Effects of spring clipping on bluebunch wheatgrass in summer
by Tracy Kay Brewer

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Animal and Range Sciences
Montana State University

Abstract:
Elk populations have increased substantially throughout much of the western U.S. More elk now cohabit with cattle than ever before. Elk grazing of native rangeland in spring may affect plant health and forage available to cattle in summer. Information is needed to help resource managers balance the needs of the plants, elk, and cattle. In response, this 3-year study quantified the effects of spring clipping on summer cattle forage. Two study sites were selected on foothill rangeland in southwestern Montana, one sagebrush grassland site and one mountain grassland site. At each location 320 bluebunch wheatgrass (Agropyron spicatum (Pursch) Scribn. & Smith) plants were individually tagged and excluded from wild and domestic ungulates. Clipping occurred in either mid-late April or mid-late May, and plants were clipped to one of 3 residual heights (3 cm, 6 cm, or 9 cm). Undipped plants served as controls. Plant response was measured in both late June and late July. Response variables included plant yield, leaf height, seedhead production, and nutritive quality (CP, NDF, ADF, and relative feed value). Treatments were applied to compare the effects of 1, 2, and 3 successive years of clipping. April clipping did not decrease bluebunch wheatgrass yield or vigor on either site in June ($P > 0.05$). However, on the mountain grassland site, 3 years of May clipping to < 6-cm stubble heights decreased plant yield and vigor in June ($P < 0.05$) and 3 years of May clipping to a 3-cm stubble height decreased plant vigor in July ($P < 0.05$). May clipping to < 9-cm stubble heights for 3 years decreased plant vigor in June on the sagebrush grassland site. April clipping did not affect bluebunch wheatgrass nutritional quality in July ($P > 0.05$), but 3 successive years of May clipping to 3 cm increased crude protein content of plants in July ($P < 0.05$). These results suggest that if elk grazing occurs at these intensities and durations in May, adjustments in cattle or elk grazing management (e.g., timing of use, stocking rates, etc.) may be needed to sustain the forage resource for both cattle and elk.

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APPROVAL

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Tracy Kay Brewer

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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Date April 22, 2002

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ABSTRACT

Elk populations have increased substantially throughout much of the western U.S. More elk now cohabit with cattle than ever before. Elk grazing of native rangeland in spring may affect plant health and forage available to cattle in summer. Information is needed to help resource managers balance the needs of the plants, elk, and cattle. In response, this 3-year study quantified the effects of spring clipping on summer cattle forage. Two study sites were selected on foothill rangeland in southwestern Montana, one sagebrush grassland site and one mountain grassland site. At each location 320 bluebunch wheatgrass (*Agropyron spicatum* (Pursch) Scribn. & Smith) plants were individually tagged and excluded from wild and domestic ungulates. Clipping occurred in either mid-late April or mid-late May, and plants were clipped to one of 3 residual heights (3 cm, 6 cm, or 9 cm). Unclipped plants served as controls. Plant response was measured in both late June and late July. Response variables included plant yield, leaf height, seedhead production, and nutritive quality (CP, NDF, ADF, and relative feed value). Treatments were applied to compare the effects of 1, 2, and 3 successive years of clipping. April clipping did not decrease bluebunch wheatgrass yield or vigor on either site in June ($P > 0.05$). However, on the mountain grassland site, 3 years of May clipping to ≤ 6-cm stubble heights decreased plant yield and vigor in June ($P < 0.05$) and 3 years of May clipping to a 3-cm stubble height decreased plant vigor in July ($P < 0.05$). May clipping to ≤ 9-cm stubble heights for 3 years decreased plant vigor in June on the sagebrush grassland site. April clipping did not affect bluebunch wheatgrass nutritional quality in July ($P > 0.05$), but 3 successive years of May clipping to 3 cm increased crude protein content of plants in July ($P < 0.05$). These results suggest that if elk grazing occurs at these intensities and durations in May, adjustments in cattle or elk grazing management (e.g., timing of use, stocking rates, etc.) may be needed to sustain the forage resource for both cattle and elk.

CHAPTER 1

INTRODUCTION

Impacts of spatial and dietary overlap among wild and domestic ungulates have received considerable attention in areas where cohabitation occurs. A large portion of historic research has focused on the impacts livestock impose upon wildlife, while a much smaller portion has focused on the impacts wildlife impose upon livestock.

In areas where cattle (*Bos taurus*) and elk (*Cervus elaphus*) cohabit, it has been documented that they consume similar diets and utilize similar portions of the landscape throughout the course of a year. Foothill rangeland is extremely valuable seasonal habitat for both species. Elk consume nearly 80% graminoids in spring on foothill rangeland (Nelson and Leege 1982a, Ngugi et al. 1992, Jones et al. 1996) and cattle consume 75-85% graminoids in summer on foothill rangeland (Stevens 1966, Ngugi et al. 1992). The existing spatial and dietary overlap of these species on foothill rangelands warrants an elevated level of attention.

Increasing elk populations, urban sprawl, conversion of native rangeland to cropland, and increased recreational activity exacerbate the impacts of spatial and dietary overlap among wild and domestic ungulates (Kasworm et al. 1984, Vavra 1992, Cronyn and Workman 1994, Sheehy and Vavra 1996, Burcham et al. 1999). In Montana, much of this overlap impacts lower elevation, foothill rangeland dominated by bluebunch wheatgrass (*Agropyron spicatum* (Pursch) Scribn. & Smith) (Mueggler 1975, Kasworm et al. 1984, Merrill et al. 1994, Wambolt et al. 1997). Bluebunch wheatgrass is an important forage species for cattle in summer and for Rocky Mountain elk (*Cervus elaphus nelsoni* Bailey) in spring.

Bluebunch wheatgrass is a principal forage species across 27% of Montana (Payne 1973) and is important forage on foothill range throughout the Pacific Northwest and the Rocky Mountain West (Meays et al. 2000). Elk spring use of bluebunch wheatgrass foothill range may alter the availability and nutritive quality of forage for livestock in the summer and has the potential to delay cattle turn-out dates onto summer range, increase annual feeding costs of a cattle operation, lower summer cattle stocking rates, and lower livestock performance. Ultimately, excessive levels of grazing may threaten the sustainability of the forage resource. The magnitude of the effects of elk spring grazing depends on the concentration of elk, seasonal variation in weather, amount of time cattle turn-outs are delayed, and recovery of the plants following defoliation.

This study examined the potential effects of spring elk grazing on summer cattle forage. The objectives were to:

1. Compare the effects of early and late spring defoliation for a single year on plant yield and plant vigor of bluebunch wheatgrass in the summer on foothill rangeland in southwestern Montana.
2. Compare the cumulative effects of early and late spring defoliation for 1, 2, and 3 years on plant yield and plant vigor of bluebunch wheatgrass in the summer on foothill rangeland in southwestern Montana.

3. Compare the effects of early and late spring defoliation on the nutritional quality of bluebunch wheatgrass in the summer on foothill rangeland in southwestern Montana.

CHAPTER 2

LITERATURE REVIEW

Foothill rangeland serves as extremely important seasonal range for a variety of grazing ungulates. Elk, mule deer (*Odocoileus hemionus hemionus*), cattle, and domestic sheep (*Ovis aries*) rely on vegetation present on seasonal ranges at various times of the year (Berg and Hudson 1984, Powell et al. 1986, Hart et al. 1991, Sheehy and Vavra 1996). In Montana, foothill rangeland occupies nearly 10 million acres, with 4.8 million acres of foothill sagebrush and 4.7 million acres of foothill grassland present (Payne 1973).

Bluebunch wheatgrass is a critically important forage species on these seasonal, foothill rangelands in Montana (Mueggler 1972, Dragt and Havstad 1987, Coughenour 1991, Wambolt et al. 1997) and in the Intermountain West (U.S. Forest Service 1937, Daubenmire 1940, Blaisdell and Pechanec 1949).

