Long-term responses of dense clubmoss (Selaginella densa Rydb.) to range renovation practices in northern Montana
by John Joseph Dolan

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Range Science
Montana State University
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Abstract:
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Resultant data were processed through an IBM 1620 II digital computer. Standard analysis of variance tests preceded Duncan'S multiple range tests used to determine differences in ground cover and herbage yield among treatments. Correlation coefficients were determined to indicate relationships between data from the major categories evaluated.

An inverse relationship between the intensity of mechanical treatment and clubmoss ground cover was discovered. Manure treatments were also shown to reduce clubmoss cover but the effects of treatment intensity were not distinct.

The treatments were shown to affect certain forage species. Litter yields increased with increased treatment intensity and this was associated with increased forage productivity.

Treatment did not affect the protein content of the vegetation.

129

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A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

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TABLE OF CONTENTS

Page

VITA ii

ACKNOWLEDGMENT iii

TABLE OF CONTENTS iv

LIST OF TABLES vii

LIST OF FIGURES viii

LIST OF APPENDIX TABLES ix

ABSTRACT x

INTRODUCTION 1

REVIEW OF LITERATURE 3

Ecology of Dense Clubmoss on the Northern Great Plains 3
General Distribution 3
Site Characteristics 5
Cover 5
Competitive Relationships 6
Ecesis 8
Factors Influencing Local Distribution of Dense Clubmoss 9
Grazing 9
Mechanical Renovation 10
Fertility 11
Water 12
Chemicals 13

DESCRIPTION OF THE AREA 14

Soils 14
Climate 17
Precipitation 17
Temperature 19
Frost-free Period 19
Wind Velocity 20
Evaporation 20
History of Use 20

EARLY RANGE IMPROVEMENT STUDIES AT NORTH MONTANA BRANCH STATION . . . 23

Preliminary Work 23
1925 - 1935 Treatments to Native Sod 23

Page

METHODS 26

Pre-sampling Procedures 26
Plot Relocation 26
Plot Modification 26
Additional Check Plot 28
Sampling Procedures 28
Estimate of Vegetative Cover 28
Transect Location 29
Placement of Transects 29
Collecting Intercept Data 31
Estimate of Herbage Production 33
Clip Plot Location 34
Clipping Procedure 34
Estimate of Litter 39
Vegetation Survey of 21 Areas 40
Data Processing 40
Estimate of Forage Protein Content 42

RESULTS AND DISCUSSION 43

Introduction 43
Response of Clubmoss to Renovation Practices 43
Live Clubmoss 44
Dead Clubmoss 44
All Clubmoss 49
Response of Needle-and-Thread 49
Ground Cover 49
Weight 50
Response of Blue Grama 51
Response of Crested Wheatgrass 51
Ground Cover 51
Weight 56
Response of Western Wheatgrass 56
Response of Annual and Biennial Forbs 57
Response of Other Species 57
Response of Total Vegetation 58
Litter 58
Ground Cover 60
Weight 60
Bare Soil 60
Protein Content of the Vegetation 60

SUMMARY AND CONCLUSIONS 62

Page

APPENDIX 64

LITERATURE CITED 80

LIST OF TABLES

		Page
I.	Average monthly precipitation (North Montana Branch Station)	18
II.	Summary of analysis of variance tests on ground cover	45
III.	Percent ground cover by species	46
IV.	Correlation coefficients showing the relationships between some major categories estimated from 17 treatment plots	50
V.	Summary of analysis of variance tests on herbage yield	52
VI.	Herbage yield in pounds per acre by species	53
VII.	Herbage yield in pounds dry matter per acre	59
VIII.	Crude protein content of grass and non-grass species	61

