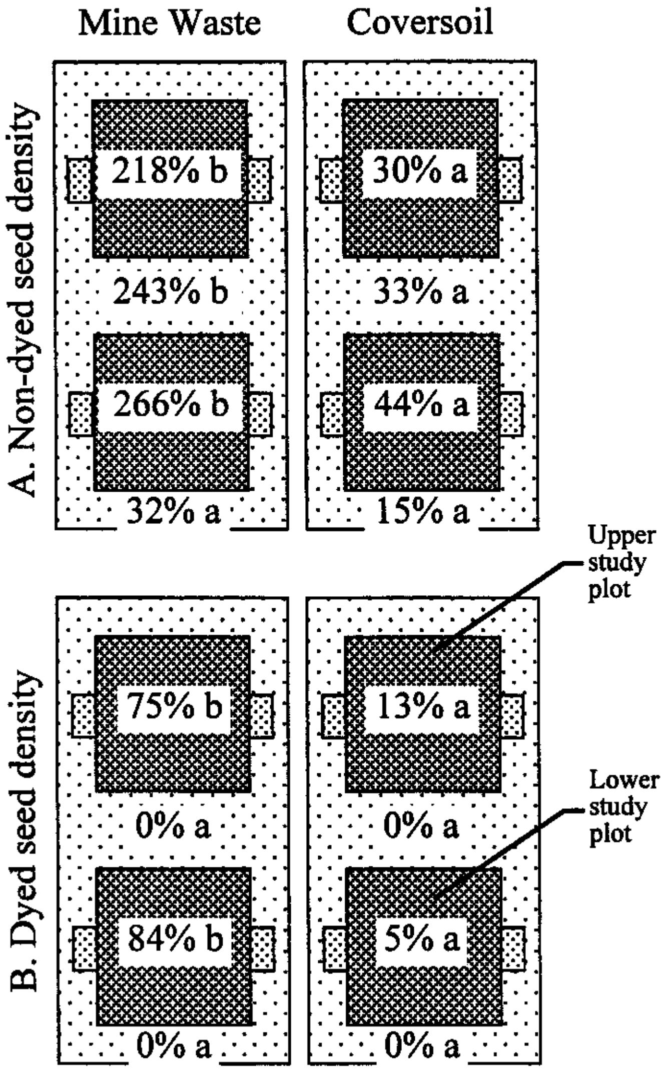

Fig. 2. Seed density, expressed as a percentage of the expected number of seeds, from soil cores collected 18 June and 4 Nov. 1995 for non-dyed (A) and dyed (B) seeds (n = 32). Mean values followed by the same letter within each graph were not significantly different.

Oxalis spp., *Polygonum douglasii*, *Potentilla* spp., and *Viola* spp. On average, the pretreatment seed bank contained a total of 35 seed m^{-2} over all species, compared to over 600 seed m^{-2} (includes live seeds, infertile seeds, and dyed seeds) that were broadcast. Because the pretreatment seed bank contained only 5 seeds that were in the same genus as those used in the study, pretreatment seed densities were not factored into the data analyses.

Non-dyed seed densities were significantly different among the 4 slope locations on untreated mine waste but not for coversoiled plots (Fig. 2A). However, the differences on mine waste were contrary to expectations if seeds preferentially move down slope: seed densities below the lower study plots were significantly lower than those for all other up-slope locations. These interpretations of the location effect were made cautiously because the location main effect ($P < 0.001$), the soil*location interaction ($P = 0.012$), and the species*location interaction ($P < 0.001$) were all significant. For the species*location interaction, seed densities below the lower study plot were significantly lower than at least 1 up-slope location for 7 species but not significant for 3 species (*Linum lewisii*, *Penstemon palmeri*, and *Artemisia tridentata*). Thus, the location main effect and species*location interaction indicated that significant location differences occurred over both soil types, whereas the soil*location interaction indicated that the location differences were significant only on mine waste. Because seed densities were 6 times greater on mine waste in comparison with coversoil, we inferred that this greater seed density on mine waste skewed the significance of the main location effect. Thus, our interpretation of the location effect was based on the soil*location interaction.

Mine waste had significantly higher seed densities than coversoil for all slope locations except below the lower study plot. The soil main effect was significant ($P = 0.017$), and mean comparisons (Fig. 2A) for the soil*location interaction indicate a significant difference between mine waste and growth medium soils for all but the lowest slope location. Mean comparisons for the soil*species interaction ($P < 0.001$) showed that mine waste had significantly higher seed densities than coversoil for all species except *Linum lewisii*, *Penstemon palmeri*, and *Artemisia tridentata* (data not shown). In addition, mean comparisons for the date main effect ($P = 0.018$) and soil*date interaction ($P < 0.00l$) indicate that: 1) significantly greater numbers of non-dyed seeds were recovered on mine waste on both sample dates; and 2) seed recovery significantly decreased with time for mine waste but did not significantly change for coversoil.

Non-dyed seed density for *Artemisia tridentata*, *Penstemon palmeri*, and *Linum lewisii* were significantly lower than those for all other species (species main effect $P < 0.001$). The species*location, species*treatment, and species*date ($P = 0.038$) interactions indicated variations in species groupings within study plot location and main plot treatment (data not shown). For example, seed densities for *Elymus elymoides, Bromus inermis, Elymus hispidus,* and *Purshia tridentata* prior to seed dispersal were significantly higher than densities after seed dispersal.

In general, results for the dyed seeds were similar to those for non-dyed seeds. For example, the recovery of dyed seeds from the upper and lower study plots was not significantly different within a particular soil type, but recovery from the upper and lower study plots was significantly greater than that between the plots and below the lower plot (Fig. 2B) only for the mine waste (location main effect $P = 0.003$; soil*location interaction $P = 0.003$). Second, densities of dyed seeds were significantly greater on mine waste than on coversoil for both the upper and lower slope locations (soil main effect $P = 0.042$). Finally, species differences for dyed seeds were also similar to those for non-dyed seeds (species main effect $P < 0.001$; species*location interaction $P < 0.001$). The most interesting results were that no dyed seeds were recovered in the plot areas located between the upper and lower study plots or below the lower study plots for either soil type (Fig. 2B). In addition, no seeds sown in the upper plots (dyed pink) were found in lower study plots nor were seeds sown in the lower study plots (dyed green) found in the upper study plots.

Seedling Densities

Seedling densities were significantly greater on both treatments with coversoil (i.e., coversoil and fertilizer plus coversoil treatments) than on plots with mine waste (i.e., untreated mine waste and fertilizer treatment). The treatment main effect was significant (P = 0.050), and mean comparisons indicate significant differences between soil types but no significant differences between fertilizer treatments (Table 2). Mean comparisons for the dump*date interaction (Fig. 3A) indicate that seedling densities on the Burns Basin Dump generally were higher than those on the North Generator Dump, but this difference was significant on only 6 of the 10 sampling dates.

Table 2. Mean comparisons of seedling density among main plot treatments (n = 80). Mean values followed by the same letter are not significantly different (P > 0.05).

Main Plot Treatment	Seedling Density
	(plants m^{-2})
Untreated Mine Waste	0.25 a
Fertilizer	0.07 a
Coversoil	17.75 b
Fertilizer & Coversoil	12.25b

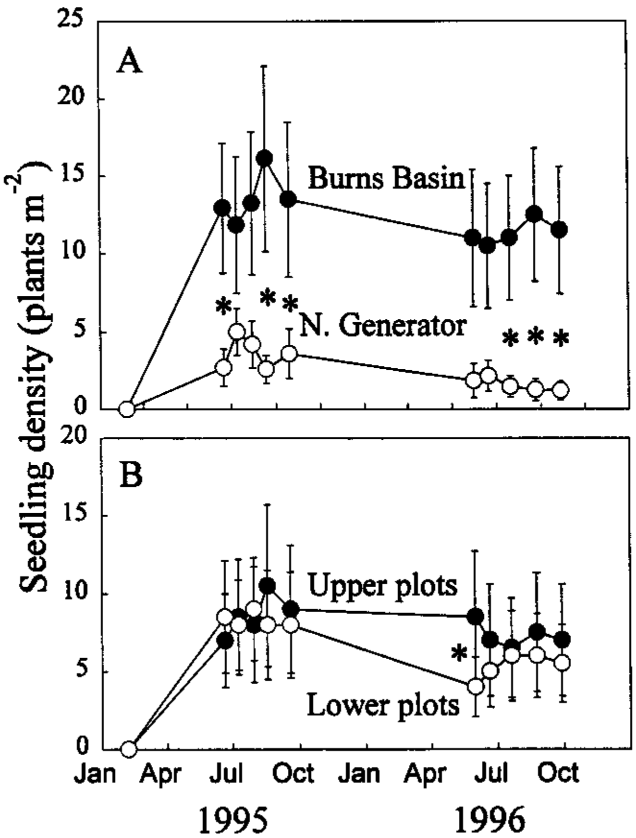

Fig. 3. Seedling density data. Asterisk indicates that means were significantly different on that particular sampling date. Error bars are standard error of the mean. A. Mean comparisons for the dump*date interaction (P = 0.018; n = 16). B. Mean comparisons for the location*date interaction (P = 0.025; n = 16).

Although the location*date interaction was significant, seedling densities at different slope locations were only statistically different on 1 measurement date early in the second growing season (Fig. 3B). The upper study plot had significantly higher seedling densities than the lower study plot on 31 May 1996, which is contrary to expectations if seeds preferentially move down slope. The location effect and all other interaction terms with location were not significant in the analysis of variance.