Elk and Cattle Use of Foothill Rangeland

Elk use of seasonal, foothill rangeland is dictated by many factors. Where elk graze in winter and early spring is heavily influenced by forage availability, which is predominantly determined by snow conditions (Nelson and Leege 1982a). Elk use of seasonal range is also dictated heavily by weather (Alt et al. 1992). Elk generally move to areas of minimal snow depth by following receding snowlines (Powell et al. 1986) and utilize accessible forage (Nelson and Leege 1982a, Skovlin 1982) as they move higher in elevation into summer ranges. Elk distribution on late winter and early spring range is also dictated by snowmelt patterns, resulting in utilization of southerly slopes first (Nelson and Leege 1982a). Nutrition is another major driving force that dictates seasonal elk movements. Pregnancy and lactation in early spring and raising a calf in late spring require females to consume a nutritious diet for maintenance and production (Vavra 1992).

Graminoids on foothill rangeland are extremely important for elk in the spring as they seek green, palatable, nutritious forage on their ascent into summer ranges. Elk spring diets can consist of as much as 85% graminoids (Nelson and Leege 1982b, Ngugi et al. 1992). Mackie (1970) documented >80% graminoids composition of elk spring diets in the Missouri River Breaks, Montana, and Stevens (1966) observed elk spring diets consisting of 77% grasses in the Elkhorn Mountains, Montana.

Cattle use of seasonal, foothill range is dictated primarily by management decisions made by ranchers and resource managers. Ranchers rely on foothill range in summer to decrease their feed costs and to defer use of lower elevation native range until fall. Summer physiological needs for cows, such as lactation and raising their current calf, the first trimester of pregnancy for next year's calf, and maintaining or improving condition prior to winter demand adequate availability and nutritional quality of summer forage for cattle (Holechek et al. 1989).

Cattle diets in summer on foothill rangeland consist primarily of graminoids. Ngugi et al. (1992) observed 93% graminoids in cattle diets in southcentral Wyoming. Kasworm et al. (1984) documented 84% graminoid composition in cattle summer diets in northcentral Montana. Similarly, Stevens (1966) observed 75% graminoids in cattle summer diets in westcentral Montana.

Physical features of the landscape also dictate cattle use of foothill rangeland. In southwestern Alberta, cattle were observed at elevations below 1490 m 84% of the time and 71% of the time on slopes of less than 10%, indicating that locale and topography influence cattle distribution on summer range (Berg and Hudson 1984). Sheehy and Vavra (1996) observed that cattle preferred to graze in areas of moderate elevation that ranged from 0-50% slope on seasonal range in the Blue Mountains of Oregon, while Mackie (1970) observed cattle grazing on areas of 1-25% slopes nearly 95 percent of the time in the summer in the Missouri River Breaks, Montana. Water availability also dictates cattle distribution on rangeland, as they tend to prefer areas within a 1-mile radius of water (Holechek et al. 1989). Mackie (1970) concluded, similarly, that in the Missouri River Breaks, Montana, cattle were observed grazing within 0.75-miles of water a majority of the time. Hart et al. (1991), however, observed that as stocking densities increase, cattle will graze areas with steeper slopes and areas that are further from water.

Elk/Cattle Relationships on Foothill Rangeland

Elk densities on suitable habitat in many Rocky Mountain states and provinces are currently at or near all-time highs (Burcham et al. 1999). Many human activities, such as urban sprawl, conversion of low elevation lands to cropland, increased livestock use on existing rangelands, timber harvest of forested uplands, road development, and increased recreation have forced a change in wild ungulate habitat use (Kasworm et al. 1984, Vavra 1992, Cronyn and Workman 1994, Sheehy and Vavra 1996, Burcham et al. 1999) and have concentrated elk in certain areas (Burcham et al. 1999). Seasonal rangelands provide important foraging areas for wild and domestic ungulates in spring and early summer when forage availability is generally limited (Sheehy and Vavra 1996). In the Rocky Mountain foothills region of Montana, elk occupy bluebunch wheatgrass sites in winter and early spring and have the potential to affect the forage resources prior to cattle grazing on the same sites in the summer. These impacts are becoming increasingly important as spatial and dietary overlap increases due to diminished suitable habitat for increasing numbers of elk. Understanding the effects of grazing on bluebunch wheatgrass is critical for management of sustainable forage resources on foothill rangeland for both cattle and elk.

Defoliation Effects on Bluebunch Wheatgrass Yield

Plant yield is one factor to consider when managing bluebunch wheatgrass on foothill rangelands. It is important because stocking levels and duration of grazing depend on the amount of forage available to grazing ungulates. Timing and intensity of defoliation largely determine plant yield throughout the year (Mueggler 1975). Growth conditions relative to timing of defoliation play a critical role in determining how bluebunch wheatgrass responds to grazing (Blaisdell and Pechanec 1949, Miller et al. 1986, Pitt 1986, Merrill et al. 1994, Westenskow-Wall et al. 1994).

Blaisdell and Pechanec (1949) evaluated the response of bluebunch wheatgrass to clipping to ground level at 10-day intervals during the growing season on sagebrush grassland range in near Dubois, Idaho. Clipping from the time the plant reached a 6.35-cm height through inflorescence emergence decreased yield at the end of the growing season the following year, but clipping after inflorescence emergence increased yield. In British Columbia, clipping bluebunch wheatgrass to a 5-cm stubble height at 10-day intervals in late April to late May at one site and mid May to late June at another site produced similar results (McLean and Wikeem 1985). Plant yield declined from late June to early July in both studies.

Fifty percent utilization by sheep during the boot stage of growth decreased bluebunch wheatgrass standing crop 46% in the fall compared to no grazing on a bluebunch wheatgrass community in northeastern Oregon (Clark et al. 2000). In contrast, clipping bluebunch wheatgrass plants to a 1-cm stubble height in May, June, and November did not decrease yield at any time throughout the growing season one or two years after treatments were applied in a study in eastern Oregon (Britton et al. 1990).

After 3 successive years of clipping bluebunch wheatgrass plants to the ground during the boot stage (May 11), Wilson et al. (1966), in a study conducted in southeastern Washington, observed >60% reduction in herbage yield the fourth year. Plants that were clipped to the ground for 3 consecutive years when spring growth reached 12.7-17.8 cm (April 24) showed only a 10% reduction in herbage yield the fourth year.

Fifty percent weight removal of bluebunch wheatgrass plants in southwestern Montana prior to flower emergence (June 25) caused a 50% reduction in herbage yield the following year, as measured post-flowering, compared to unclipped controls (Mueggler 1975). In the same study, bluebunch wheatgrass plants that were clipped to 50% of total weight on June 25, plus clipped to an 8-cm stubble height at seed-in-dough stage (July 17), suffered a 75% reduction in herbage yield the following year compared to unclipped controls.

Defoliation Effects on Bluebunch Wheatgrass Vigor

Change in plant vigor is an extremely important response to defoliation and should not be overlooked by resource managers. Plant vigor is indicated in several ways (Cook & Stubbendieck 1986). Historic and frequent indicators of plant vigor for bluebunch wheatgrass are basal area, number of vegetative and reproductive culms, leaf height, length of reproductive culms, root biomass, and plant yield (Hanson and Stoddart 1940, Weaver and Darland 1947, Evanko and Peterson 1955, Heady 1957, Mueggler 1975). Ultimately, plant vigor can help quantify the health of the plant community.

Clark et al. (1998b) focused on basal area as an indicator of plant vigor. Basal area decreased in response to mid-boot/whole plant clipped and inflorescence emergence/whole plant clipped treatments, and basal area increased in response to a mid-boot/half plant clipped treatment and for unclipped controls. These results provide evidence that clipping the whole plant decreases plant vigor. Mueggler (1975) observed a decline in bluebunch wheatgrass plant vigor the following summer, indicated by a decline in both flower stalks and total herbage production, following clipping directly prior to flower stalk emergence in the spring. Although there is some disagreement regarding the stage of plant growth at which bluebunch wheatgrass is most sensitive to defoliation, most studies indicate high sensitivity in the boot stage (Miller et al. 1986, Caldwell et al. 1981). Miller et al. (1986) also suggested that plant vigor will decline if plants are annually grazed during the boot stage. Basal area of bluebunch wheatgrass plants clipped in the fall did not decline in a study conducted in eastern Oregon (Britton et al. 1990).

McLean and Wikeem (1985) conducted a clipping study on a sagebrush grassland site in southern British Columbia to observe responses of plant vigor, represented by leaf height and number of vegetative and reproductive culms. Clipping to a 5-cm stubble height from mid April to mid May decreased overall plant vigor. Clipping to 10-cm and 15-cm stubble heights initially decreased vigor, but ultimately caused less damage than the 5-cm clipping treatment the following summer, which they attributed to the higher amounts of photosynthetic material that remained for regrowth and replenishment of root reserves.

