PROGRESS REPORT

Defoliation Effects on the Structure and Dynamics of Grassland Ecosystems

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Abstract

Grassland plants developed defoliation resistance mechanisms to compensate for herbage removal by herbivores and fire during the long period of evolution. Two types of defoliation resistance mechanisms are of particular importance to grassland managers: changes in physiological responses within grassland plants and changes in activity levels of symbiotic soil organisms in the rhizosphere. Grassland managers can beneficially manipulate these defoliation resistance mechanisms by timing grazing for a short period (7-17 days) of partial defoliation of young leaf material between the third-leaf stage and anthesis phenophase. Grass tiller numbers, aboveground herbage biomass, and nutrient content of herbage increase as a result of plant defoliation at early phenological growth stages. These increases allow for subsequent increases in stocking rate and result in improved individual livestock weight performance during a second grazing period after grass plants have reached anthesis.

Introduction

The diverse and complex nature of grassland ecosystems causes considerable difficulty in development of sound management recommendations. However, increasing knowledge of ecological principles and the intricacies of numerous mechanisms in the grassland ecosystem has allowed for development of improved management strategies.

Recently several greenhouse and laboratory studies have led to the initial understanding of defoliation resistance mechanisms grassland plants developed as evolutionary responses to defoliation by herbivores and fire. Defoliation resistance mechanisms are described in two categories (Manske 1999). External mechanisms involve herbivore-induced environmental modifications (Briske and Richards 1995). Internal mechanisms are associated with herbivore-induced physiological processes (McNaughton 1979, McNaughton 1983) and are divided into two subcategories: tolerance mechanisms and avoidance mechanisms (Briske 1991). Defoliation tolerance mechanisms facilitate growth following grazing and include both increased activity within the plant meristem and compensatory physiological processes (Briske 1991). Defoliation avoidance mechanisms reduce the probability and severity of grazing and include the modification of anatomy and growth form. Grazing resistance in grass is maximized when the cost of resistance approximates the benefits. Plants do not become completely resistant to herbivores because the cost of resistance at some point exceeds the benefits provided by the resistance mechanisms (Pimentel 1988).

Grassland management by defoliation with herbivores has the greatest beneficial effect if planned to stimulate two mechanisms: vegetative tillering from axillary buds and increased activity of symbiotic soil organisms. The physiological responses to defoliation do not occur at all times, and the intensity of the response is variable. The physiological responses can be related to different phenological growth stages of the grass plants. The key to ecological management by effective defoliation is the application of defoliation during the phenological growth stage at which the desired outcome will be triggered.

Understanding the defoliation resistance mechanisms that work within grassland plants and that stimulate the symbiotic organisms in the rhizosphere following defoliation is necessary to accomplish beneficial manipulation of these mechanisms under field conditions and to develop ecologically sound recommendations for management of our grassland ecosystems. The goals of this research project were to study the ecological effects of defoliation and to determine the season of use for domesticated grasses and native range in the Northern Plains.

Methods and Materials

The long-term study site is on the Dickinson Research Extension Center ranch, operated by North Dakota State University and located 20 miles north of Dickinson in southwestern North Dakota, U.S.A. (47º14'N.lat., 102º50'W.long.).

Soils are primarily Typic Haploborolls. Mean annual temperature is 42.2°F (5.7°C). January is the coldest month, with a mean temperature of 14.3°F (-9.9°C). July and August are the warmest months, with mean temperatures of 69.0°F (20.6°C) and 68.7°F (20.4°C), respectively. Long-term annual precipitation is 16.57 inches (420.90 mm). The growing-season precipitation (April to October) is 14.04 inches (356.73 mm), 85.0% of annual precipitation (Manske 2003). The vegetation is the Wheatgrass-Needlegrass Type (Barker and Whitman 1988) of the mixed grass prairie. The dominant native range species are western wheatgrass (*Agropyron smithii*), needleandthread (*Stipa comata*), blue grama (*Bouteloua gracilis*), and threadleaved sedge (*Carex filifolia*).