Transplant Survival

Survival of transplants on both sets of coversoiled plots was significantly greater than that on both untreated and fertilized mine waste (Table 3). No significant differences occurred between fertilized and unfertilized plots within the same soil type. The significant treatment*date interaction (P < 0.001) supported the treatment main effect results stated above. From 19 August 1995 until 28 September 1996, transplant survival was significantly higher for coversoiled plots, and no significant differences occurred between fertilizer treatments within the same soil type on any sampling date (Fig. 4). For example, even though transplant survival on untreated mine waste consistently ranked higher than survival on fertilized plots, survival rates on untreated and fertilized plots were not statistically different on any sampling date.

Table 3. Mean comparisons of transplant survivorship among main plot treatments (treatment main effect P = 0.005; n = 480). Mean values followed by the same letter are not significantly different (P > 0.05).

Main Plot Treatment	Survivorship
	(%)
Untreated Mine Waste	59% a
Fertilizer	43% a
Coversoil	82% b
Fertilizer & Coversoil	86% b

However, by the beginning of the fourth growing season (24 May 1998), survival rate decreased greatly for the coversoil treatments, and survival rates were not significantly different among treatments (Fig. 4). Although the treatment*location*date interaction was also significant (P = 0.023), differences among treatments at 1 slope location within any sample date were generally similar to those indicated by the treatment*date interaction. The exception was for the upper study plots; the difference in survival rates between the coversoil and mine waste treatment was not significant on any measurement date (data not shown).

Treatment effects did vary somewhat among species, as suggested by the significant treatment*species interaction (P < 0.001). For all species except *Penstemon palmeri* and *Chrysothamnus nauseosus*, transplant survival on mine waste (untreated and fertilizer treatment) was significantly lower than that on coversoils (data not shown). However, as with the treatment main effect and treatment*date interaction, transplant survival on the coversoil

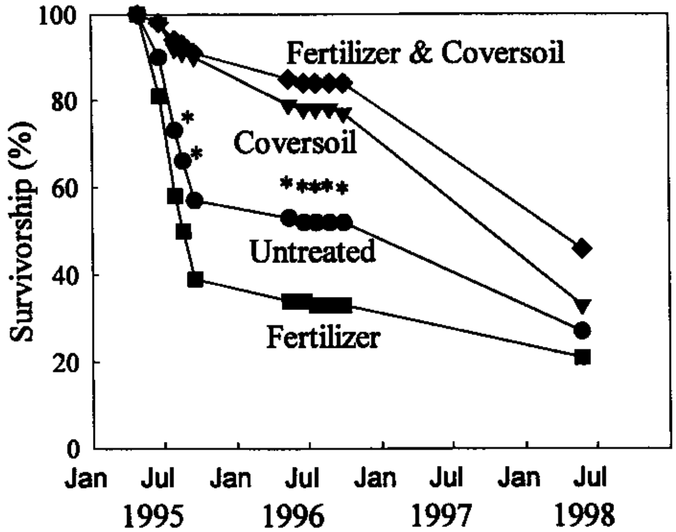

Fig. 4. Transplant survivorship data (n = 48). Treatments above the asterisk were significantly different from those below the asterisk on that particular sampling date. The treatments above or below the asterisk were not significantly different from each other. For dates without an asterisk, treatments were not significantly different.

and fertilizer plus coversoil treatments was not statistically different within any 1 species except for *Chrysothamnus nauseosus*. Similarly, the effect of fertilization on transplant survival rates for plots with mine waste soil was not significant for all species except *Bromus inermis* and *Penstemon palmeri*.

Transplant survival varied significantly among species, but species differences within any treatment were generally not significant. The species main effect (P = 0.023) indicated that survival of *Bromus inermis*, *Penstemon palmeri*, and *Sanguisorba minor* was significantly less than that of other species (data not shown). However, mean comparisons for the treatment*species interaction indicate that differences among species varied within treatment type (data not shown). Transplant survival was highest for *Penstemon palmeri* on untreated mine waste, for *Elymus elymoides* on fertilized plots, and for *Purshia tridentata* on both coversoil and fertilizer plus coversoil. However, most pairwise comparisons of species within a treatment were not significant.

Most plant mortality occurred during the first year for mine waste and fertilizer treatments but between the second and fourth years after transplanting for coversoil and fertilizer plus coversoil treatments (Fig. 4). Survivorship during the second year of the study was not significantly different among dates.

Soil Nutrients

Although soil parameters for both coversoil and mine waste were within ranges favorable to plant growth, coversoil had higher nutrient levels and fewer coarse fragments. Pre-fertilization coversoil contained significantly higher amounts of total nitrogen, potassium, phosphorus, organic carbon, and nitrate than mine waste soils, but had significantly lower electrical conductivity (Table 4). The percentage of coarse fragments (>2mm) in mine waste soils (69%) was significantly higher than that in growth medium soils (51%). Soil texture for both soil types varied greatly within each study plot and ranged between silt loam, silty clay loam, clay loam, loam, and sandy clay loam.

The dump*soil interaction was only significant for potassium (P = 0.024) and phosphorus (P = 0.027). Mean comparisons for potassium indicated that differences between mine waste and coversoil were significant for Burns Basin Dump but not for North Generator Dump (data not shown). For phosphorus, differences between mine waste and coversoil were significant at both dumps. The dump*soil interaction also indicated differences in potassium and phosphorus between dumps for coversoil but not for mine waste. Coversoil on the Burns Basin Dump had significantly greater potassium levels than that on the North Generator Dump, but significantly less phosphorus.

The dump*location interaction was only significant for nitrate (P = 0.021). Mean comparisons indicate that the upper study plots at the North Generator Dump (13 mg kg^{-1}) contained significantly greater amounts of nitrate than those at the Burns Basin Dump (4 mg kg^{-1}). However, nitrate levels in the lower study plots at the North Generator Dump (9 mg kg^{-1}) and Burns Basin Dump (4 mg kg^{-1}) were not significantly different. In addition, nitrate levels among upper and lower study plots were not significantly different within each dump.

Although significant differences among treatments for total nitrogen, phosphorus, potassium, and pH occurred 1 year after treatment (Table 5), these differences were related to soil type differences (i.e. mine waste versus coversoil), as opposed to fertilizer differences, for all soil factors except phosphorus. As occurred prior to fertilization, both coversoil treatments contained significantly higher amounts of total nitrogen, phosphorus, and potassium than both untreated and fertilized mine waste (Table 5). The reverse occurred for pH: mine waste had significantly higher pH values than coversoil. Differences due to the application of fertilizer were only detectable for phosphorus. Fertilized plots contained significantly higher amounts of phosphorus than untreated mine waste, and fertilizer plus coversoil had significantly higher phosphorus levels than coversoil (Table 5).

The dump main effect (P = 0.039) and the dump*treatment interaction (P = 0.037) were significant only for phosphorus. Over all treatments, North Generator

Table 4. ANOVA P values for the soil main effect and mean comparisons of soil properties prior to the application of fertilizer (n = 8). Mean values followed by the same letter within a row are not significantly different (P > 0.05).

Soil Property	ANOVA P value	Soil Type: Mine Waste	Soil Type: Coversoil
Total Nitrogen (%)	0.002	0.06 a	0.12 b
Potassium (mg/kg)	0.010	78 a	125 b
Phosphorous (mg/kg)	0.004	6 a	24 b
pH	NS	7.7	7.4
Organic Carbon (%)	0.029	0.7 a	1.1 b
Nitrate (mg/kg)	0.034	2 a	13 b
Elec. Conductivity (mmhos/cm)	0.031	1.2 b	0.7 a

Table 5. ANOVA P values for the treatment main effect and mean comparisons of soil properties one year after fertilization (n = 8). Mean values followed by the same letter within a row are not significantly different (P > 0.05).

Soil Property	ANOVA P value	Main Plot Treatment: Untreated Mine Waste	Fertilizer	Coversoil	Fertilizer & Coversoil
Total Nitrogen(%)	<0.001	0.06 a	0.06 a	0.14 b	0.12 b
Potassium (mg/kg)	0.007	56 a	72 a	123 b	128 b
Phosphorus (mg/kg)	<0.001	4 a	10 b	19 c	24 d
pH	0.001	7.7 b	7.7 b	7.1 a	7.1 a
E. C. (mmhos/cm)	NS	1.0	1.0	1.7	2.2

Dump plots treated with coversoil or fertilizer plus coversoil contained significantly higher amounts of phosphorus than untreated and fertilized mine waste on the North Generator Dump as well as all treatments at the Burns Basin Dump. However, treatment effects within dump were generaly similar to the main treatment effect: coversoil contained greater amounts of phosphorus than mine waste within each dump, and a fertilizer effect on soil phosphorus occurred between the untreated and fertilizer treatments (data not shown).

Plant Nitrogen Content and Biomass

Nitrogen content—Differences in plant aboveground nitrogen pools among treatments (treatment main effect P = 0.030) reflected soil type differences. Plants on coversoil with or without fertilizer contained significantly higher nitrogen pool sizes than plants on both mine waste treatments (Table 6). Nitrogen pool sizes of plants on fertilized and unfertilized plots with the same soil type were not significantly different. Mean comparisons for the treatment*species interaction (P = 0.008) indicated similar results as the main treatment effect: greater plant nitrogen pool size for plants on both coversoil treatments, but differences were significant only for *Elymus elymoides*. As observed with the treatment main effect, significant differences between unfertilized and fertilizer treatments did not occur within any 1 species (data not shown).

Table 6. Mean comparisons of transplant above ground plant nitrogen pools among main plot treatments (n = 24). Mean values followed by the same letter are not significantly different (P > 0.05).