Vogel and Van Dyne (1966) found that moderate grazing by sheep in fall, winter, and spring for four years on a foothill, mountain grassland site decreased longest leaf length of bluebunch wheatgrass in summer by 4 cm compared to no grazing. Ground level clipping of bluebunch wheatgrass plants between April 27 and June 28 reduced flower stalk production between 60 and 90%, and reduced average leaf heights between 25 and 40% the following summer in a study conducted on a sagebrush grassland site near Dubois, Idaho (Blaisdell and Pechanec 1949). Rickard et al. (1975) found similar results in a study conducted on a sagebrush grassland site in south-central Washington. Moderate, early-spring grazing by yearling steers caused a 5.5-cm decrease in average leaf length, a 5.7-cm decrease in average flowering culm length, and a 26% decrease in average basal area throughout the growing season, as compared to ungrazed plants.

In the Blue Mountains of northeastern Oregon, 50% utilization by sheep during the boot stage of bluebunch wheatgrass did not affect the number of reproductive culms present in June compared to ungrazed plants (Clark et al. 2000).

Defoliation Effects on Bluebunch Wheatgrass Nutritional Quality

Timing and intensity of defoliation and the time when response is measured are important to consider when interpreting plant response to defoliation on plant nutritional quality. Many researchers believe an increase in forage quality in the fall following spring grazing can be attributed to a longer recovery time before dormancy, the plant being in an earlier phenological stage entering winter dormancy, reducing the previous year's dead material, or a combination of these factors (Anderson and Scherzinger 1975, Miller et al. 1986, Wambolt et al. 1997, Clark et al. 2000). Unfortunately, the greatest nutritional benefits are attained by defoliation at times when the plant is the most susceptible to grazing damage (Pitt 1986). Researchers have attempted to determine which growth stage and which defoliation intensity, or combination of the two, can produce forage of greatest nutrient quality at different times of the year. Many recent studies have concentrated on forage quality in fall and winter for elk grazing (Pitt 1986, Westenskow-Wall et al. 1994, Wambolt et al. 1997, Clark et al. 1998a, Clark et al. 2000).

Clark et al. (1998a) compared three timing and intensity clipping combinations on bluebunch wheatgrass and evaluated winter forage quality. All three treatments (mid-boot/whole-plant clipped, mid-boot/half-plant clipped, and inflorescence emergence/whole-plant clipped) increased percent CP content in November compared to unclipped controls. In northeastern Oregon, clipping to a 7.6-cm stubble height just prior to boot stage did not affect percent Ca or P in November compared with unclipped controls (Westenskow-Wall et al. 1994).

On an elk winter range in northeastern Oregon, 50% removal of above-ground biomass by sheep at the boot stage increased bluebunch wheatgrass CP 4.2% in both grassland and savanna communities (Clark et al. 2000). In southwestern Montana, Wambolt et al. (1997) compared the forage quality of bluebunch wheatgrass exposed to three treatments in a rest-rotation grazing system. Percent nitrogen and P were the highest in the spring-grazed pasture at various times throughout the year, but did not differ from the rested or the fall-grazed pastures.

Dragt and Havstad (1987) evaluated the effects of summer cattle grazing on forage quality for elk in the winter in the Elkhorn Mountains, Montana. Results indicated that grazing at vegetative, boot, seedhead emergence, seed shatter, maturity, or fall regrowth stages did not affect the nutritional quality of bluebunch wheatgrass plants in March the following year compared to ungrazed plants.

Effects of Clipping Versus Grazing

The effects of clipping and grazing may not be identical, but have the potential to be similar in some grazing situations. Grazing may be more harmful than clipping to individual plants when stocking densities are relatively low (White 1973). In these instances, herbage is removed from some plants and not others and ungrazed plants may be at an advantage for utilizing available resources. In contrast, grazing may be less harmful than clipping in instances where some ungrazed tillers of an individual plant remain intact, as transfer of photosynthate is more efficient (White 1973) and photosynthesis occurs more readily. Potential differences in clipping versus grazing responses are likely minimized in areas where high stocking densities cause uniformly heavy grazing patterns. On spring range, where elk concentrate on southerly, exposed slopes that often green up before other portions of the landscape (Mackie 1970), differences between clipping and grazing are likely minimal.

Effects of Plant Competition on Bluebunch Wheatgrass Response to Defoliation

Responses of bluebunch wheatgrass to defoliation may be partially dictated by the competition imposed by surrounding vegetation (Mueggler 1972). However, on a mountain grassland site in southwestern Montana, the effects of heavy and severe clipping on herbage production and flower stalk lengths of bluebunch wheatgrass were similar under full and partial competition by neighboring plants within a 90-cm radius (Mueggler 1972). Mueggler (1972) also documented a 43% reduction in herbage production and a 95% reduction in flower stalk production on heavily grazed bluebunch wheatgrass plants under full competition measured a year following spring defoliation, as compared to ungrazed plants under full competition.

Various grazing patterns and/or the lifeform of neighboring vegetation (Peltzer and Kochy 2001) may alter levels of competitive interaction among and between individual plants within a community. Repeated grazing can decrease the competitive advantage of dominant, palatable species and allows less desirable, unpalatable species to become more dominant within the community (Weaver and Darland 1947, Pieper 1994).

CHAPTER 3

MATERIALS AND METHODS

Study Areas

The study was conducted on two foothill rangeland sites dominated by bluebunch wheatgrass in southwestern Montana. Both sites were located on private land in areas where spring elk grazing has raised some level of concern for landowners and livestock producers associated with each area.

Sagebrush Grassland Site

This site was located in Madison County, Montana, approximately 32 km southwest of Alder, Montana, within the Ruby Mountains. The study area averages 34 cm of annual precipitation, with 53% occurring as rain from April through July (Western Regional Climate Center 2002). The elevation on the study site is 2225 meters. Soils on the study area are classified as shallow to deep, Ustic Cryoboralls (Montagne et al. 1982).

The study site was occupied by the *Artemisia tridentata/Agropyron spicatum* (MONT) (big sagebrush/bluebunch wheatgrass) habitat type (Mueggler and Stewart 1980). Vegetation was dominated by mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana* (Rybd. Beetle)) and bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. & Smith), with Idaho fescue (*Festuca idahoensis* Elmer), prairie junegrass

(*Koeleria pyramidata* (Lam.) Beauv.), Sandberg bluegrass (*Poa secunda* Presl), western yarrow (*Achillea millefolium* L.), and lupine (*Lupinus spp.* Kell) also present.

Mountain Grassland Site

This site was located in Granite County, Montana, approximately 8 km west of Philipsburg, Montana, within the Sapphire Mountains. The study area averages 37 cm of annual precipitation, with 50% occurring as rain from April through July (Western Regional Climate Center 2002). The elevation of the study site is 1646 meters. Soils on the study area are classified as deep, Ustic Cryoboralls (Montagne et al. 1982).

This site was occupied by the *Festuca scabrella/Agropyron spicatum* (rough fescue/bluebunch wheatgrass) habitat type (Mueggler and Stewart 1980). Vegetation was dominated by rough fescue (*Festuca scabrella* (Torr.)) and bluebunch wheatgrass, with Idaho fescue, prairie junegrass, arrowleaf balsamroot (*Balsamorhiza sagittata* (Pursh) Nutt.), and lupine also present.

Experiment 1

Experiment 1 compared the effects of a single year of spring defoliation at various timings and intensities on plant yield and vigor of bluebunch wheatgrass plants in the summer.

At each of the two foothill rangeland sites, 70 individual bluebunch wheatgrass plants with average stature and of similar size were chosen, tagged for identification, and excluded from large animal grazing within a 0.13-ha, barbed wire exclosure

(Gross 2000). The 1999 treatment plants were excluded in Fall 1998 and the 2001 treatment plants were excluded in Fall 2000. All treatment plants were located a minimum of 1 meter away from each other to eliminate confounding of treatment effects between individual plants. No shrubs were located within a 50-cm radius of each treatment plant in order to minimize confounding effects caused by competition from neighboring plants. Prior to spring treatment in both 1999 and 2001, leaf height and basal diameter were measured on each individual plant. In addition, percent basal cover of mature, perennial grasses (basal diameter ≥3 cm) within a 0.5-m radius of each plant was recorded. Basal cover was measured to account for potential confounding effects caused by neighboring plant competition (Mueggler 1972). These measurements (i.e., leaf height, basal diameter, and basal cover) were used as covariables in the data analyses.

