Growth responses of Agropyron smithii and Bouteloua gracilis to simulated grazing and water treatments

by Stephen Dale McClelland

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

Abstract:
Plant growth responses to simulated grazing and supplemental water application influenced forage yield and canopy structure. These observations were made in vegetation representing two important grassland communities of the Northern Great Plains and were studied from 1979 to 1981 in eastern Montana. One study site was dominated by western wheatgrass (Agropyron smithii), the other by blue grama (Bouteloua gracilis). At each site, two grazing and two water treatments were applied in a 2x2 design. Repeated clipping at three-week intervals was compared with one terminal (season's end) clipping to a stubble height of 7.6 and 5.0 cm (western wheatgrass and blue grama sites, respectively). Each simulated grazing treatment included plots receiving only natural precipitation, and others receiving 2.5 cm per week of sprinkler irrigation water. Total yields of plots clipped at three-week intervals were compared with total yields of plots clipped only at season's end. Canopy structures were compared with an inclined point-contact system to record the vertical distribution of foliar density, leaf-stem ratios, and green surface area (photosynthetic surface). Grazable forage production (i.e. above clipping height) of plots harvested at season's end averaged 15% more than plots harvested periodically throughout the season. Total above ground production was not significantly affected by harvest method. Simulated grazing also reduced canopy height, leaf-stem ratios and photosynthetic surface. Application of supplemental irrigation resulted in significant increases in total above ground production, grazable forage production, foliar density, leaf-stem ratios, and photosynthetic surface.

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APPROVAL

of a thesis submitted by

Stephen Dale McClelland

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.

25 April 1983 — Date

John E. Taylor — Chairperson, Graduate Committee

Approved for the Major Department

April 25, 1983 — Date

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Approved for the College of Graduate Studies

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Date *4/25/83*

Dedicated in Loving Memory

of my Mother

26 December 1982

VITA

Stephen Dale McClelland was born in Dover, Ohio on September 28, 1955 to Curtis Dale and Naomi Ruth McClelland. After graduating in 1974 from New Philadelphia High School in New Philadelphia, Ohio, Steve attended Kent State University before completing his Bachelor of Science in Fish and Wildlife Management at Montana State University in 1979. In September of 1982, Steve married Patricia Loreen Wallenmeyer in McMinnville, Oregon. Steve's Master of Science in Range Science was completed in 1983 at Montana State University.

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ABSTRACT

Plant growth responses to simulated grazing and supplemental water application influenced forage yield and canopy structure. These observations were made in vegetation representing two important grassland communities of the Northern Great Plains and were studied from 1979 to 1981 in eastern Montana. One study site was dominated by western wheatgrass (*Agropyron smithii*), the other by blue grama (*Bouteloua gracilis*). At each site, two grazing and two water treatments were applied in a 2x2 design. Repeated clipping at three-week intervals was compared with one terminal (season's end) clipping to a stubble height of 7.6 and 5.0 cm (western wheatgrass and blue grama sites, respectively). Each simulated grazing treatment included plots receiving only natural precipitation, and others receiving 2.5 cm per week of sprinkler irrigation water. Total yields of plots clipped at three-week intervals were compared with total yields of plots clipped only at season's end. Canopy structures were compared with an inclined point-contact system to record the vertical distribution of foliar density, leaf-stem ratios, and green surface area (photosynthetic surface). Grazable forage production (i.e. above clipping height) of plots harvested at season's end averaged 15% more than plots harvested periodically throughout the season. Total above ground production was not significantly affected by harvest method. Simulated grazing also reduced canopy height, leaf-stem ratios and photosynthetic surface. Application of supplemental irrigation resulted in significant increases in total above ground production, grazable forage production, foliar density, leaf-stem ratios, and photosynthetic surface.

INTRODUCTION

Seasonal plant community development and growth are important aspects of western rangeland forage production. Community development and growth responses are often measured by plant yields and/or canopy structure.

Although many factors affect yield and canopy structure, none have more important influences than water and grazing (Clark et al. 1943, Hurtt 1951, Reed and Peterson 1961). Presently, there are many generalized ideas of water and grazing impacts on yield and canopy structure (Perry 1976, Jameson 1963). These are derived from studies of grazing and water impacts on yield and canopy structure that have assessed responses from either a grazing or a water aspect. However, by determining responses of yield and canopy structure as affected by both grazing and water, a more complete understanding of community and/or species relations to range ecosystem dynamics can be realized.

While assessing range community responses to supplemental water in eastern Montana, the High Plains Weather Modification Experiment (Weaver and Haglund 1981) sought information on the interaction of grazing and water management practices. Two sites located on the USDA Livestock and Range Research Station were selected to represent two grassland communities of the Northern Great Plains. One site was dominated by western wheatgrass (Agropyron smithii), the other by blue grama (Bouteloua gracilis).

The study had two objectives:

1) Determine how simulated grazing and supplemental summer irrigation would alter the production of western wheatgrass and blue grama communities.

2) Determine how simulated grazing and supplemental summer irrigation would alter canopy structure and forage availability.

LITERATURE REVIEW

The species of primary concern in this study were western wheatgrass and blue grama, which are widely distributed in the Great Plains (Hitchcock and Chase 1971), assume dominance over large areas there (Küchler 1964), and are important forage producers. The species differ in morphology (Hitchcock and Chase 1971), photosynthetic pathway (Waller and Lewis 1979), and, at least in the central plains, in season of growth (Kemp and Williams 1980).

This paper will examine responses of these plants to two levels of grazing and two levels of water stress.

Despite differences in morphology, photosynthetic pathway, and phenology of western wheatgrass and blue grama, both species are affected by grazing and water supplementation. Grazing and water supplement can affect many plant community responses including nutrient content, species composition, reproduction, canopy structure, biomass production, and others (Jameson 1963, McNaughton 1979, Perry 1976). However, the primary responses of grazing and water supplement are alterations in: 1) biomass production, and 2) canopy structure.

Clipping Effects on Production

Most studies of plant responses to grazing are based upon data from simulated grazing experiments. The effects of grazing and clipping are similar but not identical (White 1973). Comparisons of grazing and clipping are thoroughly reviewed by Culley et al. (1933), Jameson (1963), White (1973), and McNaughton (1979). A summary is presented in Table 1.

Table 1. Eight Characteristics In Which Grazing and Clipping Effects Differ (Cully et al. 1933, Jameson 1963, White 1973, McNaughton 1979).

1.	Utilization effects	Grazing removes herbage at heights varying from plant to plant and even within the same plant. Clipping removes all herbage above a given height from all plants.
2.	Trampling effects	Grazing provides more mechanical damage and soil compaction.
3.	Mechanical effects	Shredding, ripping, pulling, stripping and tearing of tissue by animal are contrasted with the clean cut by scissors or shears.
4.	Saliva effects	May stimulate regrowth of plant parts; absent in clipping studies.
5.	Selection preferences	The plants we select for study (species, age, size, microsite, etc.), may not be the same plants grazed and regrazed by the herbivores.
6.	Nutrient transport	Grazers may facilitate a net influx or efflux of nutrients from a site and potentially on a large scale, whereas clipping studies generally remove nutrients (leaves) from a site on a small scale.
7.	Competition	Grazing often removes herbage from one plant and not from surrounding plants. Ungrazed plants may then outcompete grazed plants for water and nutrients. Clipping is less selective.
8.	Translocation	Grazing may be less detrimental than clipping by leaving some tillers in a tiller system ungrazed. Carbohydrates may be transferred from ungrazed to grazed tillers.

Most clipping studies compare yield responses of plots clipped at some specified height, some frequency of removal and/or some stage of development with an untreated control. Jameson (1963) suggests that clipping when regrowth reaches a predetermined height or growth stage may have special merit when the objective is to determine desirable practices of hay harvesting. Clipping at specified time intervals may be more useful for studying grazing systems.

The literature shows that clipping effects vary among species and grassland communities. Clipping studies of Biswell and Weaver (1933), Cook and Stoddart (1953), Branson (1956), Heady (1961), Dwyer et al. (1963), Smoliak (1965), Dittmer (1973), Beaty and Powell (1976), Buwai and Trlica (1976), and many others compared yield responses and concluded that defoliation reduced yield below that of unclipped controls. They also showed that the more frequent and severe the clipping, the greater the reduction in yield. Hölscher (1945) and Everson (1966) demonstrated this specifically for western wheatgrass and blue grama. On the other hand, clipping sometimes increases yields, as shown by Canfield (1939), Lodge (1960), Drawe et al. (1972), Eck et al. (1975), and others.

Delayed responses to clipping were evident in low growing grasses, particularly buffalo grass and blue grama. Albertson et al. (1953) showed production of blue grama and buffalo grass was unaffected in the year of clipping but was affected in subsequent years.

Grazing and clipping both disrupt normal plant resource allocation by removal of photosynthetically active tissue (Caldwell et al. 1981) which directly reduces acquisition of required materials and energy (Conant and Risser 1974). Plants coping with the effects of defoliation must compensate for lost photosynthetic tissue by rapid replacement of photosynthetic tissue (Caldwell et al 1981) using either stored carbon reserves (Cook 1966, Donart and Cook 1970, Perry and Chapman 1974, Owensby et al. 1974, Buwai and Trlica 1976), and/or appropriate allocations of newly fixed carbon (White 1973). Caldwell et al. (1981) showed that leaf- and stem-soluble carbon pools, primarily in the form of carbohydrates, are almost completely removed by clipping. Leaf regrowth is supported primarily by crown reserves. Carbohydrate pools of diffuse root systems are reserved for root system activities when the supply of photosynthates from the shoot system is curtailed. Curtailment of root growth has nevertheless been observed after clipping (Weaver 1930, Biswell and Weaver 1933, Stoddart and Smith 1955, Burleson and Hewitt 1982). This constitutes a mechanism for conserving plant resources and aids in the re-establishment of a proper root-shoot balance.