Main Plot Treatment	Above Ground Plant Nitrogen Pools
	(g)
Untreated Mine Waste	2.8 a
Fertilizer	2.9 a
Coversoil	9.3 b
Fertilizer & Coversoil	6.9 b

Both plant aboveground nitrogen pools and tissue nitrogen content varied significantly among species (species main effect P < 0.001 for both variables), with *Penstemon palmeri* having the lowest nitrogen values (data not shown). The species*treatment interaction was only significant for the plant aboveground nitrogen pool size. Species ranking was consistent with the main treatment effect: *Chrysothamnus nauseosus* had the highest nitrogen pools and *Penstemon palmeri* had the lowest for all treatment types except coversoil. For the coversoil treatment, *Elymus elymoides* contained the highest nitrogen pools and *Chrysothamnus nauseosus* the lowest. However, the statistical grouping of species within treatment type varied.

Biomass—Plant biomass in June 1995 did not differ among treatments. None of the factors or interactions in the strip-split-split analysis of variance were significant.

Canopy volume at the beginning of the fourth growing season was significantly different among treatments for only 1 species (species main effect P < 0.00l; treatment*species interaction P < 0.001; treatment*location*species interaction P = 0.003). *Chrysothamnus nauseosus* on coversoil was significantly larger than that on mine waste (Table 7). Mean comparisons among treatments for *Elymus elymoides* and *Penstemon palmeri* indicated that plant sizes were always higher for coversoil than for mine waste, but these differences were not statistically significant. Significant differences between unfertilized and fertilizer treatments did not occur for any species (Table 7).

Water Potential

Long-term (35 yr.) average annual precipitation at the closest National Climate Data Center official weather station, Tuscarora, Nev. (41°19'N 116°13'W, 1,881m), is 33cm. Precipitation at Tuscarora for the period 1 October 1994 to 30 September 1995 was 6.5 cm above the long-term average and for the period 1 October 1995 to 30 September 1996 was 3.4 cm above the long-term average. Precipitation at the study plots averaged 73 cm and 51 cm during the 1995 and 1996 water years, respectively (data not shown). The majority of the precipitation was from snow received in the winter and early spring.

Differences in predawn plant water potential among treatments reflected soil type rather than fertilizer treatment at the Burns Basin Dump (Table 8). Mean comparisons for the dump*treatment interaction (P = 0.031) indicated that water potential of plants on plots that received the coversoil or fertilizer plus coversoil treatments was significantly greater than that on untreated mine waste or fertilizer treatments at Burns Basin Dump. Predawn plant water potential was not significantly different among treatments at the North Generator Dump.

Predawn water potential for plants located on the North Generator Dump was generally lower than that on the Burns Basin Dump. However, the difference was only statistically significant for the coversoils (Table 8). Furthermore, the dump*species*date interaction (P = 0.037) indicated that differences between dumps occurred on all dates for *Penstemon palmeri*, on all measurement dates except 1 for *Elymus elvmoides*, on none of the dates for *Chrysothamnus nauseosus.*

Table 7. Mean comparisons of transplant canopy volume, measured at the beginning of the fourth growing season 2 after transplanting, among main plot treatments for each species (n = 8). Mean values followed by the same letter within the table are not significantly different (P > 0.05).

Species	Untreated Mine Waste	Fertilizer	Coversoil	Fertilizer & Coversoil
Elymus elymoides	0.1 a	<0.l a	0.8 a	1.3 a
Penstemon palmeri	12 a	6 a	188 a	108 a
Chrysothamnus nauseosus	24 a	13 a	2,066 b	2,559 b

Table 8. Mean comparisons of predawn plant water potential (w) among main plot treatments and dump (n = 48). Mean values followed by the same letter within the table are not significantly different (P > 0.05).

Site	Mine Waste	Fertilizer	Coversoil	Fertilizer & Coversoil
	(MPa)	(MPa)	(MPa)	(MPa)
Burns Basin Dump	–0.86 b	–0.84 b	–0.53 a	–0.46 a
North Generator Dump	–0.85 b	–0.97 b	–0.81 b	–1.25 b

Predawn plant water potential values varied significantly among species (species main effect P = 0.005), with *Chrysothamnus nauseosus* (mean over all dates = –0.88 MPa) having the most negative values and *Penstemon palmeri* (–0.78 MPa) the least. The difference between *Chrysothamnus nauseosus* and *Penstemon palmeri* was significant, but no significant differences occurred between *Elymus elymoides* (–0.85 MPa) and *Chrysothamnus nauseosus* or between *Elymus elymoides* and *Penstemon palmeri*. Mean comparisons for the species*date interaction (P < 0.001) indicated that differences among species were primarily due to large differences among species early in the growing season (data not shown).

Mid-day plant water potential values varied significantly among species within the first 2 measurement dates (species*date interaction P = 0.004). Water potential for *Chrysothamnus nauseosus* was significantly lower than that for *Elymus elymoides* on the first measurement date, but differences between *Penstemon palmeri* and *Chrysothamnus nauseosus* were not significant (data not shown). On the second measurement date, *Penstemon palmeri* was significantly lower than *Elymus elymoides*, but differences in plant water potential between *Chrysothamnus nauseosus* and the other 2 species were not significant on the second measurement date. Mid-day plant water potential values among species were not significantly different on the last 2 measurement dates.

Discussion

This study examined 4 mechanisms that may influence revegetation of angle of repose slopes: 1) long distance movement of seeds along the slope face; 2) effects of coversoil on seedling establishment: 3) effects of fertilization on plant establishment; and 4) gradients of plant water status along angle of repose slopes. Physical forces such as wind and slope characteristics interact with seed and soil surface characteristics to determine seed dispersal distance and direction (Johnson and Fryer l992, Matlack l989, Watkinson l978, Westelaken and Maun 1984). For example, gravity can move seeds downslope in steep terrain. However, the results from our study indicate that long distance, downslope movement of seeds was not significant on stable slopes over the February to November time period. If seeds had been transported down slope by wind, water, or gravity, a seed gradient would have existed with fewer seeds at the upper study plots and more at the lower study plots. In addition, if seeds were moving down slope. fewer seedlings would have been present on the upper plots, provided the conditions necessary for seedling establishment were adequate. The only seed gradient detected in this study (Fig. 2A) was contrary to expectations: the area located below the lower study plot on mine waste had significantly fewer non-dyed seeds than all other up slope locations. Furthermore, no dyed seeds sown in the upper plots (dyed pink) or seeds sown in the lower plots (dyed green) were found outside of the plots in which the seeds were sown. However, note that our seed bank sampling was restricted to areas outside of erosion rills and areas of mass soil movement. With erosion and mass wastage, seeds would, of course, move long distances downslope, but seeds initially near the soil surface would likely be buried too deeply by eroding sediments for seedling emergence.

The presence of fine soil materials from coversoiling facilitated seedling emergence (Table 2) and enhanced transplant survival (Table 3), as has been noted in many previous studies (e.g. DePuit and Redente 1988, Ferris et al. 1997, Harris et al. 1996, Munshower 1994). We expected greater seedling densities on coversoil if its fine texture facilitated soil-seed contact and provided the necessary conditions for seed germination and seedling establishment. Likewise we expected higher transplant survival rates on coversoil if the fine texture enhanced soil-root contact and provided the necessary conditions for survival. In contrast, few seedlings emerged on mine waste, even when fertilized. Clearly, seed transport and fate did not greatly influence seedling distribution patterns on mine waste. On coarse textured mine waste soil, an adequate seed bank was present (Fig. 2A), yet very few seedlings emerged on these sites (Table 2). The presence of seeds along with the absence of seedlings indicates that some mechanism other than seed transport is responsible for limiting seedling establishment on mine waste. Because approximately 50% of the transplants on mine waste were able to survive during the first 2 years, mine waste soil is adequate to provide soil-root contact and water and nutrients are in sufficient quantities to sustain the growth of mature plants. Thus, low seedling densities on mine waste indicate the absence of microsite conditions that favor seed germination and seedling establishment. Although soil-seed contact was probably 1 of the inadequate microsite conditions that limited seed germination on mine waste, the data set from this study did not quantify soil-seed contact or other conditions such as soil moisture and temperature that influence seed germination and seedling emergence and survival.

Although fine textured coversoil was more susceptible to erosion and mass movement, there was no indication that soil movement was responsible for shearing roots from their shoots. If shearing occurred, seedlings would have been expected to emerge but not survive on coversoil treatments whereas transplants would have survived. Seedlings emerged and survived on coversoil (Fig. 4). Thus, shearing did not inhibit seedling survival on coversoil.

Nutrient availability did not appear to limit seedling or transplant survival on angle of repose slopes. If soil nutrients had not been available in sufficient quantities to sustain plant survival, then we expected greater seedling density and transplant survival through time on fertilized plots. However, no statistical differences in seedling density or transplant survival rates occurred between unfertilized and fertilized plots (Tables 2, 3). Results from soil analysis of mine waste also indicated that soil nutrients were present in sufficient quantities to support plant growth (Table 4). Thirdly, downslope movement of soil nutrients was not detected. If nutrients were transported downslope, then we expected a nutrient gradient with low nutrient levels at the upper study plots and high nutrient levels at the lower study plots. However, no statistical differences between upper and lower study plots occurred for soil nutrients or for plant aboveground nitrogen values.

Plant water potential data indicated no treatment or location differences. If the presence of fine textured soils had increased water-holding capacity, then we expected plants on coversoil to be less water stressed than plants on mine waste. In addition, if water had preferentially accumulated downslope, then we expected plants in the lower study plots to be less water stressed than plants in upper plots. Neither of these expectations were supported by our results.