Treatments

Hand-clipped treatments were applied to 70 individual bluebunch wheatgrass plants in spring 1999 and to another set of 70 plants in spring 2001 (total=140 plants) at each foothill rangeland site. Clipping treatments were applied at two timings in the spring to evaluate the effects of various timings of spring grazing by elk, as dictated by weather and forage availability: 1) early spring (mid-late April, 3-4 leaf stage), and 2) late spring (mid-late May, 5-6 leaf stage). Timing of treatments did not occur on the same calendar date both years, but were applied at similar phenological stages of bluebunch wheatgrass growth.

At each spring timing, three intensities of clipping were applied to evaluate the effects of various levels of spring elk grazing, as dictated by elk concentrations and length of stay on a site: 1) 3-cm residual stubble height, 2) 6-cm residual stubble height, and 3) 9-cm residual stubble height. Ten additional plants at each site remained unclipped to serve as controls. Each timing x intensity treatment combination was randomly assigned to 10 individual bluebunch wheatgrass plants (2 timings x 3 intensities x 10 plants = 60 plants + 10 unclipped control plants = 70 plants per year) at each site.

Measured Responses

Plant responses were measured in the summer of either 1999 or 2001 following spring treatment at each of the two sites. In order to account for various livestock turn-out dates onto seasonal, foothill pastures, responses were measured in both early summer (late June, boot stage) and late summer (late July, flowering stage).

Indicators of plant vigor that were measured were average leaf height and number of inflorescences produced per plant (Mueggler 1975, Rickard et al. 1975). Average leaf height of individual plants was measured in both June and July by measuring the average height of current year's leaves in their natural position to the nearest centimeter from the center of the plant crown (USDA-USDI 1996). The number of inflorescences produced per plant was only counted in July because, phenologically, the plants had not reached the flowering stage by June.

Plant yield was measured as grams of current year's herbaceous production per plant in June and July. In order to measure plant yield in July, plants could not be destructively sampled in June to attain a yield measurement. Plant yield was estimated in June by applying the average leaf height of each individual plant to a height-weight linear regression equation (Bonham 1989). Separate regression equations were developed for each site and each year. The height-weight regression equation was developed by first measuring the average leaf heights of 75 individual bluebunch wheatgrass plants outside the exclosure on each site that were representative of the treatment plants. Current year's growth of each plant was then clipped to ground level, oven-dried at 55 degrees Celsius for 48 hours, and weighed to the nearest 0.01 grams. Plant yield was measured in July by clipping current year's growth of individual treatment plants to ground level and weighing the sample after oven-drying the forage at 55 degrees Celsius for 48 hours.

Statistical Analyses

The experimental design for this study was completely randomized. Treatments were arranged in a 2x4 factorial arrangement. Factors included two timings and four intensities of treatment. Individual plants were the experimental units.

Analysis of covariance (ANCOVA) was used to test for differences in plant responses. The sagebrush grassland and mountain grassland sites were analyzed separately. Analyses were conducted using Least Squares Means in the GLM procedure of SAS (SAS 2000). The statistical model included year, timing, intensity, year x timing interaction, year x intensity interaction, timing x intensity interaction, and year x timing x intensity interaction. For each response variable, initial leaf height and initial basal diameter of each treatment plant and initial basal cover of neighboring plants were used as covariates. All covariates and interactions were retained in the model throughout the analyses. Multiple means comparisons of least squares means were made using the Tukey-Kramer method (SAS 2000). Differences were considered significant at $P \leq 0.05$.

Experiment 2

Experiment 2 compared the effects of 1 year, 2 consecutive years, and 3 consecutive years of spring defoliation at various timings and intensities on plant yield and vigor of bluebunch wheatgrass plants in the summer.

At each of the two foothill rangeland sites, 210 individual bluebunch wheatgrass plants with average stature and of similar size were chosen, tagged for identification, and excluded from large animal grazing within a 0.27-ha, barbed wire exclosure (Gross 2000). The exclosures were erected in Fall 1998. All tagged plants were located a minimum of 1 meter away from each other and no shrubs were located within a 50-cm radius of each plant in order to minimize confounding effects caused by competition from neighboring plants. Prior to spring treatment in 1999, leaf height and basal diameter were measured on each individual plant. In addition, percent basal cover of mature, perennial grasses (basal diameter ≥3 cm) within a 0.5-meter radius of each plant was recorded. Basal cover was measured to account for potential confounding effects caused by neighboring plant competition (Mueggler 1972). These measurements (i.e., leaf height, basal diameter, and basal cover) were used as covariables in the data analyses.

Treatments

Hand-clipped treatments were applied to individual bluebunch wheatgrass plants in spring of 1999, 2000, and 2001 at each foothill rangeland site. Clipping treatments were applied at two timings in the spring to evaluate the effects of various timings of spring grazing by elk, as dictated by weather and forage availability: 1) early spring (mid-late April, 3-4 leaf stage), and 2) late spring (mid-late May, 5-6 leaf stage). Timing treatments did not occur on the same calendar date each year, but were applied at similar phenological stages of bluebunch wheatgrass growth.

At each spring timing, three intensities of clipping were applied to evaluate the effects of various levels of spring elk grazing, as dictated by elk concentrations and length of stay on a site: 1) 3-cm residual stubble height, 2) 6-cm residual stubble height, and 3) 9-cm residual stubble height. Each timing x intensity treatment combination was applied to a set of 60 plants for a single year (1999 only), 2 consecutive years (1999 and 2000), or 3 consecutive years (1999, 2000, and 2001) before responses were measured, in an effort to evaluate the effects of consecutive years of grazing by elk on foothill range sites.

Thirty additional plants at each site remained unclipped to serve as controls. Ten plants were used as a control to compare against one year of clipping and responses of these 10 plants were measured in summer 1999. Ten additional control plants served as a comparison against two consecutive years of clipping, with responses measured in summer 2000. Finally, ten additional control plants served as a comparison against three consecutive years of clipping, with responses measured in summer 2001.

Each timing x intensity x duration treatment combination was randomly assigned to 10 individual bluebunch wheatgrass plants (2 timings x 3 intensities x 3 durations x 10 plants = 180 plants +30 unclipped control plants = 210 plants) at each site in spring 1999.

Measured Responses

Plant responses were measured in the summer of 1999, 2000, or 2001 following spring treatment at each of the two sites. In order to account for various livestock turn-out dates onto seasonal, foothill pastures, responses were measured in both early summer (late June, boot stage) and late summer (late July, flowering stage).

Indicators of plant vigor that were measured were average leaf height and number of inflorescences produced per plant (Mueggler 1975, Rickard et al. 1975). Average leaf height of individual plants was measured in both June and July by measuring the average height of current year's leaves in their natural position to the nearest centimeter from the center of the plant crown (USDA-USDI 1996). The number of inflorescences produced per plant was only counted in July because, phenologically, the plants had not reached the flowering stage by June.

Plant yield was measured as grams of current year's herbaceous production per plant in June and July. In order to measure plant yield in July, plants could not be destructively sampled in June to attain a yield measurement. Plant yield was estimated in June by applying the average leaf height of each individual plant to a height-weight linear regression equation (Bonham 1989). Separate regression equations were developed for each site and each year. The height-weight regression equation was developed by first measuring the average leaf heights of 75 individual bluebunch wheatgrass plants outside the exclosure on each site that were representative of the treatment plants. Current year's growth of each plant was then clipped to ground level, oven-dried at 55 degrees Celsius for 48 hours, and weighed to the nearest 0.01 grams. Plant yield was measured in July by clipping current year's growth of individual treatment plants to ground level and weighing the sample after oven-drying the forage at 55 degrees Celsius for 48 hours.

Statistical Analyses

The experimental design for this study was completely randomized. Treatments were arranged in a 2x4x3 factorial arrangement. Factors included two timings, four intensities, and three durations of treatment. Individual plants were the experimental units.