LIST OF FIGURES

		Page
1.	Close-up view of dense clubmoss	4
2.	Dense, shallow root system of dense clubmoss	4
3.	Sixteen treated plots looking west	15
4.	Relict area looking northeast from check plot 18	15
5.	Soil map of the treatment plots and relict area, North Montana Branch Station	16
6.	Diagram of chronological treatment schedule	25
7.	Vegetational aspect	27
8.	Diagram of transect locations	30
9.	Reading and recording a transect	32
10.	Diagram of clip plot locations	35
11.	Two clipping crews and field office	36
12.	Details of the clipping operation in native vegetation	36
13.	Sample page from herbage yield record book	37
14.	Recording sack numbers at the field office	38
15.	Consolidating six clip plot bags into one bag representing a treatment plot	38
16.	Collecting litter in an area invaded by crested wheatgrass	40
17.	Sample page from litter record book	41

LIST OF APPENDIX TABLES

		Page
I.	Yearly precipitation distribution at North Montana Branch Station since 1916	65
II.	Average monthly wind velocity (N. M. B. S.)	66
III.	Average monthly evaporation (N. M. B. S.)	66
IV.	Transect locations	67
V.	Transect coding key	73
VI.	Intercept type code	74
VII.	Clip plot coding key	75
VIII.	Presence of species in 21 areas	76

ABSTRACT

Residual effects of various mechanical and manuring treatments on dense clubmoss (Selaginella densa Rydb.) were investigated on an ungrazed mixed prairie site in Northern Montana.

Sixteen plots of native range were treated between 1925 and 1935. In 1965 nine transects were established in each plot to determine basal ground cover. Herbage was harvested from six clip plots per treatment plot in an effort to estimate forage production by species. Protein content of the clipped vegetation was then determined. In addition an estimate of litter production was made.

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The treatments were shown to affect certain forage species. Litter yields increased with increased treatment intensity and this was associated with increased forage productivity.

Treatment did not affect the protein content of the vegetation.

INTRODUCTION

The presence of dense clubmoss (Selaginella densa Rydb.)[1/] has long been recognized on northern mixed prairie ranges. In some areas the species has accounted for more than 80 percent of the ground cover, yet until recently investigators had not studied it intensively. Some ignored it. Others either assumed that its effect on other vegetation was negligible or theorized that it played a vital role as a soil stabilizer in the severe environment of the Northern Great Plains.

Under certain environmental conditions clubmoss probably serves as an efficient soil stabilizer. Although little is known of its water utilization characteristics, clubmoss may sometimes prevent runoff, which may ultimately benefit the range. On the other hand, there are areas where clubmoss appears to compete with other vegetation while not performing a vital function in production of forage nor in long-term stability of the range.

Recent mechanical range renovation treatments at the North Montana Branch Station near Havre have increased the productivity of preferred forage species. This effect has been partially explained by the removal of clubmoss competition for water and an increase in available nitrogen resulting from the decomposition of uprooted clubmoss. No immediate deterioration of the soil resource has resulted from removal of clubmoss on this relatively level rangeland.

Concurrent experiments of range fertilization at the same location indicated that the basal area of clubmoss decreases with increased fertil-

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1/ Hereafter referred to as clubmoss in the body of the paper.

ity. In this same experiment forage productivity increased.

Several questions arise in the areas of ecology and economy as a result of these range experiments. Will the total range resource be jeopardized by clubmoss removal? How long may the range be expected to maintain increased productivity? Will the clubmoss on such treated range return to its former abundance?

A unique opportunity to probe into these questions existed at the experiment station at Havre. Six miles north of the present range renovation experiments a series of mechanical and manure treatments were applied to similar range between 1925 and 1935. This area has remained essentially undisturbed since that time. An evaluation of these 30 to 40 year old treatments was made during the summer of 1965. This paper is a report of that evaluation.

REVIEW OF LITERATURE

Ecology of Dense Clubmoss on the Northern Great Plains

General Distribution

Late in the nineteenth century Underwood (1898) stated that clubmoss (S. rupestris (L.) Spring.) was distributed from New England to British Columbia and grew to an elevation of 7,000 feet. He considered western specimens growing at high elevation different from those of the east only to the extent that they were characteristically more compact. He theorized that this trait assisted in water conservation in the arid western environment.