When all our results are considered in total, inadequate microsite conditions for seed germination and seedling establishment on mine waste was the primary factor that inhibited plant establishment on angle of repose slopes. Although coversoiling increased both seedling emergence and transplant survival, coversoiled angle of repose slopes were more susceptible to soil erosion and mass soil movement. Soil loss was not measured in the experiment, but erosion rills and mass soil movement were visually more common on coversoil than on mine waste. In addition, transplant survival on coversoil dropped from 80% to 40% during the third growing season, and soil type differences were no longer significant. Thus, long-term revegetation success and the risk of mass soil wastage (with subsequent sediment load into the watershed) need to be carefully considered when coversoiling angle of repose slopes to revegetate from seeds.

Transplanting container-grown plants onto mine waste is an alternative to seeding that does not require coversoiling angle of repose slopes. Our results indicate that water, nutrients, and soil characteristics of mine waste were sufficient to sustain growth of container-grown plants and at least some transplants survived on mine waste through 4 growing seasons. However, survival rates and plant biomass of container-grown stock on mine waste were significantly lower than those on coversoil during much of the study period. Thus, the expense to transplant containerized stock directly onto angle of repose mine waste has to be carefully considered given the lowered potential for long term establishment of vegetation.

The results of this study indicate that although the coarse textured soils on angle of repose slopes provide for slope stability, they also limit revegetation by inhibiting seed germination and seedling establishment. In contrast, highly erosive, fine textured coversoils may enhance plant establishment and survival during the short term, but unstable slopes eventually lead to plant mortality. To ensure the highest revegetation success, an alternative method is needed that provides both good soil-seed contact and long-term soil stability. For example, hydro-seeding and hydro-mulching have been successful on angle of repose slopes (Golder 1994), but long-term slope stabilization has not been adequately established with these techniques.

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A comparison of soil chemical characteristics in modified rangeland communities

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Abstract

The effects of converting native prairie to simplified agronomic communities on primary production and soil quality are expected to differ over the short-term. A study was initiated at 4 locations: a Mixed Prairie with S*tipa comata* Trin. & Rupr. dominant in the Brown Soil Zone (1994), a Mixed Prairie with *S. comata* and *S. viridula* Trin. dominant in the Dark Brown Soil Zone (1993), and 2 in the Fescue Prairie with *Festuca campestris* Rydb. dominant in the Black Soil Zone (1993). At each of the 4 sites, 5 treatments representing common production systems were seeded as monocultures [2 grass species, alfalfa (*Medicago sativa* L. 'Beaver'), and 2 spring wheat (*Triticum aestivum* L. 'Katepwa) seeded as either continuous or as wheat-fallow], and 1 treatment consisting of abandoned cultivation were compared with a native community in a randomized complete block design with 4 replicates. One site in the Black Soil Zone was an overgrazed prairie (2.4 animal unit month ha^{-1} since 1949) and a second was mostly ungrazed for the previous 50 years with occasional light fall-grazing. Soils of the modified communities were different ($P < 0.05$) than of the native community with respect to percent carbon and nitrogen, concentration of monosaccharides, and concentration of most phosphorus constituents. Modifying the community through cultivation and seeding usually caused a reduction in the measured variable except for $NaHCO_3$ inorganic phosphorus that increased. Cultivation rather than the plants of the new community was believed responsible for most of the observed changes in C, N, and various P fractions and the loss of water-stable aggregates remaining on the 2.0 and 1.0 mm sieves. Although the contribution of seeded species on the chemical and physical characteristics would not have been significantly expressed in 2 to 3 years and many more years would be required to reach a steady state, monosaccharide distribution had nevertheless started to shift to one that was plant-affected.

Key Words: steady state, monoculture, Mixed Prairie, fescue prairie, phosphorus, soil-plant interaction

Resumen

Es de esperar que el efecto de convertir pasturas nativas a comunidades agronóinicas simples en producción priinaria y calidad de suelo, difieran a corto térrnino. Fue iniciado un estudia en cuatro sitios: una Pradera Mixta con *Stipa comata* Trin. & Rupr. dominante en la zona de suelos castafios (1994), una Pradera Mixta con *S. comata* y *S. viridula* Trin. dominante en La zona de suelos castaflo oscuro (1993) y dos en la zona de Praderas con Festucas, siendo Festuca campestris Rydb. La dominante de la zona de suelos negros (1993). En cada de los cuatro sitios, se implementaron cinco tratamientos representativos de los sistemas de producción más comunes como monocultivos [dos especies de gramineas. alfalfa (*Medicago sativa* L. 'Beaver') y dos de trigo de primavera (*Triticum aestivuin* L. 'Katepwa') sembrados en forma continua o como trigo-barbecho] y un tratamiento consistente en un cultivo abandonado comparándolo con una comunidad de plantas nativas en un diseflo de bloque seleccionado completainente al azar con cuatro niplicas. Un sitio en la zona de suelo negro fue una pradera sobrepastoreada (2,4 unidades animal por mes y por ha desde 1949) y el segundo sitio fuee prácticamente no pastoreado en los previos 50 años con pastoreos otoñales ocasionales. Los suelos de las comunidades modificadas fueron diferentes ($P < 0.05$) de las comunidades nativas con respecto al porcentaje de carbón y nitrógeno, la concentración de monosacáiridos y la concentración de la mayoria de los constituyentes del fósforo. la modificación de la comumdad a través de la cultivación y el sembrado generalmente causó una reducción en las variables medidas, excepto por el CO_3NaH fósforo inorgánico el cual aumentó. Se cree que la cultivación más que las plantas de la nueva comunidad fueron las responsables por la mayoria de los cambios observados en C, N y varias fracciones de P y la pérdida de agregados de agua-estable retenido en los tamizes de 2.0 mm y de 1.0 mm. Aunque la contribución de especies sembradas en las características químicas y fisicas no hubieran sido significadamente expresadas en 2 ó 3 años y muchos más años serian necesarios para llegar a una situación estable, sin embargo la distribución de monosacáiridos empezo a cambiarse hacia uno que era afectado por la planta.

The production-oriented goals of agriculture have resulted in tremendous changes in land-use on the prairies. A number of grass species have been introduced over the years, such as crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.), Russian wildrye (*Elymus junceus* Fisch.), smooth bromegrass (*Bromus inermis* Leyss.) and orchard grass or cock's foot (*Dactylis glomerata* L.). Other areas have been cultivated to grow wheat (*Triticum aes - tivum* L.) and alfalfa (*Medicago sativa* L.). Changes in soil quality by converting the native prairie to monocultures might be expected if the hypothesis is accepted that the prairie has devel-

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oped for optimal exploitation of the environment and any changes are retrogressive (Porter et al. 1996). However, evidence is lacking on which to base definitive conclusions. The effects of converting native prairie to monoculture systems, on primary production and soil quality, are expected to differ over the short- and long-terms. It is hypothesized that above-ground production of seeded forages and cereals will be greater than that of native range in the first few years after establishment while indices of soil quality, such as organic matter and water stable aggregates, will have been transformed. However, in the long-term, i.e., more than 10 years, above-ground production may well be similar while the rate of deterioration in soil quality may decrease. This research examines the short-term adjustments to soil disturbances.

For the study reported here, we hypothesized that the inherent or natural quality of range soils is immediately affected by the introduction, via cultivation, of monocultures. Organic C and N, monosaccharides, P, and water-stable aggregate fractions that remain on the 2.0 and 1.0 mm. sieves (>2.0 + >1.0 mm) were selected as important indicators of soil quality. Carbon and N have been studied in various grassland systems but the fate of P is relatively unknown (Schimel et al. 1985). Conversion of native grasslands to agronomic communities is expected to alter their composition in the soil, but at some time a new steady state will be reached. Steady states are generally only established in plots approaching 50–100 years such as the Rothamsted, Sanborn, and Morrow plots (Jenkinson 1991, Mitchell et al. 1991). This study attempts to establish a time frame as to when vegetation effects will start to synergise with cultivation effects leading to a new steady state.

Materials and Methods

Site Description

The study was conducted at 4 sites in southern Alberta. One site was at the Agriculture and Agri-Food Canada Substation at Onefour (49°03'N 110°27'W) with average precipitation of 310 mm, Orthic Brown (Aridic Haplustoll) soils, and a *Stipa-Bouteloua* faciation in the Mixed Prairie. The second site was at the Animal Diseases Research Institute (ADRI) near Lethbridge (49° 43'N 112°58'W) where average precipitation is 420 mm; the soils are Orthic Dark Brown (Typic Haplustoll) and the plant community is a *Stipa-Bouteloua-Agropyron* faciation in the Mixed Prairie. The third and fourth sites were at the Agriculture and Agri-Food Canada Substation west of Stavely in the Porcupine Hills (50°11'N 113° 58'W) with an average precipitation of 550 mm, Orthic Black (Typic Hapludoll) soils and in a fescue grassland dominated by rough fescue (*Festuca campestris* Rydb.). One of the Fescue Prairie sites was grazed at 2.4 animal unit month ha^{-1} since 1949 and the second was mostly ungrazed for the prior 50 years but experienced occasional light grazing in fall. The vegetation of all 4 sites has been described by Moss and Campbell (1947) and Coupland (1961). Each site was enclosed with a 4-strand barbed-wire fence that excluded livestock.

Methods

At each site, 7 treatments representing common production practices were imposed and compared with the native community in a randomized complete block design with 4 replicates. The plot size was 3 x 10 m. The treatments were: 1) native prairie, 2) crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) on the Mixed Prairie sites (Onefour and Lethbridge) and orchard grass (*Dactylis glomerata* L.) on the Fescue Prairie sites, 3) Russian wildrye (*Elymus junceus* Fisch.) on the 2 Mixed Prairie sites (Onefour and Lethbridge) and smooth bromegrass (*Bromus inermis* Leyss.) on the Fescue Prairie sites, 4) spring wheat and fallow in rotation, 5) continuous spring wheat (*Triticum aestivum* L. 'Katepwa'), 6) alfalfa (*Medicago sativa* L. Beaver'), 7) abandoned cultivated land to allow natural succession. In the grazed Fescue Prairie site, an 8th treatment was included that consisted of a native community (Treatment 8) outside the exclosure to allow a comparison of recovering grazed prairie within the exclosure.