Analysis of covariance (ANCOVA) was used to test for differences in plant responses. The sagebrush grassland and mountain grassland sites were analyzed separately. Analyses were conducted using Least Squares Means in the GLM procedure of SAS (SAS 2000). The statistical model included duration, timing, intensity, duration x timing interaction, duration x intensity interaction, timing x intensity interaction, and duration x timing x intensity interaction. For each response variable, initial leaf height, initial basal diameter, and initial basal cover of neighboring plants were used as covariates. All covariates and interactions were retained in the model throughout the analyses. Multiple means comparisons of least squares means were made using the Tukey-Kramer method (SAS 2000). Differences were considered significant at $P \leq 0.05$.

Experiment 3

Experiment 3 compared the effects of a single year and consecutive years of spring defoliation at various timings and intensities on plant nutritional quality of bluebunch wheatgrass plants in the summer to plants that were unclipped. Plants from Experiment 1 and Experiment 2 that were clipped to ground level, dried, and weighed in July were analyzed for nutritional quality.

The current year's forage clipped from individual plants in Experiments 1 and 2 provided insufficient mass for nutritional analyses. Therefore, samples from each set of 10 plants were composited prior to laboratory analyses. Following the drying and weighing procedures used in Experiments 1 and 2, each composite sample was ground to 1 mm in a Wiley mill. Each composite sample was subsequently analyzed on a dry matter basis for crude protein (CP = %N × 6.25) (AOAC 1990), neutral detergent fiber (ADF), and acid detergent fiber (NDF) (Van Soest et al. 1991). Relative feed value (RFV = 0.775 × (120 ÷ %NDF) × [88.9 – (0.779 × %ADF)]) of each composite sample was also calculated (Rohweder et al. 1978).

Statistical Analyses

Data from the sagebrush grassland and mountain grassland sites were combined for statistical analyses. The two sites were replicates in the analysis and represented foothill rangeland in southwestern Montana.

Analysis of covariance (ANCOVA) was used to test for differences in forage quality. The analyses were conducted using the GLM procedure of SAS (SAS 2000). Initial leaf height and initial basal diameter of treatment plants and initial basal cover of neighboring plants were used as covariates. The statistical model for plants from Experiment 1 included year, timing, intensity, year x timing interaction, year x intensity interaction, timing x intensity interaction, and year x timing x intensity interaction. The statistical model for plants from Experiment 2 included duration, timing, intensity, duration x timing interaction, duration x intensity interaction, timing x intensity interaction, and duration x timing x intensity interaction. All covariates and interactions were retained in the model throughout the analyses. Multiple means comparisons of least squares means were made using the Tukey-Kramer method. Differences were considered significant at $P \leq 0.05$.

CHAPTER 4

RESULTS

Sagebrush Grassland Site

Experiment 1

Plant Yield. Plant yield in June 1999 did not differ ($P > 0.05$) among treatments (Table 1). In June 2001, there were no differences ($P > 0.05$) between treatment levels when plants were clipped in April. However, clipping in May 2001 to 3 cm and 6 cm decreased June yield 2.0 and 1.5 g/plant, respectively, compared to the control treatment ($P < 0.01$ and $P = 0.01$, respectively).

Plant yield in July was unaffected ($P > 0.05$) by clipping intensity in April or May (Table 1).

Leaf Height. Leaf height in June 1999 was unaffected ($P > 0.05$) by April or May clipping in 1999 or by April clipping in 2001 (Table 2). In 2001, clipping to 3 cm and 6 cm in May decreased June leaf height 10.1 and 6.8 cm, respectively ($P < 0.01$ and $P < 0.01$). Leaf height in June 2001 was also reduced by 6.9 cm when 3-cm clipping occurred in May compared to 3-cm clipping in April ($P < 0.01$).

In July 1999, there were no differences between clipping treatments and controls for either April or May clipping ($P > 0.05$) (Table 2). April

Table 1. Least squares means for yield (±SE) of bluebunch wheatgrass plants in June and July after one year of April or May defoliation on a Sagebrush Grassland site in southwestern Montana.

Response Measured	Clipping Height	1999 April	1999 May	2001 April	2001 May
		(g / plant)		(g / plant)	
June	3 cm	1.1±0.3a[1]A[2]	1.0±0.3aA	2.2±0.3aA	1.2±0.3aA
	6 cm	2.0±0.3aA	1.7±0.3aA	2.2±0.3aA	1.7±0.3aA
	9 cm	1.1±0.3aA	1.0±0.3aA	2.4±0.3aA	2.3±0.3aAB
	Control	1.5±0.3aA	1.5±0.3aA	3.2±0.3aA	3.2±0.3aB
July	3 cm	0.3±2.7aA	3.5±2.5aA	7.9±3.0aA	4.6±2.5aA
	6 cm	9.4±2.5aA	10.9±2.6aA	7.1±2.8aA	5.9±2.4aA
	9 cm	6.7±2.6aA	7.2±2.9aA	8.0±2.5aA	6.7±2.5aA
	Control	8.5±2.7aA	8.5±2.7aA	7.1±2.8aA	7.1±2.8aA

[1]Means within rows, within years, followed by the same lowercase letter are not different (P>0.05).
[2]Means within columns, within response measurement period, followed by the same uppercase letter are not different (P>0.05).

clipping in 2001 caused no differences between treatments in July 2001 ($P > 0.05$). May clipping to 3 cm, however, reduced leaf height 9.1 cm in July 2001 compared to unclipped controls ($P < 0.01$) (Table 2).

Table 2. Least squares means for leaf height (±SE) of bluebunch wheatgrass plants in June and July after one year of April or May defoliation on a Sagebrush Grassland site in southwestern Montana.

Response Measured	Clipping Height	1999 April	1999 May	2001 April	2001 May
		---(cm)---		---(cm)---	
June	3 cm	20.3±1.3a[1]A[2]	19.0±1.2aA	21.3±1.4aA	14.4±1.2bA
	6 cm	23.7±1.2aA	22.6±1.3aA	21.1±1.3aA	17.7±1.2aAB
	9 cm	21.3±1.3aA	18.6±1.4aA	21.3±1.2aA	21.4±1.2aBC
	Control	22.6±1.3aA	22.6±1.3aA	24.5±1.3aA	24.5±1.3aC
July	3 cm	20.7±1.5aA	19.4±1.4aA	23.0±1.7aA	17.3±1.4aA
	6 cm	28.6±1.4aB	28.2±1.5aB	22.5±1.5aA	20.2±1.4aAB
	9 cm	25.0±1.5aAB	22.2±1.6aAB	22.6±1.4aA	23.5±1.4aAB
	Control	25.5±1.5aAB	25.5±1.5aAB	26.4±1.5aA	26.4±1.5aB

[1]Means within rows, within years, followed by the same lowercase letter are not different (P>0.05).
[2]Means within columns, within response measurement period, followed by the same uppercase letter are not different (P>0.05).

Seedhead Production. July seedhead production was unaffected ($P > 0.05$) by clipping at any intensity level in April or May (Table 3).

Table 3. Least squares means for seedhead production (±SE) of bluebunch wheatgrass plants in July after one year of April or May defoliation on a Sagebrush Grassland site in southwestern Montana.

	1999		2001	
Clipping Height	April	May	April	May
	-------(number / plant)------		------(number / plant)-------	
3 cm	1.1±3.1a[1]A[2]	2.4±2.9aA	5.2±3.4aA	1.6±2.9aA
6 cm	6.3±2.9aA	5.9±3.0aA	4.3±3.2aA	3.0±2.8aA
9 cm	0.2±3.0aA	2.0±3.3aA	7.1±2.9aA	6.3±2.9aA
Control	9.8±3.1aA	9.8±3.1aA	12.0±3.2aA	12.0±3.2aA

[1]Means within rows, within years, followed by the same lowercase letter are not different (P>0.05).
[2]Means within columns followed by the same uppercase letter are not different (P>0.05).

Experiment 2

Plant Yield. There were no differences ($P > 0.05$) in June or July plant yield between treatments following 1, 2, or 3 years of clipping in either April or May (Table 4).