Canopy Structure Effects on Production

Knight (1969), Risser (1971), and Conant and Risser (1974) show canopy structure is an important modifier of energy, water, and nutrient availability within the ecosystem. In particular, canopy structure is an important determinant of crop and pasture production (Watson 1952) because it influences light interception, and consequently, photosynthesis (Warren-Wilson 1965). Periodic measures of canopy structure during the growing season therefore illustrate grassland community responses to manipulation, such as grazing and water (Conant and Risser 1974). Productivity of most crops increases as leaf area increases (Jameson 1963) until light, water, or nutrients limit the growth of active plant tissue and production declines (Watson 1952, Donald and Black 1958, Caldwell et al. 1981).

In regions or seasons where water and nutrients are not limiting production, grassland ecosystems are dependent on the quantity and vertical distribution of foliar material. Donald (1951) states that the ultimate capacity of a species for biomass production, when water and nutrients are in adequate supply, depends on the degree to which a community can exploit the light falling on it. This level of production will depend on the stature and habit of the species. Species of prostrate habit and dense horizontally disposed leaves achieve a full canopy and full exploitation of light while at comparatively low stature. Tall species, with erect habit, greater height, and leaves at various levels and angles, do not readily form a continuous foliage cover, and so do not intercept all available light. Studies by Watson (1952) and Donald and Black (1958) show an interrelationship of light, leaf area, and production. They concluded that if leaf area is less than the point corresponding with optimum yield, production will be reduced by defoliation since productivity depends on leaf surface to intercept light. If leaf area is greater than the point of optimum yield, defoliation will reduce leaf area and production may increase.

Water Effects on Canopy Structure and Production

In arid regions or seasons, water limits growth. The major role of water supplementation on native range is to allow photosynthesis in dry periods. The water economy of an area may be augmented by various techniques including weather modification, irrigation, water spreading, contour furrowing, pitting, or scalping (Vallentine 1971). Supplemental water studies by Branson (1956), Klages and Ryerson (1965), Smika et al. (1965), Johns and Lazenby (1973a, 1973b), and Lavenworth and Sims (1973) showed increases in yield ranging from 50 to 330 percent over controls. Weaver (1981) working with western wheatgrass and blue grama, under weekly summer water supplements of 6, 12, and 25 millimeters per growing season-week, showed average increases of 22%, 45%, 246% respectively for blue grama and 17%, 58%, 338% respectively for western wheatgrass.

Besides effects on forage yield, there are obvious effects of water additions on canopy structure. Donald and Black (1958) working with pasture crops showed increases in density (plants per unit area of ground surface). Weaver (1981) working in western wheatgrass communities with water additions of 25 millimeters per growing season-week, showed increased densities (plants or parts of plants per unit area) at ground surface and in vertical layers above the surface, as well as the usual increase in canopy height.

METHODS

Study Description

Location. In 1977, an irrigation study was initiated as part of the High Plains Weather Modification Experiment "HIPLEX" (Weaver and Haglund, 1981), to determine the effects of increased moisture on the vegetation of the Northern Great Plains. The simulated grazing and supplemental water study reported here was conducted during the summers of 1979 through 1981 at the USDA Livestock and Range Research Station, Miles City, Montana. Two grassland ecosystems, one dominated by western wheatgrass and the other by blue grama, which comprise over 1.16 million km^2 (Küchler 1964) of the Northern Great Plains were represented.

The western wheatgrass site was 4 km southwest of Miles City on an alluvial flood plain of the Yellowstone River. The site was approximately 150 meters by 300 meters. The blue grama site was 6 km southeast of Miles City on a flood plain of the Tongue River. The site was approximately 50 meters by 150 meters.

Vegetation. Over 97% of the production of the western wheatgrass and blue grama communities was by perennial grass species. By composition, it was subjectively estimated that western wheatgrass and blue grama comprised 90% of their respective communities. Other grasses included needleandthread (*Stipa comata*), green needlegrass (*Stipa viridula*), buffalograss (*Büchloe dactyloides*), Japanese brome (*Bromus japonicus*), cheatgrass (*Bromus tectorum*), and sand dropseed (*Sporobolus cryptandrus*). The principal forbs were yellow sweetclover

(*Melilotus officinalis*) and scarlet globemallow (*Sphaeralcea coccinea*). The most conspicuous half-shrub was cudweed sagewort (*Artemisia ludoviciana*).

Vegetation of the Miles City area is described in more detail by Holscher (1945), Houston and Woodward (1966), and Olson (1982). These descriptions are put in a regional context by Coupland (1961), Nicholson and Hulett (1969), and Küchler (1964).

Grazing History. Both study sites had previously received grazing by domestic animals. Grazing at the western wheatgrass site was by cow-calf pairs during summer and was considered light (R. White personal communication). Grazing was discontinued in 1975. Grazing at the blue grama site was by cow-calf pairs during the late summer - early autumn, and was considered heavier, since it was within 100 meters of a stock water tank (R. White personal communication). Grazing was discontinued in 1976.

Climate. The climate of the study area is semiarid with a mean annual precipitation of 35.5 cm., 76% of which falls during the April to September growing season (United States Department of Commerce. Climatological Data - Montana (Miles City FFA AP) 1979-1981). Climatological data are summarized in Table 2.

Soils. Soils of the western wheatgrass and blue grama sites were classified by Soil Conservation Service personnel (M. Nichols, Miles City, Montana). The soil of the western wheatgrass site is a well-drained, fine, montmorillonitic Borollic Camborthid specifically identified as a Kobar silty clay loam, with calcium carbonate at 20 cm, and roots to 150 cm. It developed on alluvium lying in simple

Table 2. Precipitation (cm) and Average Temperature (Degrees Celsius) at Miles City, Montana 1978-1981.

	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec	Annual
Precipitation													
Normal	1.24	1.30	1.65	3.20	5.23	8.43	3.94	3.05	3.02	1.80	1.30	1.22	35.38
1978	1.30	3.02	0.30	1.19	17.30	3.53	6.37	2.05	8.63	0.68	5.51	1.60	51.51
1979	0.84	2.90	0.66	1.93	3.45	1.96	7.09	1.70	0.08	0.81	0.51	0.13	22.05
1980	0.84	0.84	0.71	1.68	0.71	7.72	1.35	5.18	1.85	4.09	0.74	0.84	26.54
1981	0.13	0.15	0.71	0.51	7.29	6.53	0.91	2.84	1.83	3.53	1.98	0.58	27.00
Temperature													Average
Normal	-9.2	-5.8	-1.0	7.4	13.5	18.3	23.6	22.5	15.5	9.3	0.2	-5.6	7.39
1978	-16.3	-11.4	-0.3	8.2	13.7	18.8	21.9	21.3	17.2	9.2	-5.2	-10.7	5.5
1979	-17.7	-13.3	-1.2	5.2	12.1	19.8	23.7	22.2	18.7	10.4	-1.2	-1.6	6.42
1980	-10.3	-4.4	-0.2	11.7	16.8	20.0	24.7	19.7	16.0	9.6	3.6	-4.2	8.58
1981	-0.6	-2.3	4.8	10.7	13.9	17.7	23.9	23.7	17.7	7.2	2.8	-5.6	9.49

relief with a 2% north slope. The soil of the blue grama site is a well-drained, fine, loamy, frigid calcareous Ustic Torriorthent specifically identified as a Havre variant loam, with calcium carbonate at 75 cm, and roots to 105 cm. It developed on a high alluvial terrace lying in simple relief with a 1% east slope.