All plots were established in spring (Dormaar and Willms 2000) by cultivating and seeding. Following cultivation, the plots were raked to remove excessive plant mass to emulate the seedbed of a well-established cultivated field. At the end of each growing season, the above ground biomass of all seeded plots was mowed to a 5-cm height and removed. The abandoned plot was cultivated several times during the first summer and plants that emerged from live tillers were removed until the second year. All seedings were in a 15-cm row spacing. The *Stipa-Bouteloua-Agropyron* and Fescue Prairie sites were prepared and established in spring 1993 and the *Stipa-Bouteloua* site was established in spring 1994.

Soil samples were taken on 22 April 1 May, and 6 June 1996, on the *Stipa-Bouteloua*, *Stipa-Bouteloua-Agropyron*, and Fescue Prairie sites, respectively. Three subsamples were taken from each plot from either the Ah(=A1) or Apj soil horizon, composited and hand-sieved in the field through a 2-mm screen. Separate samples were obtained for the determination of water-stable aggregates by passing them through an 8-mm screen in the field. Following air-drying, water-stable aggregates that had been wetted by capillarity were obtained by the wet-sieving technique using the total sample (Kemper and Koch 1966; Kemper and Rosenau 1986). Only the water-stable aggregate fractions that remained on the 2.0 and 1.0 mm. sieves (>2.0 + >1.0 mm) as a percent of the sum of all water-stable aggregates measured, were reported as it was the most meaningful comparison at the early stage of this long-term experiment.

Since soil samples were taken either from the genetic Ah horizon (8–12 cm, 10 -14 cm, 20–24 cm, and 10-14 cm thick for the Brown, Dark Brown, Black-ungrazed and Black-grazed Chernozemic soils, respectively) or the cultivated Apj horizon (i.e., 20–22 cm thick), and since most of the root mass was raked off following seedbed preparation, bulk densities were not considered to be meaningful.

Total C and N were determined by dry combustion in a Carlo Erba NA 1500 Analyzers. Acid hydrolysis was carried out essentially as outlined by Cheshire and Mundie (1966) and Cheshire (1979) except that the samples were first treated with 12M H_2SO_4 for 16 hours at room temperature, then diluted to 0.5M H_2SO_4 and held at 100° C for 1 hour (Dormaar 1984). Monosaccharides were reduced and acetylated as described by Blakeney et al. (1983). D-allose was added as the internal standard. The alditol acetates were identified with a Hewlett Packard GC 5840A equipped with a hydrogen flame ionization detector and a 30-m long glass capillary column (0.25 mm id.) wall-coated with OV-225 (50% cyanopropyl-50% methylphenylpolysiloxane) with helium as the carrier gas at a linear flow rate of 21 cm sec^{-1}. Reference alditol acetates of rhamnose, fucose, ribose, arabinose, xylose, allose, mannose, galactose, and glucose were used as standards and prepared as outlined by Blakeney et al. (1983). Polysaccharides are considered to have a plant origin if they contain substantial quantities of arabinose and xylose and predominantly of microbial origin if they contain mainly galactose and mannose (Cheshire 1979).

Phosphorus is the one major constituent of soil organic matter that must be supplied entirely from the parent material. Since loss of soil P on the Fescue Prairie was of concern (Dormaar and Willms 1998), there is a need to better understand soil P under various plant communities. Hence, changes in labile inorganic (Pi) and organic (Po) fractions were studied using a simplified modification of the sequential extraction technique (Hedley et al. 1982). Only resin, extractable Pi, $NaHCO_3$-extractable Pi and Po and NaOH-extractable Pi and Po of unlysed resin-treated soil were determined as well as total soil P.

The treatment effect was analysed in a single model including site, with replicates nested in site, to evaluate the site by treatment interactions for each variable. In each instance, the interaction was significant ($P < 0.05$) and the analysis was repeated by site. Selected site and treatment comparisons were made using single-degree of freedom contrasts (Steel and Torrie 1980) of planned comparisons.

For the chemical analysis, 3 comparisons were considered, i.e., native prairie vs. cultivation, native prairie vs. introduced forage grasses, and introduced forage grasses vs. continuous wheat since there is much debate in the literature regarding the effect of these grasses on soil chemical properties. An additional comparison of native prairie vs. abandoned cultivated land was carried out for the water-stable aggregates.

Results

Site effects were significant for each variable tested and, with 3 exceptions, each variable was different between each paired site. Only total N and sodium hydroxide-extractable total and organic phosphorus, were similar between the grazed and ungrazed Fescue Prairie sites (Tables 1 and 2). The values of each constituent tended to follow the order of mag-

Table 1. The influence of cultivation and modified plant communities on selected soil parameters.

	C	N	Mono-saccharides	Ratio[2]	Total P	Resin Pi[3]	$NaHCO_3$-extractable P[4]			NaOH-extractable P[5]		
							Total	Pi	Po	Total	Pi	Po
	($g\ kg^{-1}$)	($g\ kg^{-1}$)	($mg\ kg^{-1}$)		($mg\ kg^{-1}$)	($mg\ kg^{-1}$)	($mg\ kg^{-1}$)	($mg\ kg^{-1}$)	($mg\ kg^{-1}$)	($mg\ kg^{-1}$)	($mg\ kg^{-1}$)	($mg\ kg^{-1}$)
Treatment[1]	**Stipa-Bouteloua** (established 6 Apr. 1994; sampled 22 Apr. 1996)											
1.	17.9	1.84	4.84	0.51	419	8.76	14.5	6.66	7.79	75.3	14.5	60.8
2.	15.0	1.62	3.55	0.46	395	5.91	13.8	5.55	8.23	73.7	11.6	62.1
3.	14.9	1.59	3.65	0.48	407	6.66	13.4	5.79	7.61	74.4	11.9	62.5
4.	14.8	1.60	3.62	0.48	398	7.40	13.7	6.06	7.67	79.9	12.4	67.5
5.	15.1	1.63	3.68	0.46	394	6.35	12.9	5.77	7.13	70.4	11.6	58.8
6.	15.4	1.62	3.84	0.47	406	6.41	14.0	5.85	8.10	77.8	11.9	65.9
7.	15.1	1.61	3.33	0.55	370	6.70	13.4	6.50	6.90	71.8	12.5	59.4
	Stipa-Bouteloua-Agropyron (established 1 Apr. 1993; sampled 1 May 1996)											
1.	39.2	3.77	8.63	0.62	684	9.75	18.5	7.73	10.8	99.2	12.1	87.1
2.	30.4	2.88	6.65	0.55	689	7.31	15.9	7.30	8.60	85.2	11.2	74.1
3.	30.4	2.92	6.42	0.58	669	7.28	15.8	7.15	8.65	83.8	11.2	72.7
4.	29.6	2.96	6.01	0.47	666	8.54	15.7	6.66	9.01	83.7	10.9	72.8
5.	29.6	2.91	5.54	0.46	657	6.77	15.0	6.27	8.70	74.6	10.4	64.2
6.	31.9	3.02	6.72	0.61	656	7.42	15.8	7.19	8.56	88.8	11.6	77.1
7.	30.8	2.96	6.44	0.60	665	9.68	15.0	6.88	8.14	86.1	11.8	74.3
	Fescue (ungrazed-established 13 Apr. 1993; sampled 6 Jun. 1996)											
1.	108.5	9.74	25.6	0.70	1336	31.2	80.4	16.1	64.3	678	33.0	645
2.	85.7	7.68	23.0	0.63	1247	22.5	84.4	15.0	69.5	628	30.5	597
3.	79.0	6.85	19.3	0.54	1155	20.6	81.4	12.9	68.5	446	31.5	414
4.	84.9	7.03	18.8	0.58	1239	24.0	91.5	15.6	75.9	527	35.3	491
5.	86.0	7.69	21.5	0.50	1234	26.0	90.8	16.6	74.2	536	33.6	519
6.	91.0	7.83	20.0	0.53	1216	22.6	94.7	16.4	78.3	557	37.0	520
7.	74.8	6.30	15.7	0.52	1075	22.3	68.4	16.6	51.8	494	35.5	458
	Fescue (grazed-established 13 Apr. 1993; sampled 6 Jun. 1996)											
1.[6]	88.8	8.38	22.6	0.71	1168	20.8	72.5	10.7	61.8	598	24.8	573
2.	83.9	7.32	16.4	0.55	1145	20.6	69.8	14.4	55.1	559	29.3	530
3.	80.8	7.63	16.6	0.59	1140	20.9	71.9	14.4	57.5	544	28.6	516
4.	78.5	6.99	16.2	0.67	1150	20.5	80.3	13.9	66.4	622	33.5	588
5.	74.3	7.65	17.3	0.55	1137	21.9	78.8	15.8	62.9	549	32.2	517
6.	82.6	7.19	17.1	0.62	1147	19.5	73.3	16.3	57.1	543	32.4	511
7.	76.9	6.45	15.9	0.55	1144	21.4	78.8	16.1	62.7	505	36.4	469
8.[7]	80.7	7.70	15.6	0.56	1167	21.2	81.4	8.7	72.7	550	25.6	525

[1]1 = native prairie-ungrazed; 2 = crested wheatgrass on the *Stipa-Bouteloua* and *Stipa-Bouteloua-Agropryon* sites and orchard grass on the Fescue sites; 3 = Russian wildrye on the *Stipa-Bouteloua* and *Stip Bouteloua-Agropyron* sites and smooth bromegrass on the Fescue sites; 4 = wheat-fallow; 5 = wheat-continuous; 6 = alfalfa; 7 = abandoned.
[2]Galactose + Mannose/Xylose + Arabinose.
[3]Resin extractable Pi; Pi = inorganic P.
[4]$NaHCO_3$ extractable P, Pi, and Po after resin extraction; Po = Organic P.
[5]NaOH extractable P, Pi, and Po after $NaHCO_3$ extraction.
[6]Native prairie grazed since 1949 at 2.4 animal unit month ha^{-1} until 13 Apr. 1993.
[7]Native prairie grazed since 1949 at 2.4 animal unit month ha^{-1}.