The grazing treatments and nongrazed control were organized as a paired-plot design. The nongrazed control, 4.5-month Twice-over Rotation treatment, and 6.0-month Seasonlong treatment had two replications. The 4.5-month Seasonlong treatment had three replications. The long-term nongrazed treatments had not been grazed, mowed, or burned for more than 30 years prior to the start of data collection.

The 4.5-month Twice-over Rotation (4.5 TOR) management strategy began on a fertilized (50lbs N/acre on 1 April) crested wheatgrass pasture, with grazing starting as close as possible to 1 May and continuing on that forage type for about 31 days. The livestock then followed a rotation sequence through three native range pastures during the next 135 days. Each pasture was grazed for two periods, one period of 15 days between 1 June and 15 July (third-leaf stage to anthesis phenophase), followed by a second period of 30 days after 15 July and prior to mid October. The first pasture grazed in the sequence was the last pasture grazed the previous year. The livestock were moved to an Altai wildrye pasture on 15 October, where they grazed for about 30 days, until as close as possible to 15 November, when the calves were weaned at about 244 days of age.

The 4.5-month Seasonlong (4.5 SL) management strategy began on an unfertilized crested wheatgrass pasture, with grazing starting as close as possible to 1 May and continuing on that forage type for about 31 days. The livestock were moved to one native range pasture on 1 June, where they grazed for 135 days, until 15 October. Cows and calves were then moved to crop aftermath, where they grazed for about 30 days, until as close as possible to 15 November, when the calves were weaned at about 244 days of age.

The 6.0-month Seasonlong (6.0 SL) management strategy began as close as possible to 16 May, with grazing on one native range pasture. The livestock remained on this pasture for 183 days, until as close as possible to 15 November, when the calves were weaned at about 244 days of age.

Each treatment was stratified on the basis of three range sites (sandy, shallow, and silty). Samples from the grazed treatments were collected on both grazed quadrats and quadrats protected with cages (ungrazed). Aboveground plant biomass was collected on 11 sampling dates from April to November. The major components sampled were cool- and warm-season grasses, sedges, forbs, standing dead, and litter. Plant species composition was determined by the ten-pin-point frame method (Cook and Stubbendieck 1986) between mid July and August. A standard paired-plot t-test was used to analyze differences between means (Mosteller and Rourke 1973).

Commercial crossbred cattle were used on all grazing treatments in this trial. Individual animals were weighed on and off each treatment and on each rotation date. Cow and calf mean weights were determined for each grazing period. Live-weight performance of average daily gain and accumulated weight gain for cows and calves was used to evaluate each treatment. Cow animal unit equivalent (AUE) was determined through calculation of the metabolic weight of the average animal as a percentage of the metabolic weight of a 1000-pound cow (Manske 1998).

Results and Discussion

Pasture and forage costs, net returns after pasture-forage costs, and costs per pound of calf gain for five grazing management strategies are shown in tables 1 and 2.

Pasture-forage costs per period for a cow-calf pair grazing during the spring portion of the lactation period were $41.85 on the 12-M Repeated Seasonal, $18.40 on the 6.0-M Seasonlong, $16.47 on the 4.5-M Seasonlong, $36.44 on the 4.0-M Deferred, and $15.95 on the 4.5-M Twice-over Rotation treatments. The net returns per acre after pasture-forage costs were -$0.58 for the 12-M Repeated Seasonal, $0.83 for the 6.0-M Seasonlong, $13.29 for the 4.5-M Seasonlong, $14.13 for the 4.0-M Deferred, and $41.82 for the 4.5-M Twice-over Rotation treatments.

Pasture-forage costs per period for a cow-calf pair grazing during the summer portion of the lactation period were $98.65 on the 12-M Repeated Seasonal, $159.26 on the 6.0-M Seasonlong, $111.25 on the 4.5-M Seasonlong, $58.26 on the 4.0-M Deferred, and $78.84 on the 4.5-M Twice-over

Rotation treatments. The net returns per acre after pasture-forage costs were $6.54 for the 12-M Repeated Seasonal, $2.13 for the 6.0-M Seasonlong, $7.02 for the 4.5-M Seasonlong, $11.83 for the 4.0-M Deferred, and $14.79 for the 4.5-M Twice-over Rotation treatments.