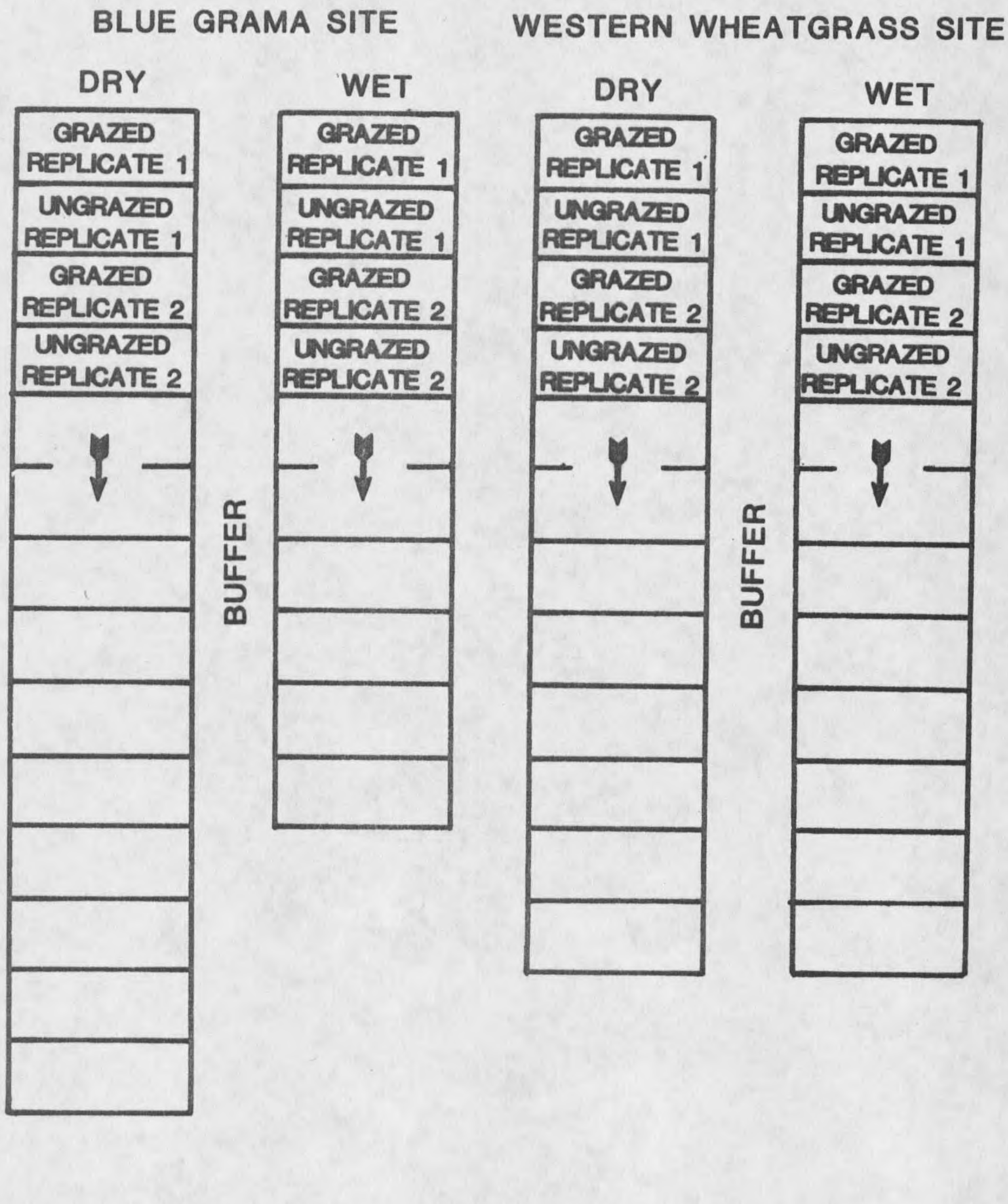
Experimental Design

The experimental design at each study site was a 2 x 2 systematic block with two simulated grazing and two water treatments (Figure 1). Depending upon space available, each treatment had five to seven replicates; that is, the blue grama site had an unbalanced design of 5 replicates of wet grazed/ungrazed treatments and 7 replicates of dry grazed/ungrazed treatments, while the western wheatgrass site had balanced design of 6 replicates per treatment. Each experimental plot was 2 x 6 meters.

The simulated grazing treatments were: 1) Grazed, consisted of plots repeatedly clipped every 21 days (i.e., 4 times in the June - September growing season), 2) Ungrazed, consisting of plots clipped at the end of the growing season (in September, corresponding with the fourth "grazed" clip date). "Grazing" was accomplished with a rear-bagging Toro[1] lawn mower. Grazing heights were arbitrarily chosen at 7.6 cm and 5.0 cm, after surveying surrounding pastures for the western wheatgrass and blue grama sites, respectively. Using methods described by Holscher and Wookfolk (1953) average percent utilization by weight with such grazing heights were estimated to result in 64%

[1]Mention of a namemark does not imply its approval to the exclusion of other products that may also be suitable.

Figure 1. Experimental Plot Design for Western Wheatgrass and Blue Grama, 1979-1981.



utilization of western wheatgrass and 30% for blue grama. These authors suggest average "proper" utilization of 45% and 41% for western wheatgrass and blue grama subtypes respectively, under continuous summer grazing (May to November) in eastern Montana.

The water treatments were: 1) Dry, received only natural precipitation. Precipitation was below average for the study period 1979 - 1982 (Table 2), 2) Wet, received supplemental sprinkler irrigation water of 2.5 cm per week during the growing season. These plots were intended to represent wet years or irrigated communities. They also served to protect the investigator from failure due to possible drought conditions often found in eastern Montana. Supplemental water applications were applied in early morning under windless conditions. Wedge gauges were used to record average water received by treatments. Water applications are further described by Weaver (1981). Specific amounts of water received by treatment plots are summarized in Table 3.

Canopy Structure Analysis

Canopy structure will be defined as the vertical distribution of foliar material differentiated as to leaf, stem, or inflorescence.

Point contact data were recorded during 1981, just before each grazing sample collection date, for all treatments and both sites. Samples were taken with a motorized inclined point-contact system described by Knight (1973). The pin's angle of inclination was 32.5° from the horizontal. Three sampling positions were randomly placed at the 2 meter edge in each treatment. This placement allowed data collection without disturbance of biomass collection procedures.

Table 3. Summer Natural and Supplemental Moisture (cm) Received By Western Wheatgrass (AGSM) and Blue Grama (BOGR) Sites, 1979-1981.

	May	Jun	Jly	Aug	Total
1979					
Natural*	3.45	1.96	7.09	1.70	14.20
1980					
Natural	0.71	7.72	1.35	5.18	14.96
AGSM Irrigation	2.31	10.90	10.52	7.92	31.65
AGSM Total	3.02	18.62	11.87	13.10	46.61
BOGR Irrigation	2.64	7.29	14.17	10.44	34.54
BOGR Total	3.35	15.01	15.52	15.62	49.50
1981					
Natural	7.29	6.53	0.91	2.84	17.57
AGSM Irrigation	**	2.57	10.87	11.66	25.10
AGSM Total	7.29	9.10	11.78	14.50	42.67
BOGR Irrigation	2.34	2.13	10.16	10.49	25.12
BOGR Total	9.36	8.66	11.06	13.33	42.69

* Though a similar irrigation regime was applied in 1979-1980-1981, 1979 records are not available.

**Irrigation Moisture Not Applied.

Sampling positions were marked with iron nails driven into the ground for ease of frame relocation. Exact repositioning of the frame on successive sample dates eliminated plot to plot variation as a source of error. Each sample consisted of 15 pins located 5 cm apart for a total of 45 pins per treatment. All pin contacts were recorded as to vertical height of contact, species, plant part, and physical condition, defined as live or dead plant tissue.

Biomass Production Analysis

Grazable forage here is defined as biomass produced above the clipping heights of 7.6 cm for the western wheatgrass and 5.0 cm for the blue grama site. Total above-ground biomass is defined as production both above and below clipping levels.

Grazable forage samples were harvested from all treatments at both sites during the summer months of 1979 - 1981. The "grazed" plot samples were collected four times, every 21 days, except in 1979, which had three sampling periods. The "ungrazed" plot samples were collected at season's end which corresponded with the last grazing sample collection. Samples were separated into grass, forb, and shrub categories in all years except 1979, where totals were used. Samples were bagged and dried to constant weight at 50° Celsius. The samples were sifted in a 35 mesh screen to remove soil material, then weighed to the nearest 0.1 gram.

To estimate total above-ground biomass, samples were collected from all treatments at both sites in October of 1981 for biomass produced below the grazing height. Samples were taken from 8 regularly placed frames (2 x 5 dm., 2 per plot) per treatment. Total plant material was clipped to ground level by hand, and dried and weighed just as was the grazable forage material.

Statistical Analysis

Mean biomass production values were calculated for each treatment and analyzed for significant differences at the 99% level of confidence using an Analysis of Variance Multi-Factor and LSD mean separation tests. Means and standard errors were calculated from the canopy structure frequency data for each treatment. Regressions were formulated using biomass production values and canopy structure frequency data.

RESULTS AND DISCUSSION

A 2x2 factorial experiment was carried out to determine effects of grazing on two major grassland communities under dry and wet year conditions. The unirrigated plots received less than long-term average precipitation (Table 2) during the study period. The irrigated plots received water equivalent to the wettest years in the region. Grazing plots in each treatment were clipped at three week intervals to a height of 5.0 cm (blue grama site) or 7.6 cm (western wheatgrass site).

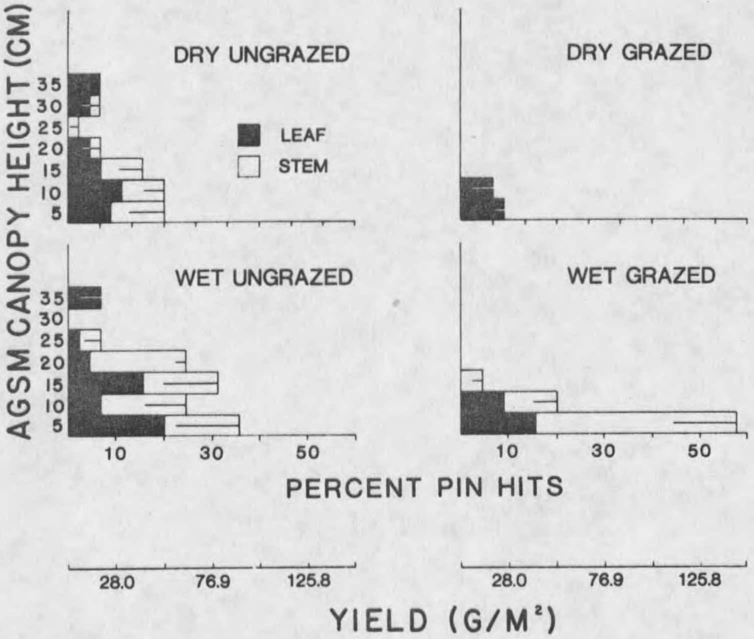
Community responses were measured in terms of total above ground production, grazable production (i.e. that above clipping height), and canopy structure (i.e. vertical distribution of biomass and total plant area). Structural components were subdivided according to leaf-stem-fruit and live-dead. These parameters are treated separately in the following sections.