Leaf Height. There were no differences in June leaf height between treatments and controls ($P > 0.05$) when plants were clipped for 1, 2, or 3 years in April or for 1 or 2 years in May (Table 5). However, three consecutive years of May clipping to 3,

Table 4. Least squares means for yield (±SE) of bluebunch wheatgrass plants in June and July after 1, 2, or 3 years of April or May defoliation on a Sagebrush Grassland site in Southwestern Montana.

Response Measured	Clipping Height	April 1 Year	April 2 Years	April 3 Years	May 1 Year	May 2 Years	May 3 Years
		(g / plant)			(g / plant)		
June	3 cm	1.2±0.5a[1]A[2]	2.5±0.5aA	2.4±0.5aA	1.4±0.5aA	1.2±0.5aA	0.9±0.5aA
	6 cm	2.4±0.5aA	3.1±0.5aA	2.1±0.5aA	1.9±0.5aA	1.3±0.5aA	1.5±0.5aA
	9 cm	1.5±0.5aA	2.2±0.5aA	2.6±0.5aA	0.9±0.5aA	3.0±0.5aA	1.3±0.5aA
	Control	1.7±0.5aA	3.1±0.6aA	3.2±0.5aA	1.7±0.5aA	3.1±0.6aA	3.2±0.5aA
July	3 cm	3.8±2.2aA	8.1±2.3aA	7.5±2.2aA	5.2±2.2aA	2.7±2.2aA	3.9±2.2aA
	6 cm	10.6±2.3aA	5.3±2.2aA	5.9±2.3aA	14.7±2.2aA	2.9±2.4aA	4.3±2.3aA
	9 cm	8.2±2.6aA	8.3±2.3aA	4.9±2.3aA	12.7±2.3aA	6.0±2.2aA	3.9±2.2aA
	Control	11.0±2.2aA	4.2±2.9aA	1.3±2.3aA	11.0±2.2aA	4.2±2.9aA	1.3±2.3aA

[1]Means within rows, within timings, followed by the same lowercase letter are not different ($P>0.05$).
[2]Means within columns, within response measurement period, followed by the same uppercase letter are not different ($P>0.05$).

Table 5. Least squares means for leaf height (±SE) of bluebunch wheatgrass plants in June and July after 1, 2, or 3 years of April or May defoliation on a Sagebrush Grassland site in southwestern Montana.

Response Measured	Clipping Height	April			May		
		1 Year	2 Years	3 Years	1 Year	2 Years	3 Years
		(cm)			(cm)		
June	3 cm	22.0±1.1a[1]A[2]	23.1±1.2aA	21.1±1.1aA	20.5±1.1aA	20.3±1.1aA	12.3±1.1bA
	6 cm	25.0±1.2aA	23.4±1.2aA	20.6±1.2aA	24.3±1.1aA	19.5±1.1abA	17.3±1.2bA
	9 cm	23.3±1.2aA	22.9±1.1aA	22.2±1.2aA	20.1±1.2abA	22.7±1.1aA	16.4±1.1bA
	Control	24.1±1.2aA	25.4±1.5aA	23.5±1.2aA	24.1±1.2aA	25.4±1.5aA	23.5±1.2aB
July	3 cm	22.6±1.3aA	23.5±1.3aA	23.8±1.3aA	21.3±1.3aA	19.3±1.3aA	16.3±1.3aA
	6 cm	30.6±1.3aB	22.9±1.3bA	22.4±1.3bA	30.1±1.3aB	19.7±1.3bA	19.3±1.3bA
	9 cm	26.6±1.3aAB	21.4±1.3aA	22.8±1.3aA	24.2±1.3aAB	22.3±1.3aA	22.2±1.3aA
	Control	27.4±1.3aAB	24.0±1.7aA	24.5±1.3aA	27.4±1.3aAB	24.0±1.7aA	24.5±1.3aA

[1]Means within rows, within timings, followed by the same lowercase letter are not different ($P>0.05$).
[2]Means within columns, within response measurement period, followed by the same uppercase letter are not different ($P>0.05$).

6, or 9 cm decreased June leaf height 11.2, 6.2, and 7.1 cm, respectively, compared to the control ($P < 0.01$, $P = 0.05$, and $P < 0.01$, respectively). Clipping to 3 cm in May for 3 consecutive years decreased June leaf height an average of 8.1 cm compared to 1 and 2 years of May clipping to 3 cm ($P < 0.01$). Clipping to 6 cm in May for 3 years decreased June leaf height 7.0 cm versus 1 year of 6-cm clipping in May ($P < 0.01$). Clipping to 9 cm in May for 3 years decreased leaf height 6.3 cm compared to 2 years of 9-cm clipping in May ($P = 0.02$).

July leaf height did not differ ($P > 0.05$) between clipping treatments and the unclipped control (Table 5). April clipping to 6 cm for 2 and 3 consecutive years decreased July leaf height 7.7 and 7.2 cm, respectively ($P = 0.01$ and $P < 0.01$, respectively), versus one year of 6-cm clipping in April. May clipping to 6 cm for 2 and 3 consecutive years decreased July leaf height 10.4 and 10.8 cm, respectively ($P < 0.01$ and $P < 0.01$, respectively), versus one year of 6-cm clipping in May.

Seedhead Production. There were no differences ($P > 0.05$) in seedhead production among treatments following 1, 2, or 3 years of clipping at any intensity (Table 6).

Table 6. Least squares means for seedhead production (±SE) of bluebunch wheatgrass plants in July after 1, 2, or 3 years of April or May defoliation on a Sagebrush Grassland site in southwestern Montana.

Clipping Height	April			May		
	1 Year	2 Years	3 Years	1 Year	2 Years	3 Years
	(number / plant)			(number / plant)		
3 cm	3.3±2.9a[1]A[2]	8.2±3.0aA	14.4±2.8aA	3.3±2.8aA	2.3±2.9aA	2.2±2.9aA
6 cm	5.4±2.9aA	0.0±4.2aA	10.8±3.0aA	7.5±2.8aA	0.0±3.8aA	4.5±2.9aA
9 cm	4.2±3.0aA	0.0±3.8aA	7.2±3.0aA	2.9±3.0aA	0.0±3.9aA	11.0±2.9aA
Control	11.1±2.9aA	7.9±3.8aA	13.0±2.9aA	11.1±2.9aA	7.9±3.8aA	13.0±2.9aA

[1]Means within rows, within timings, followed by the same lowercase letter are not different (P>0.05).
[2]Means within columns followed by the same uppercase letter are not different (P>0.05).

Mountain Grassland Site

Experiment 1

Plant Yield. In 1999, April clipping to 9 cm increased June yield 1.6, 2.1, and 1.8 g/plant, respectively, compared to 3-cm, 6-cm, and no clipping in April ($P = 0.01$, $P < 0.01$, and $P < 0.01$, respectively), and May clipping to 9 cm increased June yield 1.7, 1.7, and 1.4 g/plant, respectively, compared to 3-cm, 6-cm, and no clipping in May ($P < 0.01$, $P < 0.01$, and $P = 0.01$, respectively) (Table 7).

July 1999 plant yield responses were similar to those in June 1999, with the 9-cm, April clipping treatment causing 7.3, 7.3, and 7.4 g/plant greater July yields, respectively, than 3-cm, 6-cm, and no clipping in April ($P < 0.01$, $P < 0.01$, and $P < 0.01$), and the May, 9-cm clipping treatment causing 4.9, 5.2, and 4.7 g/plant greater July yields, respectively, than 3-cm, 6-cm, and no clipping in May ($P < 0.01$, $P < 0.01$, and $P < 0.01$) (Table 7).

In 2001, April clipping to 3 cm decreased June yield 1.2 g/plant compared to the control ($P = 0.02$), and May clipping to 3 and 6 cm decreased June yield 1.6 and 1.4 g/plant, respectively, compared to unclipped plants ($P < 0.01$ and $P < 0.01$, respectively) (Table 7). July yield in 2001 did not differ among treatments following either April or May clipping ($P > 0.05$).

Leaf Height. In 1999, clipping to 9 cm in April increased June leaf height 6.8, 10.7, and 8.1 cm, respectively, compared to 3-cm, 6-cm, and no clipping in April ($P = 0.01$, $P < 0.01$, and $P < 0.01$, respectively), and clipping to 9 cm in May increased

Table 7. Least squares means for yield (±SE) of bluebunch wheatgrass plants in June and July after one year of April or May defoliation on a Mountain Grassland site in southwestern Montana.