Pasture-forage costs per period for a cow-calf pair grazing during the fall portion of the lactation period were $51.20 on the 12-M Repeated Seasonal, $35.39 on the 6.0-M Seasonlong, $13.26 on the 4.5-M Seasonlong, $19.53 on the 4.0-M Deferred, and $12.18 on the 4.5-M Twice-over Rotation treatments. The net returns per acre after pasture-forage costs were -$2.91 for the 12-M Repeated Seasonal, -$5.69 for the 6.0-M Seasonlong, -$0.67 for the 4.5-M Seasonlong, -$1.51 for the 4.0-M Deferred, and $17.81 for the 4.5-M Twice-over Rotation treatments.

Pasture and forage costs per season for a cow-calf pair during the lactation production period were $191.69 on the 12-M Repeated Seasonal, $212.34 on the 6.0-M Seasonlong, $140.98 on the 4.5-M Seasonlong, $114.23 on the 4.0-M Deferred, and $106.79 on the 4.5-M Twice-over Rotation treatments. The net returns per acre after pasture-forage costs were $2.79 for the 12-M Repeated Seasonal, $0.75 for the 6.0-M Seasonlong, $5.17 for the 4.5-M Seasonlong, $10.33 for the 4.0-M Deferred, and $17.00 for the 4.5-M Twice-over Rotation treatments.

Costs per pound of calf weight gain during the lactation production period were $0.54 for the 12-M Repeated Seasonal, $0.64 for the 6.0-M Seasonlong, $0.39 for the 4.5-M Seasonlong, $0.32 for the 4.0-M Deferred, and $0.25 for the 4.5-M Twice-over Rotation treatments.

The treatment with the lowest pasture-forage costs, the highest net return per acre after pasture-forage costs, and the lowest cost per pound of calf weight gain during the lactation production period was the Twice-over Rotation system.

The Twice-over Rotation system, used to manage native range during the 137 days of the summer lactation production period, applies defoliation treatments to grass plants at the appropriate phenological growth stages to stimulate the defoliation resistance mechanisms within the plants and the activity of the symbiotic microorganisms in the rhizosphere. This stimulation increases both secondary tiller development of grasses and nutrient flow in the rhizosphere, resulting in increased plant basal cover and aboveground herbage biomass and improved nutritional quality of forage. The increase in quantity and quality of herbage permits an increase in stocking rate levels, improves individual animal performance, increases total accumulated weight gain, reduces acreage required to carry a cow-calf pair for the season, improves net return per cow-calf pair, and improves net return per acre (Manske et al. 1988, Manske 1994, 1996).

After the defoliation resistance mechanisms have been stimulated by partial defoliation at the proper phenological growth stages, the quantity of herbage biomass produced is related to the amounts of sunlight and soil water available to the plants and to the amount of remaining leaf surface area that is photosynthetically active. When cows remove a greater amount of leaf material than is required to promote high levels of herbage production, the quantity of standing herbage biomass is reduced.

Conclusion

Additional research is needed to quantify exudation material; soil organism activity and biomass; nitrogen, carbon, and phosphorus cyclic flows; and development of axillary buds into tillers. Such research would lead to a more complete understanding of the defoliation resistance mechanisms of grassland plants and enable grassland managers to manipulate defoliation for the increased benefit of the grassland ecosystems.