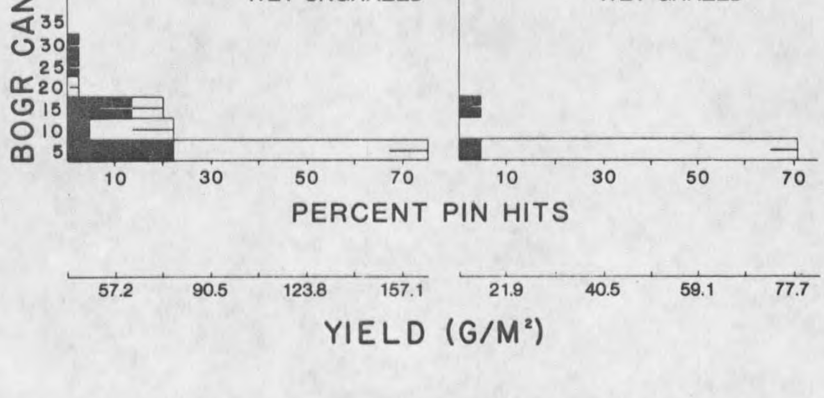
Canopy Structure

Distribution of Leaf Stem Surface and Biomass

The vertical distribution of plant leaf and stem surface (point contacts) at maximum standing crop is shown in figure 2. Since point contacts are usually well-correlated with biomass (Greig - Smith 1964, Conant and Risser 1974), it is desirable to regress the number of point contacts in 15 probes (or percent pin contact) against biomasses recorded to allow simultaneous discussion of surface and biomass structure. Resultant conversion scales (Figure 2) will be average scales for leaf stem surface versus biomass throughout the

Figure 2. Vertical Stratification of Canopy Cover From the Western Wheatgrass and Blue Grama Sites, Percent Pin Contacts (% Pin Contacts Plus Standard Error), Leaf-Stem Ratios (x), and Total Above Ground Yield (grams/m^2) at Maximum Standing Crop, 1981. Yields are Predicted From Regression Analysis. (Figure 1).





canopy because no effort was made to develop separate regressions for each canopy layer.

Data from leaf stem surface contacts against biomass (Figure 3) fit linear regressions better than curvilinear regressions attempted. Correlation coefficients for western wheatgrass and blue grama ranged from 0.87 to 0.90. Western wheatgrass regressions had the highest correlation coefficients when data from water and grazing treatments were combined, while blue grama values were highest when the data were separated by grazing treatment.

While it was not directly pertinent to the immediate study goal, one cannot help asking why the regression lines differ. Differences between the species are probably due to growth form differences, with western wheatgrass having a greater weight (gram/pin contact) than blue grama. Field observations suggest that western wheatgrass has longer, coarser stems than blue grama and if so, these might contribute to the high weights observed. Similarly, the low weight (grams/pin contact) of grazed blue grama may be due to the rarity of stems relative to proportions present in ungrazed plants.

Factors Affecting Canopy Structure

This study examined changes in canopy structure with respect to species, water level, grazing level, and season. Later discussion is simplified if seasonal effects are considered first.

Season. Lateral bars in figure 4 indicate the amount of material present in each 5 cm layer of each species - treatment community at four dates. The similarity of most sets of bar lengths between early July and early September show that basic canopy structures had evolved

Figure 3. Regressions and Correlations From Western Wheatgrass and Blue Grama Sites, 1981. (Pin Contacts/Plot Above Grazing Height with Grazable Forage Yield/Plot).

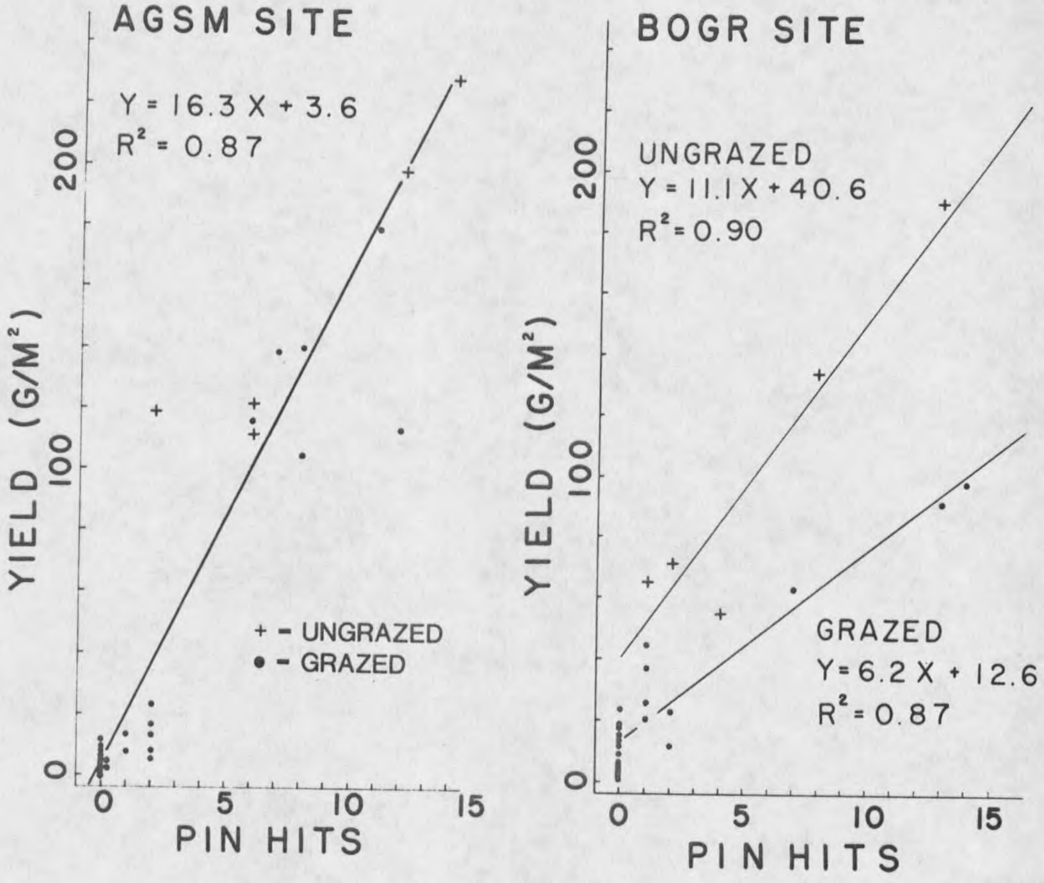
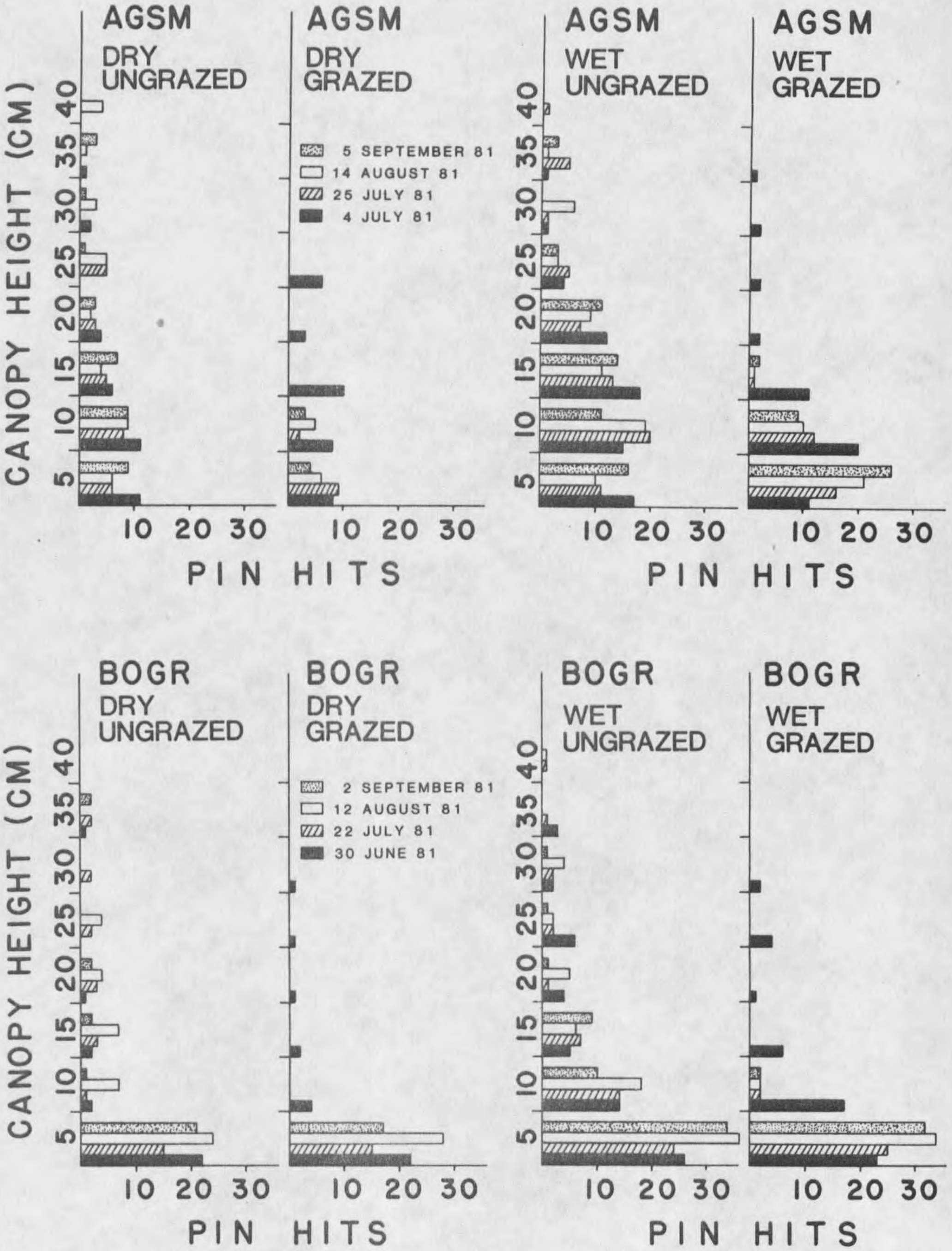