Response Measured	Clipping Height	1999 April	1999 May	2001 April	2001 May
		(g / plant)		(g / plant)	
June	3 cm	1.9±0.3a[1]A[2]	1.4±0.3aA	0.6±0.3aA	0.2±0.2aA
	6 cm	1.4±0.3aA	1.4±0.3aA	1.1±0.2aAB	0.4±0.2aA
	9 cm	3.5±0.3aB	3.1±0.3aB	1.2±0.3aAB	1.4±0.3aAB
	Control	1.7±0.2aA	1.7±0.2aA	1.8±0.3aB	1.8±0.3aB
July	3 cm	1.9±0.8aA	1.6±0.8aA	2.0±0.8aA	1.1±0.7aA
	6 cm	1.9±0.8aA	1.3±0.8aA	2.1±0.7aA	0.9±0.7aA
	9 cm	9.2±1.0aB	6.5±0.9aB	2.9±0.7aA	2.2±0.7aA
	Control	1.8±0.7aA	1.8±0.7aA	2.5±0.8aA	2.5±0.8aA

[1]Means within rows, within years, followed by the same lowercase letter are not different (P>0.05).
[2]Means within columns, within response measurement period, followed by the same uppercase letter are not different (P>0.05).

June leaf height 10.5, 9.9, and 8.1 cm, respectively, compared to 3-cm, 6-cm, and no clipping in May ($P < 0.01$, $P < 0.01$, and $P < 0.01$) (Table 8). In 2001, April clipping to 3 cm decreased June leaf height 8.0 cm compared to the control ($P = 0.01$). May clipping to 3 and 6 cm decreased June leaf height 11.7 and 5.5 cm, respectively

Table 8. Least squares means for leaf height (±SE) of bluebunch wheatgrass plants in June and July after one year of April or May defoliation on a Mountain Grassland site in southwestern Montana.

Response Measured	Clipping Height	1999 April	1999 May	2001 April	2001 May
		---(cm)---		---(cm)---	
June	3 cm	21.6±1.3a[1]A[2]	17.9±1.2aA	12.1±1.2aA	4.0±1.2bA
	6 cm	17.7±1.2aA	18.5±1.2aA	16.4±1.1aAB	10.2±1.2bB
	9 cm	28.4±1.5aB	28.1±1.5aB	16.8±1.2aAB	15.7±1.2aC
	Control	20.3±1.2aA	20.3±1.2aA	20.1±1.3aB	20.1±1.3aC
July	3 cm	20.9±1.4aA	14.3±1.4bA	18.5±1.4aA	9.4±1.3bA
	6 cm	17.7±1.4aA	19.4±1.4aAB	18.7±1.3aA	14.5±1.3aAB
	9 cm	22.0±1.7aA	22.7±1.6aB	20.1±1.4aA	18.3±1.4aBC
	Control	19.2±1.3aA	19.2±1.3aAB	21.7±1.5aA	21.7±1.5aC

[1]Means within rows, within years, followed by the same lowercase letter are not different (P>0.05).
[2]Means within columns, within response measurement period, followed by the same uppercase letter are not different (P>0.05).

($P < 0.01$ and $P = 0.05$, respectively), compared to 9-cm, May clipping, and June leaf height was decreased 16.1 and 9.9 cm, respectively, by May, 3-cm and 6-cm clipping compared to controls ($P < 0.01$ and $P < 0.01$) (Table 8).

July leaf height did not differ between treatments following April defoliation in either 1999 or 2001 ($P > 0.05$) (Table 8). May clipping in 1999 to 3 cm decreased

July leaf height 8.4 cm compared to 9-cm clipping in May ($P < 0.01$), and May clipping in 2001 to 3 and 6 cm decreased July leaf height 12.3 and 7.2 cm, respectively, compared to the control ($P < 0.01$ and $P = 0.01$, respectively).

Seedhead Production. In 1999, clipping to 9 cm in April resulted in 11.3, 13.5, and 11.7 more seedheads per plant than the 3-cm, 6-cm, and control treatments, respectively ($P < 0.01$, $P < 0.01$, and $P < 0.01$) (Table 9). There were no differences ($P > 0.05$) in seedhead production between treatments and controls when clipping occurred in May of 1999 or in either April or May of 2001.

Table 9. Least squares means for seedhead production (±SE) of bluebunch wheatgrass plants in July after one year of April or May defoliation on a Mountain Grassland site in southwestern Montana.

Clipping Height	1999		2001	
	April	May	April	May
	--------(number / plant)---------		--------(number / plant)---------	
3 cm	1.2±1.6a[1]A[2]	1.2±1.6aAB	3.3±1.7aA	1.2±1.6aA
6 cm	-1.0±1.6aA	-2.0±1.6aA	1.8±1.5aA	-0.1±1.6aA
9 cm	12.5±2.0aB	7.7±2.0aB	2.4±1.6aA	2.4±1.6aA
Control	0.8±1.5aA	0.8±1.5aAB	1.9±1.8aA	1.9±1.8aA

[1]Means within rows, within years, followed by the same lowercase letter are not different (P>0.05).
[2]Means within columns followed by the same uppercase letter are not different (P>0.05).

Experiment 2

Plant Yield. Clipping in April to 9 cm for one year increased June yield 1.7, 2.1, and 1.7 g/plant, respectively, versus one year of 3-cm, 6-cm, and no clipping in April ($P = 0.01$, $P < 0.01$, and $P = 0.01$, respectively) (Table 10). Two and 3 consecutive years of April clipping to 9 cm decreased June yield 2.5 and 1.9 g/plant, respectively, versus a single year of April clipping to 9 cm ($P < 0.01$ and $P < 0.01$). Three consecutive years of clipping to 6 cm in April resulted in 1.6 g/plant greater herbage production in June than 2 years of April clipping to 6 cm ($P = 0.02$).

May clipping to 9 cm for a single year increased June yield 1.7 and 1.6 g/plant, respectively, compared to a single year of May, 3-cm or 6-cm clipping ($P = 0.01$ and $P = 0.01$) (Table 10). Three years of May clipping to 3 and 6 cm decreased June yield 1.5 g/plant compared to the controls ($P = 0.04$ and $P = 0.04$). Two and 3 consecutive years of 9-cm, May clipping decreased June yield 2.2 and 2.3 g/plant, respectively, versus one year of 9-cm clipping in May ($P < 0.01$ and $P < 0.01$).

One year of 9-cm clipping in April increased July yield 8.1, 7.8, and 6.7 g/plant, respectively, compared to one year of 3-cm, 6-cm, and no clipping in April ($P < 0.01$, $P < 0.01$, and $P < 0.01$), and one year of 9-cm clipping in May increased July yield 5.4, 5.2, and 5.2 g/plant, respectively, compared to one year of 3-cm, 6-cm, and no clipping in May ($P = 0.01$, $P = 0.01$, and $P = 0.01$) (Table 10). Two and 3 consecutive years of April clipping to 9 cm decreased July yield 7.7 and 6.5 g/plant, respectively, compared to a single year of 9 cm clipping in April ($P < 0.01$ and $P <$

Table 10. Least squares means for yield (±SE) of bluebunch wheatgrass plants in June and July after 1, 2, or 3 years of April or May defoliation on a Mountain Grassland site in southwestern Montana.

Response Measured	Clipping Height	April			May		
		1 Year	2 Years	3 Years	1 Year	2 Years	3 Years
		(g / plant)			(g / plant)		
June	3 cm	1.7±0.3a[1]A[2]	0.9±0.3aA	0.8±0.3aA	1.3±0.3aA	0.3±0.3aA	0.4±0.3aA
	6 cm	1.3±0.3abA	0.9±0.3aA	2.5±0.3bB	1.4±0.3aA	0.8±0.3aA	0.4±0.3aA
	9 cm	3.4±0.3aB	0.9±0.3bA	1.5±0.3bAB	3.0±0.3aB	0.8±0.3bA	0.7±0.3bAB
	Control	1.7±0.3aA	1.0±0.3aA	1.9±0.3aAB	1.7±0.3aAB	1.0±0.3aA	1.9±0.3aB
July	3 cm	2.5±0.8aA	2.2±0.8aA	2.5±0.9aA	2.2±0.9aA	-0.2±0.9aA	0.0±0.9aA
	6 cm	2.8±0.8aA	2.0±0.8aA	3.8±0.9aA	2.4±0.9aA	1.8±0.8aA	0.5±0.9aA
	9 cm	10.6±0.9aB	2.0±0.8bA	3.0±0.8bA	7.6±0.9aB	0.8±0.8bA	2.1±0.8bA
	Control	2.4±0.9aA	1.6±0.8aA	1.5±0.8aA	2.4±0.9aA	1.6±0.8aA	1.5±0.8aA

[1]Means within rows, within years, followed by the same lowercase letter are not different (*P*>0.05).
[2]Means within columns, within response measurement period, followed by the same uppercase letter are not different (*P*>0.05).