Table 2. Comparison of the influence of cultivation and modified plant communities on selected soil parameters.

	C	N	Mono-saccharides	Ratio[2]	Total P	Resin Pi[3]	$NaHCO_3$-extractable P[4]			NaOH-extractable P[5]		
							Total	Pi	Po	Total	Pi	Po
	($g\ kg^{-1}$)	($g\ kg^{-1}$)	($mg\ kg^{-1}$)									
Treatment[1]						**Stipa-Bouteloua** (established 6 Apr. 1994; sampled 22 Apr. 1996)						
1 vs 2-7	<0.001	<0.001	<0.001	0.007	<0.001	<0.001	0.15	<0.001	0.610	0.661	<0.001	0.176
1 vs 2,3	<0.001	<0.001	<0.001	0.002	0.004	<0.001	0.40	<0.001	0.757	0.411	<0.001	0.346
2,3 vs 5	0.798	0.349	0.500	0.324	0.261	0.683	0.095	0.572	0.062	0.024	0.613	0.035
						Stipa-Bouteloua-Agropyron (established 1 Apr. 1993; sampled 1 May 1996)						
1 vs 2-7	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	0.011	<0.001
1 vs 2,3	<0.001	<0.001	<0.001	<0.001	0.178	<0.001	<0.001	0.074	<0.001	<0.001	0.021	<0.001
2,3 vs 5	0.176	0.910	<0.001	<0.001	<0.001	0.016	0.027	0.002	0.865	<0.001	0.061	<0.001
						Fescue (ungrazed-established 13 Apr. 1993; sampled 6 Jun. 1996)						
1 vs 2-7	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	0.185	0.001	<0.001	0.033	<0.001
1 vs 2,3	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.126	<0.004	0.009	<0.001	<0.001	<0.001
2,3 vs 5	0.218	0.061	0.360	<0.001	0.065	<0.001	<0.001	<0.001	0.002	0.984	<0.001	0.045
						Fescue (grazed-established 13 Apr. 1993; sampled 6 Jun. 1996)						
1[6] vs 2-7	0.001	<0.001	<0.001	<0.001	0.248	0.950	0.136	<0.001	0.449	0.002	<0.001	<0.001
1 vs 2,3	0.027	0.001	<0.001	<0.001	0.262	0.834	0.455	<0.001	0.021	0.003	<0.001	0.002
2,3 vs 5	0.007	0.476	0.233	0.302	0.501	0.050	0.002	0.001	0.007	0.874	<0.001	0.693
1 vs 8[7]	0.017	0.025	<0.001	<0.001	0.984	0.638	0.002	<0.001	<0.001	0.007	0.264	0.007

[1]1 = native prairie-ungrazed; 2 = crested wheatgrass on the *Stipa-Bouteloua* and *Stipa-Bouteloua-Agropryon* sites and orchard grass on the Fescue sites; 3 = Russian wildrye on the *Stipa-Bouteloua* and *Stipa Bouteloua-Agropyron* sites and smooth bromegrass on the Fescue sites; 4 = wheat-fallow; 5 = wheat-continuous; 6 = alfalfa; 7 = abandoned.
[2]Galactose + Mannose/Xylose + Arabinose.
[3]Resin extractable Pi; Pi = inorganic P.
[4]$NaHCO_3$ extractable P, Pi, and Po after resin extraction; Po = Organic P.
[5]NaOH extractable P, Pi, and Po after $NaHCO_3$ extraction.
[6]Native prairie grazed since 1949 at 2.4 animal unit month ha^{-1} until 13 Apr. 1993.
[7]Native prairie grazed since 1949 at 2.4 animal unit month ha^{-1}.

nitude: *Stipa-Bouteloua* < *Stipa-Bouteloua-Agropyron* < grazed fescue < ungrazed fescue.

Cultivating and seeding grasses, alfalfa, and wheat produced a change compared to the Ah horizons in most chemical constituents (Tables 1 and 2). Sodium bicarbonate or sodium hydroxide-extractable total or organic P were not affected (P > 0.05) by treatment on the *Stipa-Bouteloua* site and total P and resin-extractable Pi was unaffected (P > 0.05) by treatment on the grazed Fescue Prairie site. These results were consistent in a comparison of native with all other treatments or native with only the grass treatments (Tables 1 and 2).

The chemical constituents in soils of 2 grass species were mostly similar (P > 0.05) with continuous wheat in the *Stipa-Bouteloua* site but tended to differ in the P constituents of the *Stipa-Bouteloua-Agropyron* and Fescue Prairie sites (Tables 1 and 2). Harvesting fescue grassland on the grazed site reduced (P < 0.05) soil C, N, monosaccharides, sodium bicarbonate Pi, and sodium hydroxide total and organic P while increasing sodium bicarbonate total and organic P (Tables 1 and 2).

The water-stable aggregate fractions that remained on the 2.0 and 1.0 mm sieves tended to be greater in the native grassland soils than in the cultivated treatments (Table 3). In the ungrazed native Fescue Prairie site the proportion tended to be similar (P = 0.073) to all other treatments combined. The proportion of water-stable aggregates of the native soil were similar (P = 0.612) to the perennial grass treatments only on the *Stipa-Bouteloua-Agropyron* site. The proportion of water-stable aggregates in soil of the perennial grasses was different (P < 0.05) from soil of continuous wheat in the *Stipa-Bouteloua-Agropyron* and ungrazed native Fescue Prairie sites but similar (P > 0.05) on the other sites (Table 3).

Table 3. Water-stable aggregate fraction that remained on the 2.0 and 1.0 mm sieves as percent of total from undisturbed and modified prairie at 4 research sites.

	Stipa-Bouteloua	*Stipa-Bouteloua Agropyron*	Fescue Enclosure	Fescue Grazed[1]
Treatment	(%)			
Native, ungrazed (1)	23.8	43.4	44.2	48.3
Crested wheatgrass (2)	11.8	46.9	33.2[2]	43.8[2]
Russian wildrye (3)	10.5	42.8	33.7[3]	37.2[3]
Wheat, fallow (4)	8.6	31.9	43.0	43.2
Wheat, continuous (5)	14.4	36.6	43.6	46.4
Alfalfa (6)	15.7	35.2	30.9	42.4
Abandoned cultivation (7)	11.8	32.3	31.3	30.8
Native, grazed[4] (8)				44.8
Avg[5]	13.8[a]	38.4[c]	36.7[b]	41.7[d]
Contrasts				
Trt. 1 vs 2 to 7	<0.001	0.035	0.073	0.011
Trt. 1 vs 2 and 3	<0.001	0.612	0.032	0.028
Trt 1 vs 7	<0.001	0.004	0.017	<0.001
Trt. 2 and 3 vs 5	0.156	0.010	0.010	0.090
Trt. 1 vs 8				0.358

[1]1= native prairie grazed since 1949 at 2.4 animal unit month ha^{-1} until 13 Apr. 1993.
[2]orchard grass
[3]smooth bromegrass
[4]native prairie grazed since 1949 at 2.4 animal unit month ha^{-1}
[5]means in row having the same letter do not differ significantly (P > 0.05).

Discussion

The short-term changes in soil quality of the Ah or Ap horizon are heavily influenced by soil mixing and to a much lesser extent by the new plant community. Nevertheless, they do provide a benchmark from which to examine subsequent genesis and an opportunity to compare the contribution to soil quality between different cultivated communities. Too many studies look only at the long-term differences and then hypothesise soil mixing effects.

Many changes occurred among the soil parameters measured the moment native prairie was converted to cultivated land. Losses of total C, N, P, water-stable aggregates, and monosaccharides were immediate. The polysaccharides changed towards being more of plant origin, i.e., increased levels of xylose and galactose. Cultivation and reseeding produced significant short-term effects on the C, N, and P parameters in all 4 sites that were influenced by the new plant community.

Biological activity parameters have been shown to be sensitive indicators of within-site temporal and soil quality changes (Dormaar and WilIms 2000). In the present study, P was selected as a potentially useful parameter since it serves as an indicator in investigations of pedogenetic processes with essentially the only source of soil P being weathered primary minerals of the parent material. The loss of total P results from a combination of soil mixing and plant removal during the preparation of the site for the various treatments.

Harvesting above-ground dry matter is a common pathway for nutrient loss on anthropocentrically managed land. It shows up in this study, because we examined it at the moment of a major change well prior to the development of new steady states.

An examination of annual loss of resin-, $NaHCO_3$-, and NaOH extractable P through the removal of above ground biomass may well have to be carried out in the future to get a better understanding of P cycling. The distribution and flow of the more labile forms of P can provide a valuable index to the levels and kinds of biological activity in an ecosystem (Cole et al. 1977). Given enough time, the new root systems of the various treatments will bring up and process P again from the parent material. It will then be of interest to determine the total mass of P in a soil profile to the depth of the various root masses. It may also confirm on a field scale the conclusion reached in growth chambers that rhizospere changes in P and phosphatase activity levels are a function of plant species and soil type (Dormaar 1988, McKenzie et al. 1995). Within the 6 cultivated treatments it is clear that the presence of vegetation, even via partially intact root mass, is already indicative of a plant-soil interaction.