At the turn of the century Rydberg (1900) examined clubmoss specimens from seven Montana locations. Specimens from the Little Rocky Mountains, an isolated mountain group 60 miles southeast of Havre, were included. He separated S. densa (Figure 1) from S. rupestris mainly by the "striking difference in habitat" and noted that it appeared more "moss-like" than its eastern ally. Rydberg described S. densa as growing on exposed hillsides, among gravel or rocks throughout the Rocky Mountain region and eastward to the Black Hills of western Nebraska. Later Rydberg (1932) again used habitat to differentiate among three species of Selaginella. He separated S. densa Rydb. from S. selaginoides (L.) Link. and S. rupestris (L.) Spring. by stating that its range was restricted to hills and mountains.

These early reports of clubmoss on the Northern Great Plains were made by taxonomists. Their papers were characteristically concerned with distinguishing species, and largely neglected the ecological aspects of the plant community.

The first recorded observation of clubmoss near the North Montana

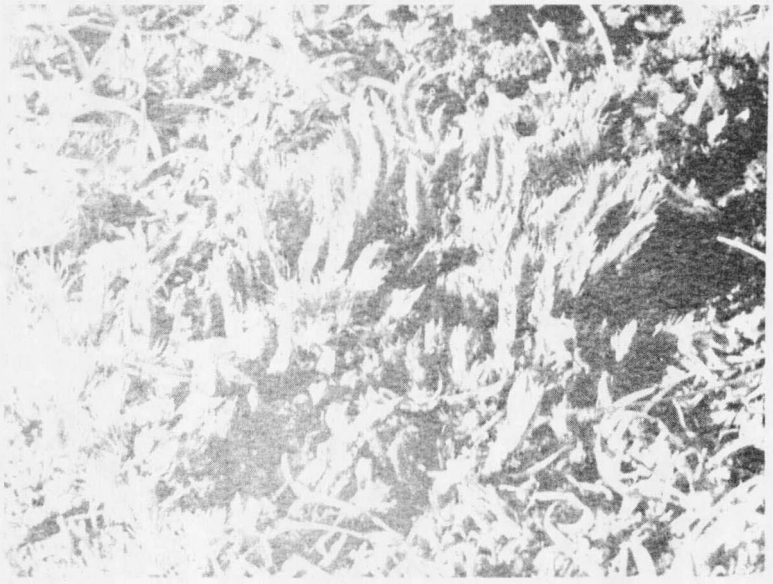


Figure 1. Close-up view of dense clubmoss. Natural size.

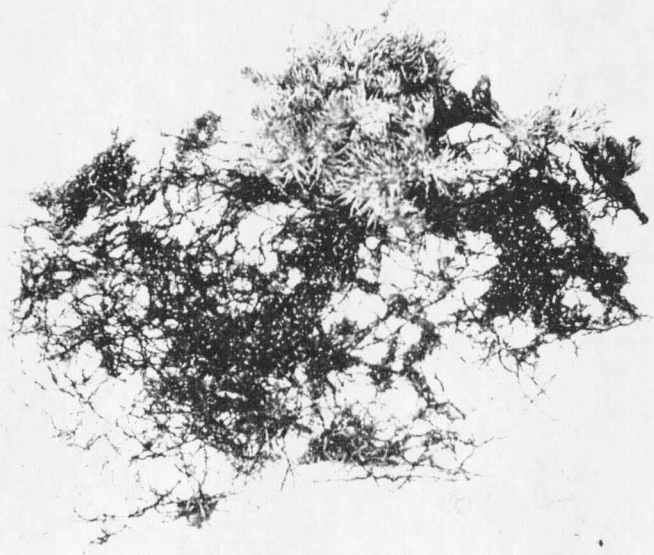


Figure 2. Dense, shallow root system of dense clubmoss.

Branch Station was made four miles northeast of the study site by H. L. Shantz in 1916 (Phillips, 1963).