0.01) (Table 10). Similarly, 2 and 3 consecutive years of May clipping to 9 cm decreased July yield 6.8 and 5.5 g/plant, respectively, compared to a single year of 9-cm clipping in May ($P < 0.01$ and $P < 0.01$).

Leaf Height. There were no differences in June leaf height between treatments and controls ($P > 0.05$) when plants were clipped for 1, 2, or 3 years in April (Table 11). Three consecutive years of 3-cm clipping in April decreased June leaf height 7.4 cm compared to 1 year of 3-cm clipping in April ($P = 0.02$). Two and 3 consecutive years of 9-cm clipping in April decreased June leaf height 10.6 and 11.1 cm compared to a single year of 9-cm clipping in April ($P < 0.01$ and $P < 0.01$).

A single year of May, 3-cm and 6-cm clipping decreased June leaf height 10.2 and 9.6 cm, respectively, compared to one year of May, 9-cm clipping ($P < 0.01$ and $P < 0.01$) (Table 11). Two years of 3-cm clipping in May decreased June leaf height 7.5 cm compared to the unclipped control ($P = 0.04$). May clipping to 3 and 6 cm for 3 consecutive years decreased June leaf height 11.0 and 9.4 cm, respectively, versus the unclipped controls ($P < 0.01$ and $P < 0.01$). Three consecutive years of 3-cm and 6-cm clipping in May decreased June leaf height 9.3 and 8.3 cm, respectively, compared to a single year of May clipping to 3 and 6 cm ($P < 0.01$ and $P = 0.01$, respectively). Two and 3 consecutive years of 9-cm clipping in May decreased June leaf height 10.0 and 24.9 cm, respectively, versus a single year of 9-cm clipping in May ($P < 0.01$ and $P < 0.01$).

There were no differences in July leaf height between treatments and controls ($P > 0.05$) when plants were clipped for 1, 2, or 3 years in April or for 2 years in May

Table 11. Least squares means for leaf height (±SE) of bluebunch wheatgrass plants in June and July after 1, 2, or 3 years of April or May defoliation on a Mountain Grassland site in southwestern Montana.

Response Measured	Clipping Height	April 1 Year	April 2 Years	April 3 Years	May 1 Year	May 2 Years	May 3 Years
		(cm)			(cm)		
June	3 cm	20.9±1.4a[1]A[2]B	17.4±1.3abA	13.5±1.3bA	17.0±1.4aA	10.7±1.4abA	7.7±1.4bA
	6 cm	16.9±1.3aA	17.4±1.3aA	21.0±1.4aB	17.6±1.3aA	15.3±1.3abAB	9.3±1.4bA
	9 cm	27.3±1.4aB	16.7±1.3bA	16.2±1.3bAB	27.2±1.3aB	17.2±1.3bAB	2.3±1.3bAB
	Control	19.9±1.4aAB	18.2±1.3aA	18.7±1.4aAB	19.9±1.4aAB	18.2±1.3aB	18.7±1.4aB
July	3 cm	21.7±1.4aA	19.4±1.5aA	14.7±1.4aA	14.9±1.5aA	10.7±1.5aA	10.0±1.6aA
	6 cm	18.1±1.4aA	19.1±1.5aA	22.3±1.5aB	19.4±1.4aAB	14.5±1.5abA	11.5±1.5bAB
	9 cm	22.4±1.5aA	18.4±1.4aA	16.2±1.4aAB	23.7±1.5aB	16.6±1.4abA	13.3±1.4bAB
	Control	19.3±1.5aA	16.0±1.4aA	18.6±1.5aAB	19.3±1.5aAB	16.0±1.4aA	18.6±1.5aB

[1]Means within rows, within timings, followed by the same lowercase letter are not different ($P>0.05$).
[2]Means within columns, within response measurement period, followed by the same uppercase letter are not different ($P>0.05$).

(Table 11). One year of May, 3-cm clipping decreased July leaf height 8.8 cm compared to one year of May, 9-cm clipping ($P = 0.01$). Three consecutive years of May clipping to 3 cm decreased July leaf height 8.6 cm compared to the unclipped control ($P = 0.02$). Three consecutive years of 6-cm and 9-cm clipping in May decreased July leaf height 7.9 and 10.4 cm, respectively, compared to a single year of 6-cm and 9-cm clipping in May ($P = 0.04$ and $P < 0.01$, respectively).

Seedhead Production. Clipping to 9 cm for 1 year in April increased seedhead production by 12.9, 14.3, and 13.2 seedheads per plant, respectively, compared to one year of 3-cm, 6-cm, and no clipping in April ($P < 0.01$, $P < 0.01$, and $P < 0.01$) (Table 12). Two and 3 consecutive years of 9-cm clipping in April decreased seedhead production 13.1 and 14.7 seedheads per plant compared to a single year of 9-cm clipping in April ($P < 0.01$ and $P < 0.01$).

Two and 3 years of 9-cm clipping in May decreased seedhead production by 9.0 and 9.2 seedheads per plant compared to 1 year of 9-cm clipping in May ($P = 0.02$ and $P = 0.02$) (Table 12).

Table 12. Least squares means for seedhead production (±SE) of bluebunch wheatgrass plants in July after 1, 2, or 3 years of April or May defoliation on a Mountain Grassland site in southwestern Montana.

Clipping Height	April			May		
	1 Year	2 Years	3 Years	1 Year	2 Years	3 Years
	(number / plant)			(number / plant)		
3 cm	1.8±1.6a[1]A[2]	-0.4±1.6aA	-0.2±1.6aA	2.2±1.7aAB	-2.3±1.7aA	-0.3±1.8aA
6 cm	0.4±1.6aA	1.6±1.6abA	9.3±1.7bB	-0.2±1.6aA	1.9±1.6aA	-0.5±1.7aA
9 cm	14.7±1.7aB	1.6±1.6bA	0.0±1.6bA	8.9±1.6aB	-0.1±1.6bA	-0.3±1.6bA
Control	1.5±1.7aA	1.4±1.6aA	3.0±1.7aAB	1.5±1.7aAB	1.4±1.6aA	3.0±1.7aA

[1]Means within rows, within timings, followed by the same lowercase letter are not different (P>0.05).
[2]Means within columns followed by the same uppercase letter are not different (P>0.05).

Experiment 3

Nutritional Quality After a Single Year of Clipping

There were no differences between treatments and the control ($P > 0.05$) in crude protein content (Table 13), percent acid detergent fiber (Table 14), percent neutral detergent fiber (Table 15), or relative feed value (Table 16) when clipping occurred in April or May at any intensity.

Table 13. Least squares means for percent crude protein (±SE) of bluebunch wheatgrass plants in July after one year of April or May defoliation in southwestern Montana.

Clipping Height	1999 April	1999 May	2001 April	2001 May
	---------------(%)---------------		--------------(%)---------------	
3 cm	5.2±0.5a[1]A[2]	5.5±0.5aA	8.7±0.6aA	10.3±0.5aA
6 cm	4.6±0.5aA	4.8±0.5aA	8.5±0.5aA	8.2±0.5aAB
9 cm	4.3±0.8aA	4.4±0.7aA	7.9±0.5aA	7.4±0.5aB
Control	5.5±0.6aA	5.5±0.6aA	8.8±0.6aA	8.8±0.6aAB

[1]Means within rows, within years, followed by the same lowercase letter are not different ($P>0.05$).
[2]Means within columns followed by the same uppercase letter are not different ($P>0.05$).