Figure 4. Growing Season Vertical Stratification of Western Wheatgrass and Blue Grama Canopy Cover. Total Pin Contacts for Each Treatment Plot and Sampling Date.



by July 4 and remained little changed for the rest of the summer. The principal exception to this statement is seen in black bars (early July) on grazed plots; these show the presence of plant material in upper layers which was to be cut in the first grazing and never reappeared there due to repeated clipping of these plots. Results showed no changes occurred in the season studied; however, it is obvious that changes occur over a longer term (Harper 1977).

Species. The fact that western wheatgrass and blue grama differ in their morphological growth characteristics is well-known (Hitchcock and Chase 1971), and has been further demonstrated with study results (Figure 4).

Water. Application of supplemental water to ungrazed western wheatgrass and blue grama communities did not significantly increase canopy height of either community (Figure 4). Supplemental water increased canopy heights of grazed communities slightly by supporting growth into the grazed layer (Figure 4). Total leaf stem surface and biomass increased in both species (Figure 4) as a result of increased foliar density in all canopy layers.

The fact that water additions did not significantly increase canopy height and vertical distribution of biomass in western wheatgrass and blue grama communities is in contrast with the results of Weaver et al. (1981).

Grazing. While pregrazing measures (Figure 4, early July) show that plants of grazed plots are capable of reaching into higher canopy layers, later measures show that grazing essentially eliminates growth above the grazing height (5 cm in blue grama, and 7.6 cm in western wheatgrass) in dry plots and greatly reduces it in irrigated plots.

As a result of grazing, plants become more prostrate by reducing plant size, thereby appearing to concentrate material in the unclipped canopy layer (Figure 4). Such concentrations of leaf surface in the unclipped layer would maximize photosynthesis in a grazing-stressed system. Total quantities of leaf surface in the first layer of grazed plots are not, however, increased over ungrazed controls (Figure 2). There appears to be little true compensation in these western wheatgrass and blue grama communities.

Leaf-Stem Canopy Structure

Water and grazing might affect leaf-stem ratios (allocation of carbon) as well as community height and biomass. Leaf-stem ratios are important both because of the relatively high nutritional quality of the leaves and because grazing animals prefer leaves to stems (Cook and Harris 1950, Arnold 1964).

Grazing had little effect on seasonal declines of leaf-stem ratios under dry conditions, whereas with supplemental moisture, grazing maintained high leaf-stem ratios throughout the season (Table 4). Apparently, under dry conditions senescence of leaves occurred at a higher rate than under moist conditions. Supplemental water further supported growth of new leaves on shortened stems.

Leaf-stem ratios tend to be low in the lowest canopy layers (Tables 5, 6). These low ratios are a necessary correlate of the support functions of stems in any community. However, this trend may be counteracted to some extent in some grassland communities by the

Table 4. Total Leaf-Stem Ratios of the Western Wheatgrass and Blue Grama Sites, 1981.

Western Wheatgrass

Date	July 4	July 25	August 14	September 5
Treatment				
Dry Grazed	4.3	1.2	0.1	0.0
Dry Ungrazed	2.5	4.5	1.0	0.8
Wet Grazed	2.8	1.6	2.2	2.4
Wet Ungrazed	1.8	1.3	1.8	1.3

Blue Grama

Date	June 30	July 22	August 12	September 2
Treatment				
Dry Grazed	1.8	14.0	3.0	1.4
Dry Ungrazed	1.9	0.8	0.8	0.9
Wet Grazed	1.9	12.5	4.1	5.8
Wet Ungrazed	1.9	2.2	1.2	1.8

Table 5. Stratified Leaf - Stem Ratios From the Western Wheatgrass Site, 1981.

	Date	July 4		July 25		August 14		September 5	
Treatment	Height	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem
Dry	5 cm	3	5	5	4	1	5	0	4
Grazed	10 cm	8	0	1	1	0	5	0	3
	15 cm	9	1						
	20 cm	3	0						
	25 cm	7	1						
Dry	5 cm	6	5	1	5	2	4	5	4
Ungrazed	10 cm	9	2	6	2	7	2	4	5
	15 cm	5	1	3	2	3	1	4	3
	20 cm	3	1	2	1	1	1	1	2
	25 cm	0	0	4	1	1	4	1	0
	30 cm	2	0			1	0	1	2
	35 cm	0	1			1	0	0	3
	40 cm					0	4		
Wet	5 cm	6	5	8	8	12	9	19	7
Grazed	10 cm	17	3	9	3	9	1	5	4
	15 cm	10	1	1	0	1	0	2	0
	20 cm	1	1						
	25 cm	1	1						
	30 cm	1	1						
	35 cm	0	1						
Wet	5 cm	9	8	2	9	3	7	7	9
Ungrazed	10 cm	10	5	15	5	13	6	8	3
	15 cm	15	3	9	4	10	1	7	7
	20 cm	8	4	7	0	7	2	9	2
	25 cm	1	3	3	2	1	2	2	1
	30 cm	1	0	0	1	4	2	0	0
	35 cm	0	1	0	5	0	1	0	3
	40 cm			0	1				

Table 6. Stratified Leaf - Stem Ratios of Blue Grama, 1981. Ratios Calculated from Pin Contacts.

	Date	June 30		July 22		August 12		September 2	
Treatment	Height	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem
Dry	5 cm	19	3	14	1	21	7	10	7
Grazed	10 cm	1	3						
	15 cm	0	2						
	20 cm	0	1						
	25 cm	0	1						
	30 cm	0	1						
Dry	5 cm	18	5	12	3	19	5	12	9
Ungrazed	10 cm	1	1	0	1	1	6	0	1
	15 cm	0	2	0	3	0	7	0	2
	20 cm	0	1	0	3	0	4	1	1
	25 cm	0	0	0	2	0	4	0	2
	30 cm	0	0	0	2				
	35 cm	0	1	0	2				
Wet	5 cm	20	3	23	2	27	7	29	3
Grazed	10 cm	11	6	2	0	2	0	0	2
	15 cm	4	2						
	20 cm	0	1						
	25 cm	0	4						
	30 cm	0	2						
Wet	5 cm	24	2	20	4	23	14	24	10
Ungrazed	10 cm	10	4	14	0	14	4	8	2
	15 cm	3	2	3	4	2	4	3	6
	20 cm	1	3	0	1	1	4	1	0
	25 cm	0	6	0	2	0	2	0	1
	30 cm	0	2	0	2	0	4	0	1
	35 cm	0	3	0	1				
	40 cm			0	1				

appearance of stems which lift reproductive structures above the canopy for better wind pollination and/or seed dispersal.

Photosynthetic Canopy Structure

Because photosynthesis depends more on green surface than morphology, the distribution and amount of green surface (photosynthetic surface) in the various canopies (Table 7) as affected by water availability, grazing, and season, may be important. Later discussion is simplified if water and season effects are considered first.

Water and Season. With adequate water, photosynthetic surface (live-dead ratios) increased as season progressed (Table 7), as a result of increases in photosynthetic surface in all canopy layers (Tables 8, 9). However, if water becomes limiting, leaves die and photosynthetic surface declines (Table 7).

Similarly, Bokhari (1976) showed that the chlorophyll content of western wheatgrass was maintained throughout the season by supplemental moisture, while Rauzi and Dobrenz (1970) showed chlorophyll content declined with season in western wheatgrass and blue grama without additional water.

Grazing. Photosynthetic surface in ungrazed plots decreased exponentially as height decreased in blue grama while in western wheatgrass it tended to decline both above and below the level of maximum canopy density (Figure 5). Grazing converts the photosynthetic surface of western wheatgrass to an exponentially declining one, similar to that observed in blue grama (Figure 5).

Table 7. Total Photosynthetic Surface (Live/Dead Pin Contact Ratio) of the Western Wheatgrass and Blue Grama Sites, 1981.