Site Characteristics

Two ecological features of S. densa var. densa were noted by Tryon (1955). Its habitat was characteristically dry and open and the species did not thrive in the presence of other plants. Tryon indicated that clubmoss was abundant in areas of moderate rainfall and in locally dry habitats in moist areas. He found it on barren soil and on rocky, gravelly or cliff areas where other vegetation was not abundant.

Coupland (1950) found clubmoss most commonly on medium-textured soils, less commonly on sandy soils and rarely on clay in the Canadian mixed prairie. Sturm (1954) suggested that the species was associated with poor sites and thin soils in northern Montana. In Wyoming's Big Horn Mountains Beetle (1956) found clubmoss associated with dry, shallow soils of granitic origin. The species occurred most frequently on sandy loam soils in northeastern Montana according to Majorowicz (1963).

Areas on which clubmoss occurred in the Palouse Prairie region of southwestern Montana were found to be in higher range condition than areas on which it did not occur (Van Dyne and Vogel, 1966). However, the soils on which the species was found were shallower and contained more rock and gravel but less sand than soils on which the species did not occur.

Cover

Clarke et al. (1942) reported a heavy cover of clubmoss on the prairie in southern Canada. Although clubmoss cover commonly ranged from 10 to 25 percent, a cover of up to 50 percent was not unusual. These researchers

stated that the clubmoss cover prevented wind and water erosion and trampling damage. In addition they reported that sheep grazed the species during the spring, an occurrence generally thought to be uncommon. Coupland (1950) observed that clubmoss occurred with a frequency of 74 to 98 percent in his study of the Canadian mixed prairie and provided 6 to 25 percent ground cover on medium textured soils.

Heady (1952) reported that on a Montana mixed prairie "relict" area clubmoss provided 28.5 percent ground cover. Seed plants occupied 3.4 percent ground cover. Investigations by Sturm (1954), using a point quadrat method, indicated a clubmoss cover of 12.4 percent in the same relict area.

Competitive Relationships

The earliest available evidence suggesting that clubmoss presented some competition to other plant species was noted on a site at the North Montana Branch Station which had a history of heavy grazing for about 30 years. The 1925 annual station report (North Montana Branch Station, 1925) stated that as a result of cultural treatments to "native sod" in which the cover of a "species resembling liverworts"[2/] had been disturbed, western wheatgrass (Agropyron smithii)[3/] tended to increase and an opportunity was thereby presented for increased growth of all forage species.

Although clubmoss probably was present on that site as a natural part of the plant community before restricted herds of domestic livestock became an influencing factor, the degree to which it occurred is not known. It was present in 1925 to such an extent that it provoked comment at a

2/ Later changed to Selaginella in an undated, uninitialed correction.
3/ Botanical names according to Booth, 1950, and Booth and Wright, 1962.

time and place when only the most apparent aspects of vegetation received recognition.

In his analysis of Canadian mixed prairie vegetation Coupland (1950) did not include clubmoss because its ecological relationships were not understood and its influence on the habitat and other vegetation considered small. Further work in the same region led Clarke and Tisdale (1945) to state that although clubmoss was abundant over much of the area it exerted little influence in the plant association because of its low water and nutrient requirements. Clarke et al. (1947) observed that clubmoss as well as Sandberg bluegrass (Poa secunda) and Hood's phlox (Phlox hoodii) increased as a result of the 1929-1936 drought. Blue grama (Bouteloua gracilis), needle-and-thread (Stipa comata) and western wheatgrass decreased.

Majorowicz (1963) suggested that clubmoss competed for moisture by intercepting water from low intensity storms, thus subjecting it to rapid evaporation.

Tryon (1955) credited the shallow but extensive root network of clubmoss (Figure 2) with the ability to utilize rapidly small quantities of water. This matted root system was also described by Wagner (1966). He traced it to a maximum depth of about 3 inches and noted its probable water interception capability. Wagner further noted that this characteristic, which is apparently an asset during part of the year, would conversely limit the growing season of clubmoss to those periods when moisture is available at very shallow depths.