The percent Pi (i.e., resin + $NaHCO_3$ + NaOH) of total P within all treatments was more or less identical to that of the native prairie. Conversely, the difference between the native prairie vs the cultivated plots for percent Po ($NaHCO_3$ + NaOH) of total P was 16 vs 18, 14 vs 12, and 53 vs 48 for the ungrazed Brown, Dark Brown, and Black Chernozemic soils, respectively, and 54 vs 51 for both the recovering native prairie vs cultivated treatments and recovering native prairie vs grazed native prairie. It can be hypothesized that, at least for the Black Chernozemic site, the increased root mass and litter (Porter et al. 1999) and thus increased microbiological population, is in part responsible for the higher levels of Po under native prairie.

Root mass is not necessarily a measure of active, metabolically functional root tissue. In fact, it has been shown (Dormaar and Ketcheson 1960) that finely ramified root mass, and thus with increased potential to foster microbial growth and activity in their rhizospheres, can actually be of lesser weight than coarse roots with less root hairs. Further, the introduced grasses and wheat were sown in rows. The soil was not as yet filled with ramifying root mass as under native prairie. This then may help to explain some of the changes observed.

The loss of the water-stable aggregate fraction that remained on the 2.0 and 1.0 mm sieves (>2.0 + >1.0 mm) as percent of total water-stable aggregates is in part the result of loss of organic binding agents ranging from short-chain organic molecules, such as polysaccharides, to plant roots. Polysaccharides are considered to be an organic binding agent of transient persistence (Tisdall and Oades 1982), while roots and bacterial cells can be classified as having more of temporary persistence. With decreased root mass (Porter et al. 1999) a potential mechanical framework for the formation and initial stabilization of macroaggregates (Elliott and Coleman 1988) is lost. To restore a stable macroaggregate structure, the direct and indirect effects of roots and external hyphae will be essential (Jastrow etal. 1998).

Many other parameters could have been selected. One of these could have been litter mass. However, it was too soon for the cultivated and resown plots to have any litter buildup as yet. Attention can be called to the effect of above- and belowground litter at a future examination of the experiment. Once the introduced grasses and legume have had a chance to approach a steady state, a careful examination of fine root structure vs root mass per se, together with potential energy available for microbial processes, may be on. At that time, clipping of half the plots will further enhance insight into the strong influence of roots on soil chemical and biochemical processes. This would then be a simulation of grazing, even though it does not uncouple the N pathway, through standing dead to litter, decomposers, and soil organic matter, in the presence of large animals by removing part of the N in grazing and returning it in urine and faeces.

Two interacting factors strongly influence chemical and biological processes on rangelands. Herbivory impacts carbon flow to roots and transfer of nutrients off-site. Species composition impacts nutrient cycling and soil biochemical processes related to rhizosphere interactions. Our research attempted to isolate single species vegetation factors that influence soil physical and chemical characteristics. Moreover, we wanted to determine the time frame in which measurable changes in soil characteristics occurred due to the influence of a particular plant species. Our data show that in as little as 3 years, a specific species can significantly alter soil chemical and physical attributes relative to a native grassland. These results suggest that trajectories of soil evolution can be radically altered depending on the nature of vegetation occupying the soil. This approach can be criticized as being reductionist, since it does not relate to the effect of mammal herbivore superimposition. This criticism is valid particularly in the light of the literature review regarding the potential belowground changes possible following defoliation by grazing (Johnston 1961, Manske 1995). Nevertheless, it seemed logical to us to understand the effect of various soil-plant manipulations first before dealing with the further complexity added by the effects of grazing by mammal herbivores.

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Book Reviews

Natural Resources: Ecology, Economics, and Policy. By Jerry L. Holechek, Richard A. Cole, James T. Fisher, and Raul Valdez. 2000. Prentice-Hall, Upper Saddle River, New Jersey. 730 p. US$94.80 hardback. ISBN 0-13-896077-1.

This books seeks "to introduce students to the science of natural resource management, coupling the latest concepts and technology with proven traditional approaches" (p. xix). The book is over 700 pages long and its 23 chapters are divided into 6 sections. In the rest of this review, I shall first comment on the contents of 5 of the book's 6 sections. I shall then conclude with some general observations.

Section 1 provides the reader with an introduction to the basics of what the authors call "management foundations." Subjects as diverse as the history of natural resource use, basic ecology, conservation economics, and planning are covered here. Chapter 3 contains a very nice introduction to ecology. Topics such as population structure and dynamics, community structure and functions, and ecosystem structure and functions are nicely described by the authors. In particular, the authors do a good job of pointing out that "the world can support far more humans if they eat only plant material compared to if they eat a large amount of meat" (p. 80). However, the discussion of resilience (p. 68) would have profited from a clear indication of the fact that this term has *2* meanings, one in the sense of C.S. Holling and the second in the sense of S.L. Pimm.

Chapter 4 contains a rather unsatisfactory account of the economics of conservation. Here are 2 examples of what I have in mind. On p. 105, the authors say that "[p]roducers maximize profits by minimizing their costs." The implication of this sentence is that cost minimization implies profit maximization. However, this implication is *false*. In fact, the converse of this sentence is true, i.e., firms minimize costs by maximizing their profits (see p. 63 of *Microeconomic Analysis*, 3rd edition, by Hal Varian). Second, in their discussion of pollution taxes on p. 109, the authors say that a "pollution tax is...set equal to the damages the firm does." At the very least, this sentence is misleading because the authors do *not* specify whether they are referring to total or marginal damages. Generally speaking, a pollution tax is set equal to the *marginal* social damage caused by the negative externality under consideration. There are many other sentences like the 2 that I have just quoted. Collectively, they lead to a rather unclear and erroneous understanding of some of the basic concepts of economics.

The 4 chapters in Section 2 discuss air, water, and land resources. Two chapters here are particularly noteworthy. Chapter 7 on water resources contains a competent description of watershed and water quality management. With regard to water needs in the USA, this chapter rightly points out a "major conflict is how to satisfy recreation, aesthetic, and biodiversity protection needs for water while continuing to meet the growing needs of agricultural irrigation and fast growing western cities" (p. 208). Chapter 9 contains a nice account of ecosystems in the USA. The many useful diagrams and pictures of terrestrial and aquatic ecosystems make this account very readable.

The subject of Section 3 is land based renewable resources. The discussion in this section is competent for the most part, and the treatment of rangelands (Chapter 11) and farmlands (Chapter 12) is especially compelling. In Chapter 11, the authors forcefully argue that a "careful analysis of grazing management research shows the stocking rate has had far more impact on range condition, forage production, livestock production, and economic returns than any specialized grazing system" (p. 356).

Chapter 12 argues that although there are a number of food and environmental problems in the world, given opposite technological developments, it should be possible to address these problems satisfactorily. Although this is a useful chapter, the economics discussion here leaves room for improvement. To see why, consider the following 2 examples. On p. 377, the authors say that the price "elasticity of demand refers to the relationship between quantity of a product demanded and price." If not altogether incorrect, this sentence is certainly misleading because the same sentence can be used to explain the meaning of a demand function. What the authors should have said is that the price elasticity of demand measures the *per cent change* in quantity demanded in response to a given *per cent change* in the price of a good. On p. 383, the authors state that "[a]griculture is one of the most competitive of all industries." Nothing could be further from the truth. In fact, because agriculture is a *highly distorted* industry with many market imperfections and government programs, it is one of the more *noncompetitive* industries.

The relatively brief Section 4 discusses the conservation and the management of wildlife, fisheries, and biodiversity. The best chapter here is Chapter 15. After noting that wildlife in the USA is now valued less for its commercial consumptive uses and more for its recreational consumptive and nonconsumptive uses, this chapter correctly points out that future wildlife management policy will need to integrate "wildlife programs with those for timber, rangeland, water, fishery, recreation, wilderness and mineral development..." (p. 501).

The integration of natural resource management is the subject of the 3 chapters of Section 6. The objective of Chapter 21 is to discuss why "living standards and economic progress vary widely among different countries" (p. 633). This chapter says that in order to improve the human condition, it will be necessary to pay attention to 7 salient factors such as national unity and the protection of private property rights. Although the discussion of these 7 factors is fine, the discussion of economic concepts is, once again, less than satisfactory. For instance, on p. 640, there is an incomplete discussion of cartels that suggests that cartels "basically attempt to limit exports in years of excess supply." There is no systematic discussion of why cartels form and why they often fail. The p. 642 discussion of the debt crisis of the 1980's notes that in "the past, developing countries often borrowed beyond their capability to repay their debts." What about the role of the banks? There is no discussion of possible imprudence by the banks in making loans. Finally, on pp. 642–643, the book comments on the many economic successes of Chile in the post-1973 time period. There certainly have been many economic successes in Chile during this time period and these are worth commenting on. However, a balanced account of Chile would have said something about the form of government in Chile during most of this time period and the human costs that have come along with these economic successes.

Chapter 23 focuses on sustainable development, technology, and the future. In its discussion of the subject of conservation, this chapter points out that one "particularly troublesome difficulty is the inability to compare ecosystem services that can be priced in economic terms with those that cannot..." (p. 672). The authors conclude the proceedings on a hopeful note. In their opinion, "major advances in human thinking will continue to lead to a sustainable and improving future" (p. 685). They might be right.