Western Wheatgrass

Sample Date	July 4	July 25	August 14	September 2
Dry Grazed	36.0	0.1	0.1	0.2
Dry Ungrazed	16.5	1.3	0.8	0.3
Wet Grazed	6.0	6.3	7.0	11.3
Wet Ungrazed	10.3	4.3	6.3	11.5

Blue Grama

Sample Date	June 30	July 22	August 12	September 2
Dry Grazed	31/0*	2.8	0.1	0.0
Dry Ungrazed	13.5	0.9	0.4	0.2
Wet Grazed	16.7	12.5	8.0	16.0
Wet Ungrazed	59.0	6.4	4.6	4.3

*31 Live Pin Contacts/0 Dead Pin Contacts

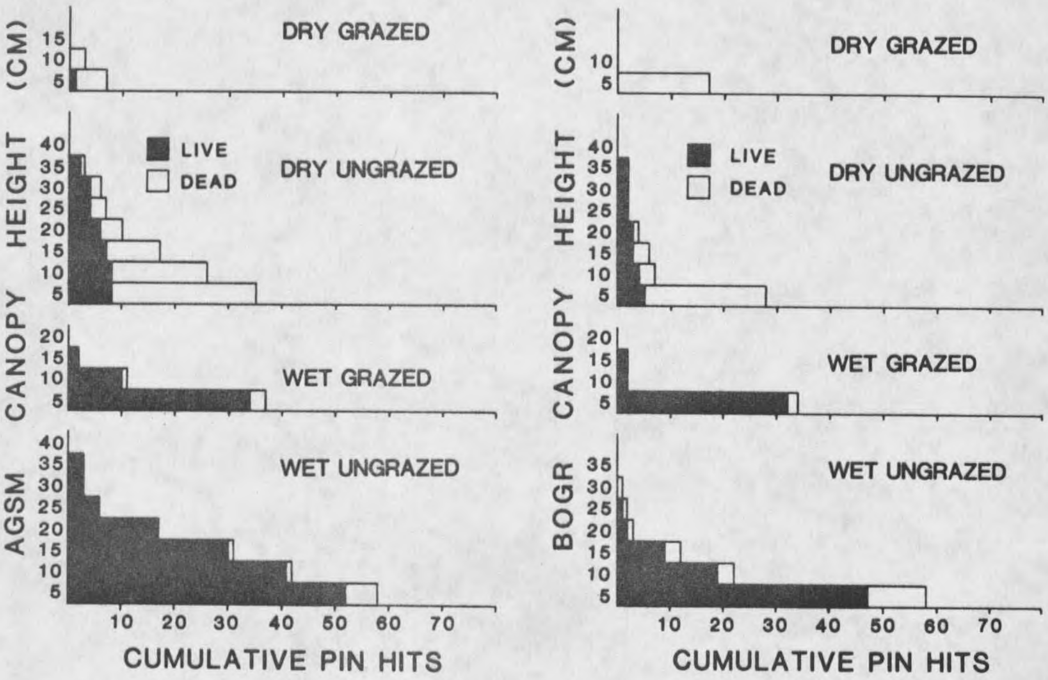
Table 8. Stratified Photosynthetic Surface (Live-Dead Ratio) of the Western Wheatgrass Site, 1981.

Date		July 4		July 25		August 14		September 5	
Treatment	Height	Live	Dead	Live	Dead	Live	Dead	Live	Dead
Dry Grazed	5 cm	7	1	1	8	0	6	1	3
	10 cm	8	0	0	2	0	5	0	3
	15 cm	10	0						
	20 cm	3	0						
	25 cm	8	0						
Dry Ungrazed	5 cm	9	2	2	4	2	4	0	9
	10 cm	11	0	4	4	3	6	1	8
	15 cm	6	0	3	2	1	3	1	6
	20 cm	4	0	2	1	2	0	2	1
	25 cm	0	0	4	1	3	2	0	1
	30 cm	2	0			1	0	2	1
	35 cm	1	0			1	0	2	1
	40 cm					1	3		
Wet Grazed	5 cm	5	6	15	1	19	2	24	2
	10 cm	19	1	9	3	8	2	8	1
	15 cm	11	0	1	0	1	0	2	0
	20 cm	2	0						
	25 cm	2	0						
	30 cm	2	0						
	35 cm	1	0						
Wet Ungrazed	5 cm	11	6	8	3	7	3	11	5
	10 cm	15	0	15	5	18	1	10	1
	15 cm	18	0	10	3	10	1	14	0
	20 cm	12	0	7	0	8	1	11	0
	25 cm	4	0	4	1	3	0	3	0
	30 cm	1	0	1	0	6	0	0	0
	35 cm	1	0	5	0	1	0	3	0
	40 cm			1	0				

Table 9. Stratified Photosynthetic Surface (Live-Dead Ratios) of the Blue Grama Site, 1981.

Date		June 30		July 22		August 12		September 2	
Treatment	Height	Live	Dead	Live	Dead	Live	Dead	Live	Dead
Dry	5 cm	22	0	11	4	2	26	0	17
Grazed	10 cm	4	0						
	15 cm	2	0						
	20 cm	1	0						
	25 cm	1	0						
	30 cm	1	0						
Dry	5 cm	21	2	4	11	3	21	1	19
Ungrazed	10 cm	2	0	0	1	0	7	1	1
	15 cm	2	0	1	2	2	5	0	2
	20 cm	1	0	3	0	4	0	1	1
	25 cm	0	0	2	0	4	0	0	0
	30 cm	0	0	1	1			0	0
	35 cm	1	0	2	0			2	0
Wet	5 cm	21	2	23	2	30	4	30	2
Grazed	10 cm	16	1	2	0	2	0	0	0
	15 cm	6	0					2	0
	20 cm	1	0						
	25 cm	4	0						
	30 cm	2	0						
Wet	5 cm	25	1	23	1	34	3	28	8
Ungrazed	10 cm	14	0	14	0	15	3	10	0
	15 cm	5	0	5	2	4	2	7	2
	20 cm	4	0	1	0	3	2	1	0
	25 cm	6	0	0	2	1	1	1	0
	30 cm	2	0	2	0	3	1	0	1
	35 cm	3	0	0	1	0	0		
	40 cm			0	1	0	1		

Figure 5. Stratified Cumulative Photosynthetic Surface Pin Contacts For Western Wheatgrass and Blue Grama Sites, 1981. Cumulative Pin Contacts are Calculated by Summed Total Pin Contacts of Layers Below, Excluding Those Above.



Total Above-Ground Production

Total above-ground production was measured in 1981 at season's end. Supplemental water significantly increased yields in both western wheatgrass and blue grama communities, whether grazed or ungrazed (Table 10). Total yields from grazed plots were not significantly different from those in ungrazed plots (Table 10).

Table 10. Total Above Ground Production (g/m^2) for the Western Wheatgrass and Blue Grama Sites, 1981.

	Dry		Wet	
	Grazed	Ungrazed	Grazed	Ungrazed
Western Wheatgrass				
Total Yield	152.2[a*]	148.5[a]	329.1[b]	335. 3[b]
Blue Grama				
Total Yield	100.6[a]	107.9[a]	306.0[b]	299.4[b]

*Means within rows which share the same superscripts do not differ significantly LSD ($P \leq .01$).

Grazable Forage Production

It seems obvious that forage well above ground level will be used first and that forage at ground level will be less used. After surveying grazing heights in surrounding pastures, grazing height was arbitrarily defined as 5 cm for blue grama and 7.6 cm for western wheatgrass. Using the method discribed by Holscher and Woolfolk (1953) such grazing heights were estimated to result in 30% and 64%

Figure 6. Total Grazable Forage Yields From Blue Grama and Western Wheatgrass Sites, 1979-1981. Means of Growth Form Categories and Standard Errors of Total Yields Presented.