Data have shown that defoliation of grass plants between the third-leaf stage and anthesis has beneficial effects on the physiological responses within the plant, which allow for greater tiller development, and beneficial effects on the symbiotic rhizosphere activity, which increase the amount of available nitrogen for plant growth. Deliberate and intelligent manipulation of these defoliation resistance mechanisms can increase secondary tiller development and total herbage biomass. The secondary tillers raise the nutrient content of the herbage and thereby improve individual animal weight performance during the later portion of the grazing season. The additional herbage biomass allows for a higher stocking rate and a greater amount of herbage remaining standing after grazing. Increased secondary tiller growth results in increased plant density, canopy cover, and litter cover. These increases reduce the impact of raindrops, reduce and slow runoff, reduce erosion, and improve water infiltration.

The Twice-over Rotation strategy systematically grazes each of three to six native range pastures for two grazing periods. The first rotation period occurs between the third-leaf stage and anthesis phenophase (1 June to 15 July), with grazing for seven- to seventeen-days in each pasture, and the second rotation period occurs between mid July and mid October, with grazing in each pasture for a period double the length of the first. The combination of these two grazing periods maximizes the beneficial effects of the defoliation resistance mechanisms of grassland plants when adequate quantities of photosynthetically active leaf surface area remain standing after each grazing period.

Acknowledgment

I am grateful to Sheri Schneider for assistance in research data processing and production of this manuscript. I am grateful to Amy M. Kraus for assistance in preparation of this manuscript.

Table 1. Costs and returns during the spring, summer, and fall portions of the lactation production period for grazing management strategies.

		12-M Repeated Seasonal*	6.0-M Seasonlong	4.5-M Seasonlong	4.0-M Deferred	4.5-M Twice-over Rotation
Spring Lactation Period		Native Rangeland	Native Rangeland	Crested Wheatgrass Unfertilized	Crested Wheatgrass Unfertilized	Crested Wheatgrass Fertilized
Accumulated Calf Wt.	lbs	55.80	28.80	59.21	136.04	67.58
Weight Value @ $0.70/lb	$	39.06	20.16	41.45	95.23	47.31
Pasture and Forage Costs	$	41.85	18.40	16.47	36.44	15.95
Net Return/c-c pr	$	-2.79	1.76	24.98	58.78	31.36
Net Return/acre	$	-0.58	0.83	13.29	14.13	41.82
Cost/lb of Calf Gain	$	0.75	0.64	0.27	0.27	0.24
Summer Lactation Period		Native Rangeland	Native Rangeland	Native Rangeland	Native Rangeland	Native Rangeland
Accumulated Calf Wt.	lbs	246.60	282.87	286.33	196.50	302.77
Weight Value @ $0.70/lb	$	172.62	198.01	200.43	137.55	211.94
Pasture and Forage Costs	$	98.64	159.26	111.25	58.26	78.84
Net Return/c-c pr	$	73.98	38.75	89.18	79.29	133.10
Net Return/acre	$	6.54	2.13	7.02	11.83	14.79
Cost/lb of Calf Gain	$	0.40	0.56	0.39	0.30	0.26
Fall Lactation Period		Native Rangeland	Native Rangeland	Cropland Aftermath	Native Rangeland	Altai Wildrye
Accumulated Calf Wt.	lbs	54.00	17.73	12.57	23.10	52.77
Weight Value @ $0.70/lb	$	37.80	12.41	8.80	16.17	36.94
Pasture and Forage Costs	$	51.20	35.39	13.26	19.53	12.18
Net Return/c-c pr	$	-13.40	-22.98	-4.46	-3.36	24.76
Net Return/acre	$	-2.91	-5.69	-0.67	-1.51	17.81
Cost/lb of Calf Gain	$	0.95	1.99	1.05	0.85	0.23

*Based on estimated calf weight

Table 2. Range cow and calf performance and costs and returns during the lactation production period for grazing management strategies.