This is a voluminous book that covers much material on natural resources. As such, instructors contemplating using this book as a text will have considerable flexibility in choosing material for introductory courses. In addition to this, many of the chapters are both well written and informative. Having said this, I would be remiss in my duties if I did not also say that there are some disquieting aspects to this book. First, the coverage of economics certainly leaves room for improvements. Second, the tone of this book is more descriptive and less analytic. Finally, many of the chapters in this book contain no summaries and there are no questions for students to think about. As such, let me conclude this review by saying that although this book will not be an effective text for introductory courses in natural resource economics, if used intelligently, the book may well prove to be useful in introductory courses in environmental studies.—*Amitrajeet A. Batabyal*, Utah State University, Logan, Utah.

Ecoforestry. The Art and Science of Sustainable Forest Use. Edited by Alan Drengson and Duncan Taylor, with 39 text contributors. New Society Publishers, Gabriola Island, British Columbia, Canada and Stony Creek, Connecticut, U.S.A. 312 p. US$24.95 paper. ISBN 0-86571-365-0.

Worldwide, many different views exist on how forests should be managed and used. *Ecoforestry* is a compilation of papers on the theory of ecosystem management. The book looks at the forest as "something far more than the trees within it; it is a community of hundreds of thousands of life forms that collaborate for sustainability." The foreword of this book presents the idea that the economic "machine" has driven the past and current system of forest management. In this "machine society," it becomes solely the values and forms of the technical instruments—including corporations—that finally determine the organization of human activity and our relationship to nature." The theme prevalent throughout this collection of writings is to challenge this economically driven system of forest management and replace it with a more ecosystem friendly, sustainable system.

Contributed papers are organized into 6 sections. The introduction clearly presents the different views and conflicts of the forest management issue. People seem to be a polarized at the extremes of the issue, and many fail to consider the conservationist stance that all uses can be met through responsible management. The turmoil at Clayoquot Sound in British Colombia is examined, as are possible solutions to its many conflicts.

Ecoforestry Principles and Practices, the first section of the book, introduces the reader to the philosophy and structure of ecoforestry. Many terms and ideas are defined to help the reader understand the underlying principles of the book. Past forestry practices and mishaps are explored. The book attempts to change our view of the forest to a "weblike system that produces many things that are useful to human beings." Stressed is the idea of ecological management as a whole: "Ecological planning considers the health of the system, which is based on intimate knowledge of the system." Sustainability and ecologically responsible restoration are the focus of the latter part of this section, and many examples and ideas of sustainable forest use are presented.

Section 2 covers ecosystem maintenance and use of indicators and species in ecosystem monitoring. This section contains several interesting papers, but the section lacks continuity from topic to topic. The information presented on the intricate roles of fungi and woody debris in the forest is interesting, and the discussion of the management of wildfire was probably the most informative of the section.

Past and current examples of ecoforestry are presented in section 3, and of major concern are examples from around the world where ecoforestry has been successful. One particular paper that I found informative describes the ecoforestry management system used in Switzerland that has been used for approximately one hundred years. It may well set the standard for forest practices around the world in the future. Another interesting topic was that of special forest products; in the future, they may be an important part of optimizing economic possibilities from forest resources.

The last 2 sections of the book focus on future use of forests, and how to develop better management strategies for them. Kinds and degrees of forest certification, professional standards, and evaluation of them are hot topics in many natural resource disciplines. The last section describes an ecocentric approach to forestry and its alternatives and benefits. Future values and views of the forest will shape the use and path that ecoforestry follows.

I found *Ecoforestry* to be interesting and informative at introducing new ideas and elements of forest management. The book should interest foresters and land managers, as well as anyone else who wants to know more about the forest as a whole.—*Ryan Smith*, Washington State University, Pullman, Washington.

Repairing Damaged Wildlands. By Steven G. Whisenant. 1999. Cambridge University Press, 40 West 20th Street, New York, NY 10011-4211, USA. 312 p. US$29.95 paper. ISBN 0-521-66540-X.

Traditionally, restoration of wildland systems has focused on reintroducing plant species, altering small components of the physical systems, and utilizing intensive, high-cost mechanical treatments. In *Repairing Damaged Wildlands* Steve Whisenant presents a process-oriented landscape-scale approach to repairing the growing number of damaged wildlands throughout the world. He emphasizes restoring physical processes that will promote autogenic repair and sustainable recovery mechanisms. A thorough understanding of physical and biological systems, and awareness of socioeconomic impacts are essential in developing sustainable restoration projects on wildlands worldwide.

In 8 chapters, this book provides a compilation of international research on restoring damaged wildland systems. These chapters walk the reader step-by-step through developing a sustainable restoration project. These steps are: (1) wildland degradation and repair, (2) assessing damage to primary processes, (3) repairing damaged primary processes, (4) directing vegetation change, (5) selecting plant materials, (6) site preparation and seedbed management, (7) planting, (8) planning repair programs for wildland landscapes. Whisenant utilizes a vast pool of resources to formulate a well-written approach to restoring damaged lands and sustaining them over time with minimal intensive inputs and costs. The approach emphasized is one of process and is not designed as a field manual for individual projects. Rather, this book provides an excellent reference for developing unique restoration projects that will satisfy a manager's detailed objectives.

Chapter 1 develops an understanding of the sources of wildland degradation and how they affect the repair processes. Once the sources of degradation are identified, realistic objectives of restoration must be developed. In developing these objectives Whisenant analyzes several philosophical approaches, including agronomic and ecological ones that have traditionally been utilized. He recommends moving beyond these traditional approaches to strategies oriented toward *processes*. "The recovery and maintenance of processes, rather than species, is the key to ecosystem resilience (Breedlow et al. 1988) and repair (Whisenant 1995; Whisenant and Tongway 1995; Bradshaw 1996)" (p. 20).

Once objectives are formed and the damage is at least partly understood, a further understanding of the physical and biological processes are needed. Chapter 2 is a helpful reference for understanding these complex interactions. A restoration effort must conserve resources and sustain processes to provide long-term sustainability. The manager must understand what it means to have properly functioning systems. Whisenant evaluates hydrologic functions, soil relationships, nutrient cycling and other wildland processes. Several tables in this chapter provide information for future reference.

In Chapter 3, attention is focused on repairing these damaged primary processes. The emphasis is on restoring processes that will generate autogenic recovery and develop successional sequences toward sustainable physical and biological communities. Soil surface conditions must first be improved to create favorable microtopographic conditions for seedling establishment and erosion control. To increase resource retention there must be an understanding of the following appropriate vegetation for the nutrients available within the system, restoration of biotic processes into the soil and enhancement of organic materials.

Once primary processes have been restored, it is then time to focus on directing vegetation change, the subject of Chapter 4. In order to effect vegetation change, it is first necessary to understand its meaning as, "any dynamic vegetation pattern where dominant populations of one or more species on a site are being replaced by new populations of the same or different species (Burrows 1991)" (p. 101). An understanding of successional processes is emphasized throughout this chapter. Once again, Whisenant points out that goals and objectives must be thoroughly outlined and understood prior to directing vegetational change. In order to restore sustainable plant communities, there must be an understanding of resource availability, and wildlife and livestock impacts. Autogenic development is evaluated to ensure that the plant community has sufficient resources to provide seed dispersal and tolerate seed predation.

In Chapter 5, Whisenant provides a good broad-scale reference for selecting plant materials. Proper selection of plant materials is essential in introducing vegetation onto a prepared site. Species and species mixtures are evaluated by comparing native species with non-native species that are often necessary in restoration. Species mixtures must be chosen to restore both individual species and functional diversity. If properly selected, these plant materials will provide for site stabilization and primary process repair throughout the restoration process. A thorough understanding of these basic ideas will allow the manager to select the most suitable materials for a project. Whisenant evaluates the use of seed, and provides helpful hints on applying the mixtures and on planting whole plants or plant parts.

Site preparation and seedbed management are discussed in Chapter 6. Whisenant evaluates the manipulation of the site and propagule availability through 3 separate approaches: unassisted natural recovery, assisted natural recovery, and artificially induced recovery. Each of these approaches requires a different level of restoration activity. In order to understand which approach is preferable, you must first understand something about seedling establishment. Several methods of seedbed preparation are evaluated which can provide suitable environments for seedling establishment: mechanical methods; chemical methods; burning methods; and biological methods. Further discussion is directed at special seedbed considerations in arid environments, saline soils, and active sand dunes.

Planting methods are evaluated in Chapter 7. The different methods evaluated are thoroughly explained to give an understanding of which method may be the most useful for each individual restoration project. Economic considerations are included. Direct seeding provides a flexible, low cost alternative to many other planting methods. Seed preparation, seeding rates, seeding depth and other components of direct seeding are evaluated. Several different direct seeding techniques are evaluated in this chapter including drill seeding, interseeding, broadcast seeding, hydroseeding and many others. Transplanting is a more labor intensive, higher cost approach that is necessary in many wildland environments. Different methods are evaluated and planting densities are suggested. The chapter concludes with a discussion of how to maintain these planted landscapes.

Chapter 8 provides a thorough format for planning wildland restoration programs. Emphasis is placed on understanding landscapes, and the scales they encompass, along with necessary guidelines to follow in restoration. Development of alternatives is recommended within a decision-making framework that accounts for changes that may occur throughout a restoration project.

Repairing Damaged Wildlands should be a useful reference for any individual landowner, land manager, or resource management professional who is interested in understanding the processes involved in ecological restoration. Its focus on restoring physical and ecological processes needs to be understood and applied in order to promote sustainable restoration of wildland systems.—*Lance E. Davisson*, Washington State University, Pullman, Washington.

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