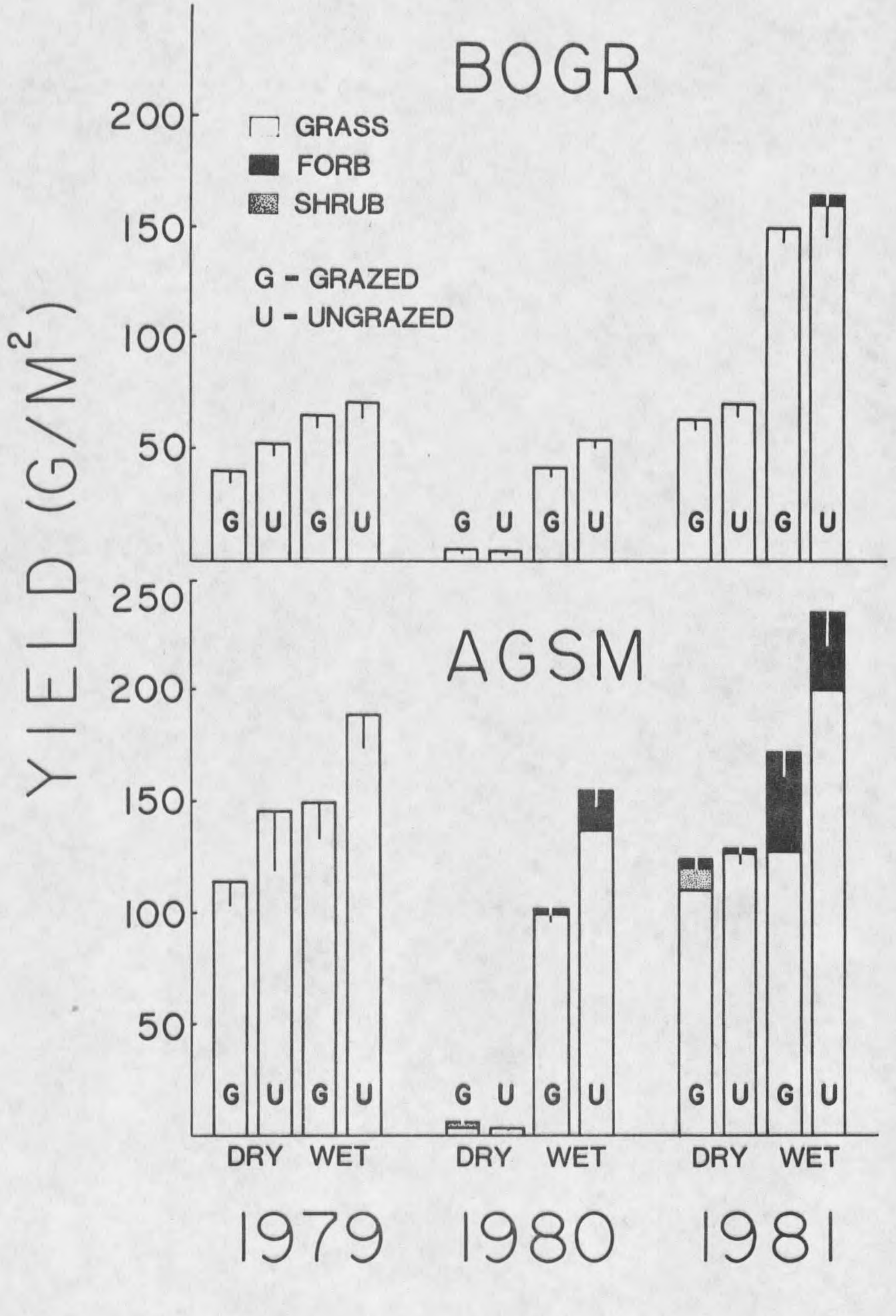


Table 11. Grazable Forage Production (g/m^2) of the Western Wheatgrass and Blue Grama Sites, 1979-1981.

	Dry		Wet	
	Grazed	Ungrazed	Grazed	Ungrazed
Western Wheatgrass				
Grass 1980	4.9^{a}*	3.8^{a}	102.8^{b}	137.4^{c}
Grass 1981	111.6^{a}	120.1^{a}	127.1^{a}	201.4^{c}
Forb 1980	0.0^{a}	0.0^{a}	2.0^{a}	17.2^{b}
Forb 1981	4.3^{a}	0.7^{a}	45.6^{b}	34.5^{b}
Shrub 1980	0.7^{a}	0.0^{a}	0.0^{a}	0.0^{a}
Shrub 1981	8.1^{a}	7.9^{a}	0.0^{a}	0.0^{a}
Total 1979	114.2^{a}	146.0^{b}	150.2^{b}	187.9^{c}
Total 1980	5.6^{a}	3.8^{a}	104.8^{b}	154.5^{c}
Total 1981	124.0^{a}	128.7^{a}	172.7^{b}	235.5^{c}
Blue Grama				
Grass 1980	4.6^{a}	3.7^{a}	41.6^{b}	54.3^{c}
Grass 1981	62.8^{a}	70.5^{a}	150.2^{b}	164.9^{c}
Forb 1980	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
Forb 1981	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
Shrub 1980	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
Shrub	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}
Total 1979	40.2^{a}	52.3^{b}	65.3^{c}	71.2^{c}
Total 1980	4.6^{a}	3.7^{a}	41.6^{b}	54.3^{c}
Total 1981	62.8^{a}	70.5^{a}	150.2^{b}	164.9^{c}

*Means within rows which share the same superscripts do not differ significantly LSD ($P \leq .01$).

utilization by weight for blue grama and western wheatgrass respectively. Actual utilization, defined as the amount of material by weight removed at time of sampling was measured in 1981 using the grazed/ungrazed height-weight method described by Lommasson and Jensen (1943). The assumptions are that observations be made at maximum height in growth which corresponds to maximum weight. This methodology does not account for growth form differences, changes in basal cover, quiescence, senescence, or time of peak standing crop, all of which may be affected by grazing and/or water supplement. Without consideration of these factors, underestimates of utilization will occur.

Treatment utilization measures take at season's end (early September) for blue grama showed 24% and 26% for dry and wet plots respectively. Western wheatgrass measures were 51% and 48% for dry and wet respectively. Dry plots may underestimate utilization if peak standing crop was early in the season and losses occurred through senescence (leaf fall, seed shatter) or transport of material below ground prior to collection date. Regrowth after collection would further result in underestimates of total seasonal utilization. Wet plots may underestimate utilization if water prolongs growth beyond sample collection date. Grazing may also affect utilization measures if material is concentrated below grazing height thereby altering the height-weight curve. Changes may also occur if grazing increased tillers (basal cover) as season progressed.

Holscher and Woolfolk (1953) recommended use of western wheatgrass as 45% and 41% for blue grama. Proper use is the maximum degree and time of use of current year's growth which will either maintain or improve range condition. Actual utilization figures suggest over-use for western wheatgrass and under-use for blue grama considering the recommendations of Holscher and Woolfolk (1953). Study results show that grazing did reduce the productivity on wet plots but did not affect it on dry plots (Figure 6). However, basal cover (Table 13) increased on all plots. This implies that western wheatgrass may have been under-used regardless of water treatment. A careful consideration of methodology and the interpretation of results must follow any measure of use.

Using these definitions, comparisons of grazable forage production on blue grama and western wheatgrass communities in the three years, 1979 - 1981 were made.

Under dry-year conditions, grazable forage production in ungrazed plots exceeded production of grazed plots for both western wheatgrass and blue grama communities in two of three years (Figure 6; Table 11). Total forage production was comprised primarily of grasses, with insignificant amounts of forbs and shrubs. No single component of the total forage production (Figure 6; Table 11) differed significantly between grazing treatments.

Under wet-year conditions (i.e. with supplemental water) total production from blue grama (except 1979) and western wheatgrass grazed plots were significantly less than the ungrazed plots in all study years (Figure 6, Table 11).

One may speculate that clipping removed so much leaf surface that plants could not maximize use of available water and nutrient

Table 12. Total Production (g/m^2) Below Grazing Height for the Western Wheatgrass and Blue Grama Sites, 1981.

	Dry		Wet	
	Grazed	Ungrazed	Grazed	Ungrazed
Western Wheatgrass				
Total	28.3^{a*}	19.8^{a}	156.4^{b}	99.3^{c}
Blue Grama				
Total	37.8^{a}	37.4^{a}	155.8^{b}	134.5^{b}

*Means Within Rows Which Share the Same Superscripts Do Not Differ Significantly ($P \leq 0.01$), Student t-test.

Table 13. Basal Area Measures (Percent) for the Western Wheatgrass and Blue Grama Sites, 1981. Measures Taken at Season's End Corresponding to Last Grazing Sample Collection Data.

	Dry		Wet	
	Grazed	Ungrazed	Grazed	Ungrazed
Western Wheatgrass				
Western Wheatgrass	4.0	1.2	8.5	3.7
Other Plants	0.4	0.0	1.6	2.0
Litter	15.5	14.6	14.6	17.9
Bare Ground	80.0	84.2	75.2	76.4
Blue Grama				
Blue Grama	15.3	8.0	23.4	12.2
Other Plants	0.0	0.0	1.0	0.5
Litter	33.5	32.1	20.0	20.0
Bare Ground	51.2	59.6	55.6	67.3

resources. Consistent with this hypothesis, Holscher (1945), Branson (1956), Dwyer et al. (1963), Smoliak (1965), Everson (1966), Dittmer (1973), Owensby et al. (1974), Beaty and Powell (1976), and others have observed lower production due to clipping in thin stands of vegetation. In dense or taller grass regions clipping may increase production as shown by Canfield (1939), Lodge (1960), Drawe et al. (1972), Eck et al. (1975), and Singh and Mall (1976). These results are probably due to reductions in internal shading and/or increased respiration within the canopy.

If we assume that 1981 data for total above-ground standing crop are typical, we must conclude that while grazable forage production is reduced by grazing (but significantly so only with supplemental water), total above-ground production is unaffected. For this to occur, production below the grazing height of grazed plots had to equal or exceed that of ungrazed plots (Table 12). This may be explained if grazed plots had a competitive advantage for growth and/or biomass production. Grazed plots do in fact show at least twice the basal area (Table 13) and higher leaf-stem ratios (Tables 5,6, last sample date) than ungrazed plots.

One may speculate on the apparent under-utilization of both western wheatgrass and blue grama with respect to interpretation of production results. Increases in utilization would result in the expected increase in grazable forage production of both grazed and ungrazed plots due to lower clipping levels. Because of species' morphological differences, one might expect blue grama to be less affected by repeated clipping since growing points are nearer the soil surface. Both species have shown a resistance to grazing by altered growth form. One might expect this prostrate form to continue as clipping levels are lowered until species vigor is reduced. Study results indicate that clipping produced both a negative and positive response in production. A negative response occurred above the grazing height by decreasing productivity, and a positive response occurred below by increasing production through increased basal area. If western wheatgrass and blue grama are limited to a minimum prostrate growth form, then repeated clipping at lower levels may increase production. Study results of watered plots suggest utilization was not enough to reduce leaf area below the optimum levels for growth. If utilization was increased, repeated clipping may increase production.