		12-M Repeated Seasonal*	6.0-M Seasonlong	4.5-M Seasonlong	4.0-M Deferred	4.5-M Twice-over Rotation
Length of Season	days	198	183	198	198	198
Acres/Month	ac	3.19	4.04	3.27	2.01	1.72
Acres/Season	ac	20.69	24.24	21.21	13.04	11.14
Cow ADG	lbs		0.12	0.30	0.55	0.93
Cow Gain/Acre	lbs		0.91	2.78	8.30	16.56
Cow Gain/Season	lbs		21.96	58.86	108.20	184.52
Calf ADG	lbs	1.80	1.80	1.81	1.80	2.14
Calf Gain/Acre	lbs	17.23	13.59	16.88	27.27	37.98
Calf Gain/Season	lbs	356.40	329.40	358.11	355.64	423.12
Weight Value@$0.70/lb	$	249.48	230.58	250.68	248.95	296.18
Pasture and Forage Costs	$	191.69	212.34	140.98	114.23	106.79
Net Return/c-c pr	$	57.79	18.24	109.70	134.72	189.39
Net Return/Acre	$	2.79	0.75	5.17	10.33	17.00
Cost/lb of Calf Gain	$	0.54	0.64	0.39	0.32	0.25

*Based on estimated calf weight

Literature Cited

Barker, W.T., and W.C. Whitman. 1988. Vegetation of the Northern Great Plains. Rangelands 10:266-272.

Briske, D.D., and J.H. Richards. 1995. Plant responses to defoliation: a physiological, morphological and demographic evaluation. p. 635-710. *in* D.J. Bedunah and R.E. Sosebee (eds.), Wildland plants: physiological ecology and developmental morphology. Society for Range Management. Denver, CO.

Briske, D.D. 1991. Developmental morphology and physiology of grasses. p. 85-108. *in* R.K. Heitschmidt and J.W. Stuth (eds.), Grazing management: an ecological perspective. Timber Press. Portland, OR.

Cook, C.W., and J. Stubbendieck. 1986. Range research: basic problems and techniques. Society for Range Management. Denver, CO. 317 p.

Manske, L.L., M.E. Biondini, D.R. Kirby, J.L. Nelson, D.G. Landblom, and P.J. Sjursen. 1988. Cow and calf performance on seasonlong and twice-over rotation grazing treatments in western North Dakota. Proceedings of the North Dakota Cow-Calf Conference. Bismarck, ND. p.5-17.

Manske, L.L. 1994. Ecological management of grasslands defoliation. p. 130-136. *in* F.K. Taha, Z. Abouguendia, and P.R. Horton (eds.), Managing Canadian rangelands for sustainability and profitability. Grazing and Pasture Technology Program. Regina, Saskatchewan, Canada.

Manske, L.L. 1996. Economic returns as affected by grazing strategies. p. 43-55. *in* Z. Abouguendia (ed.), Total Ranch Management in the Northern Great Plains. Grazing and Pasture Technology Program, Saskatchewan Agriculture and Food. Regina, Saskatchewan, Canada.

Manske, L.L. 1998. Animal unit equivalent for beef cattle based on metabolic weight. NDSU Dickinson Research Extension Center. Range Management Report DREC 98-1020. Dickinson, ND. 3p.

Manske, L.L. 1999. Can native prairie be sustained under livestock grazing? p. 99-108. *in* J. Thorpe, T.A. Steeves, and M. Gollop (eds.), Proceedings of the Fifth Prairie Conservation and Endangered Species Conference. Provincial Museum of Alberta. Natural History Occasional Paper No. 24.

Manske, L.L. 2003. Ombrothermic interpretation of range plant water deficiency from temperature and precipitation data at the Ranch Headquarters of the Dickinson Research Extension Center in western North Dakota, 1982-2002. NDSU Dickinson Research Extension Center. Range Research Report DREC 03-1019f. Dickinson, ND. 16p.

McNaughton, S.J. 1979. Grazing as an optimization process: grass-ungulate relationships in the Serengeti. American Naturalist 113:691-703.

McNaughton, S.J. 1983. Compensatory plant growth as a response to herbivory. Oikos 40:329-336.

Mosteller, F., and R.E.K. Rourke. 1973. Sturdy Statistics. Addison-Wesley Publishing Co., MA. 395 p.

Pimentel, D. 1988. Herbivore population feeding pressure on plant hosts: feedback evolution and host conservation. Oikos 53:289-302.