CONCLUSIONS

Data presented show that grazing lowered grazable forage production. The loss of production might be due to 1) reduction of photosynthetic surface to limiting values and/or 2) lowering of the canopy to sub-grazing levels. On the other hand, grazing produced no significant differences in total above-ground production. This is apparently due to relatively high production below the grazing height, where grazed plot production equalled or exceeded ungrazed plots. If so, grazed plots may have had a competitive advantage for growth and/or production by increased basal area and/or greater leaf surface.

Community development as measured by canopy structure showed the basic structure had evolved by early July and remained little changed as the season progressed. Grazing produced the expected lowering of canopy height, resulting in plants with prostrate growth characteristics. Data further show that grazing was ineffective in maintaining early season levels of leaf-stem ratios and photosynthetic surface.

One also expects supplemental moisture to increase biomass production and augment canopy structure. Data presented show significant increases in grazable forage and total above-ground production. Added water did not increase canopy height, but did increase canopy density. Data further show that water prolonged early season levels of leaf-stem ratios and photosynthetic surface.

These results support no concrete conclusions about below ground production. It is conceivable that grazing induced a net downward transport of photosynthates as a grazing-resistance strategy or that net movement was upward to rebuild the photosynthetic canopy.

Data presented here suggest that in years of average or below average precipitation, periodic grazing will lower forage production without increases in forage quality. With water supplement and/or in years of high precipitation forage quality (leafiness) and quantity will increase, though periodic grazing reduces the latter. Welker (1982) showed that forage digestibility did not increase with water supplements of 6, 12, or 25 mm per growing season-week. Most ranching operations would consider water application impractical, due to unavailability of water and economic costs of irrigation equipment. Weather modification programs may provide the resource.

Grazing and water supplements may have negative effects on western wheatgrass and blue grama communities. Continued grazing in successive years of low precipitation may reduce plant vigor, causing changes in community composition to less desirable species. Added water over the long term will most certainly allow changes in community composition to more mesic and/or opportunistic species. Yellow sweetclover and scarlet globemallow were two species which were observed to increase with added water during the study period. The exact extent of community changes will depend upon timing and amount of water received. Water additions may also result in communities that are less able to withstand extreme fluctuations in precipitation (i.e. drought).

The western wheatgrass and blue grama communities were representative of areas often found in the Northern Great Plains. The responses of these two communities to supplemental water and simulated grazing have allowed a more concise understanding of community and/or species relations to range ecosystem dynamics. This understanding may allow improved management practices in these or other grassland communities.

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LITERATURE CITED

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APPENDICES

Appendix 1

Table 14. Mean Pin Contacts (From Treatment Plots) of Western Wheatgrass, 1981.

Treatment	Height (cm)	July 4 X	July 4 S.E.	July 25 X	July 25 S.E.	August 14 X	August 14 S.E.	September 5 X	September 5 S.E.
Dry Grazed	5	2.7	1.8	3.0	1.7	2.0	1.2	1.3	0.3
	10	2.7	0.9	0.7	0.3	1.7	0.9	1.0	0.6
	15	3.3	1.2						
	20	1.0	1.0						
	25	2.7	0.7						
Dry Ungrazed	5	3.7	0.3	2.0	0.6	2.0	1.2	3.0	1.2
	10	3.7	1.3	2.7	0.3	3.0	2.1	3.0	0.6
	15	2.0	1.0	1.7	0.9	1.3	0.3	2.3	0.7
	20	1.3	0.7	1.0	1.0	0.7	0.3	1.0	0.6
	25	0.0	0.0	1.7	0.9	1.7	0.9	0.3	0.3
	30	0.7	0.7			0.3	0.3	1.0	0.6
	35	0.3	0.3			0.3	0.3	1.0	0.0
	40					1.3	0.9		
Wet Grazed	5	3.7	1.2	5.3	0.9	7.0	1.5	8.7	2.0
	10	6.7	2.4	4.0	0.6	3.3	0.9	3.0	0.6
	15	3.7	1.5	0.3	0.3	0.3	0.3	0.7	0.3
	20	0.7	0.3						
	25	0.7	0.6						
	30	0.7	0.6						
	35	0.3	0.3						
Wet Ungrazed	5	5.7	2.3	3.7	0.7	3.3	1.5	5.3	2.0
	10	5.0	1.0	6.7	1.3	6.3	1.9	3.7	1.2
	15	6.0	1.5	4.3	1.7	3.7	0.7	4.7	1.8
	20	4.0	1.7	2.3	0.7	3.0	1.2	3.7	0.3
	25	1.3	0.3	1.7	0.9	1.0	0.0	1.0	0.6
	30	0.3	0.3	0.3	0.3	2.0	1.0	0.0	0.0
	35	0.3	0.3	1.7	0.9	0.3	0.3	1.0	0.6
	40			0.3	0.3				

Appendix 2

Table 15. Mean Pin Contacts (From Treatment Plots) of Blue Grama, 1981

Treatment	Height (cm)	June 30 X	June 30 S.E.	July 22 X	July 22 S.E.	August 12 X	August 12 S.E.	September 2 X	September 2 S.E.
Dry Grazed	5	7.3	0.9	5.0	0.6	9.3	1.9	5.7	0.9
	10	1.3	0.9						
	15	0.7	0.3						
	20	0.3	0.3						
	25	0.3	0.3						
	30	0.3	0.3						
Dry Ungrazed	5	7.7	0.7	5.0	0.0	8.0	1.7	7.0	1.5
	10	0.7	0.3	0.3	0.3	2.3	0.9	0.3	0.3
	15	0.7	0.3	1.0	0.6	2.3	0.9	0.7	0.7
	20	0.3	0.3	1.0	1.0	1.3	1.3	0.7	0.7
	25	0.0	0.0	0.7	0.7	1.3	0.9	0.0	0.0
	30	0.0	0.0	0.7	0.7			0.0	0.0
	35	0.3	0.3	0.7	0.7			0.7	0.7
Wet Grazed	5	7.7	2.0	8.3	0.3	11.3	0.9	10.7	0.9
	10	5.7	2.6	0.7	0.7	0.7	0.7	0.7	0.3
	15	2.0	1.0						
	20	0.3	0.3						
	25	1.3	0.3						
	30	0.7	0.3						
Wet Ungrazed	5	8.7	1.2	8.0	1.7	12.3	2.3	11.3	1.2
	10	4.7	1.5	4.7	0.7	6.0	4.0	3.3	1.2
	15	1.7	0.9	2.3	0.9	2.0	0.0	3.0	2.1
	20	1.3	0.3	0.3	0.3	1.7	1.2	0.3	0.3
	25	2.0	1.0	0.7	0.7	0.7	0.3	0.3	0.3
	30	0.7	0.7	0.7	0.7	1.3	0.9	0.3	0.3
	35	1.0	1.0	0.3	0.3	0.0	0.0		
	40			0.3	0.3	0.3	0.3		

Appendix 3

Table 16. Stratified Cumulative Photosynthetic Surface (Live - Dead Ratios) of the Western Wheatgrass Site, 1981.

Treatment	Dates / Height (cm)	July 4		July 25		August 14		September 5	
		Live	Dead	Live	Dead	Live	Dead	Live	Dead
Dry Grazed	5	36	1	1	10	1	11	1	6
	10	29	0	0	2	0	5	0	3
	15	21	0						
	20	11	0						
	25	8	0						
Dry Ungrazed	5	33	2	15	12	14	18	8	27
	10	24	0	13	8	12	14	8	18
	15	13	0	9	4	9	8	7	10
	20	7	0	6	2	8	5	6	4
	25	3	0	4	1	6	5	4	3
	30	3	0			3	3	4	2
	35	1	0			2	3	2	1
	40					1	3		
Wet Grazed	5	42	7	25	4	28	4	34	3
	10	37	1	10	3	9	2	10	1
	15	18	0	1	0	1	0	2	0
	20	7	0						
	25	5	0						
	30	3	0						
	35	1	0						
Wet Ungrazed	5	62	6	51	12	53	6	52	6
	10	51	0	42	9	46	3	41	1
	15	36	0	28	4	28	2	31	0
	20	18	0	18	1	18	1	17	0
	25	6	0	11	1	10	0	6	0
	30	2	0	7	0	7	0	3	0
	35	1	0	6	0	1	0	3	0
	40			1	0				

Appendix 4

Table 17. Stratified Cumulative Photosynthetic Surface (Live - Dead Ratios) of the Blue Grama Site, 1981.

Treatment	Dates Height (cm)	June 30		July 22		August 12		September 2	
		Live	Dead	Live	Dead	Live	Dead	Live	Dead
Dry Grazed	5	31	0	11	4	2	26	0	17
	10	9	0						
	15	5	0						
	20	3	0						
	25	2	0						
	30	1	0						
Dry Ungrazed	5	27	2	13	15	13	33	5	23
	10	6	0	9	4	10	12	4	4
	15	4	0	9	3	10	5	3	3
	20	2	0	8	1	8	0	3	1
	25	1	0	5	1	4	0	2	0
	30	1	0	3	1			2	0
	35	1	0	2	0				
Wet Grazed	5	50	3	25	2	32	4	32	2
	10	29	1	2	0	2	0	2	0
	15	13	0						
	20	7	0						
	25	6	0						
	30	2	0						
Wet Ungrazed	5	59	1	45	7	60	13	47	11
	10	34	0	22	6	26	10	19	3
	15	20	0	8	6	11	7	9	3
	20	15	0	3	4	7	5	2	1
	25	11	0	2	4	4	3	1	1
	30	5	0	2	2	3	2	0	1
	35	3	0	0	2	0	1		
	40			0	1	0	1		