Tryon (1955) observed that although clubmoss is not particularly adapted for water storage or prevention of water loss it has a unique ability to

revive after severe desiccation. A herbarium specimen of S. densa var. densa replanted by Tryon grew after six months in the herbarium. He attributed this ability to "unusual physical and chemical properties of the cell contents."

Similar verification of the ability of clubmoss to survive long periods of drought was made by Webster and Steeves (1964). After 33 months in a laboratory without water some clubmoss plants were revived. These experimenters concluded that this ability was related to "some physiological mechanism" in the cells. They suggested that the vital parts of the cell were in some way protected although the specific process could not yet be explained. Wagner (1966) observed changes in top growth 10 minutes after watering a dormant sod of clubmoss. Two hours after watering the plants began to turn green.

Ecesis

Little is known of the ecesis of clubmoss. Fragmentation is a possible means of dispersal. Young sporophytes have been reported only occasionally (Lyon, 1901; Tryon, 1955). Webster and Steeves (1964) have observed sporophytes of clubmoss in all stages of development in a mixed prairie habitat in central Saskatchewan. This suggests that the introduction of clubmoss into a new area could perhaps take place more rapidly than would be expected by the slow vegetative spreading process. Wagner (1966) observed that in a moist greenhouse environment maximum lateral top growth of clubmoss was slightly more than 1 inch per year. Under range conditions maximum lateral top growth was less than 1/2 inch per year.

Factors Influencing Local Distribution of Dense Clubmoss

The literature concerning the response of clubmoss to stimuli is limited. Effects of various influences upon clubmoss have been noted in most cases only incidentally from investigations primarily concerned with vegetation other than clubmoss.

Grazing

Coupland (1950) observed that clubmoss increased on Canadian mixed prairie if protected from grazing. A decrease was noted following grazing. This he attributed to the trampling of grazing animals. Coupland[4/] offered another possible explanation for this response of clubmoss. After a period of grazing the surface soil is drier than if protected by ungrazed vegetation. Thus, a larger proportion of the clubmoss might be dormant during a dry period and recorded as dead during summer studies.

In 1960 Smoliak compared the effects of two grazing systems on the vegetation of southeastern Alberta. After a period of nine years clubmoss ground cover had decreased on continuously grazed pasture. The species had increased under a system of deferred-rotation grazing. Vogel (1960) indicated that clubmoss did not increase with grazing in southwestern Montana but may have increased following protection from grazing. In southwestern Montana Van Dyne and Vogel (1966) and Vogel and Van Dyne (1966) found that clubmoss decreased more on grazed range than on protected areas. Clubmoss cover was observed to decrease under intensive grazing.

Hubbard (1951) observed a highly significant increase of clubmoss in

4/ Coupland, R. T. 1966. Personal correspondence.

southeastern Alberta under a system of continuous grazing as well as under rotational grazing. The study was made during the dry years 1931 through 1937, therefore the lack of water may have confounded the results. Sturm (1954) also reported an increase in clubmoss resulting from grazing on both year-long and spring-grazed ranges in northern Montana.

On the mixed prairie ranges of southeastern Alberta, Smoliak (1965b) noted changes in the basal area of clubmoss as grazing practices varied. A highly significant increase in basal area of live clubmoss resulted from light grazing. Smoliak[5/] indicated that this increase of clubmoss can be expected primarily in an area subjected to light grazing after long-term protection. A highly significant decrease was observed after 14 years deferment. Smoliak suggested that the change in clubmoss cover was related to speciation changes which resulted from grazing intensity. As an area was grazed the aspect changed from Stipa-Bouteloua to Bouteloua-Stipa. Deferment after a history of grazing caused taller mid-grasses such as needle-and-thread to increase to the detriment of short grasses. The resulting decrease in clubmoss was attributed to greater shading by the taller species and a heavier mulch accumulation.

Mechanical Renovation

Visual estimates of the effects of mechanical treatments on clubmoss were cited in the annual reports of the North Montana Branch Station during the treatment period (North Montana Branch Station, 1916-1937). Severe mechanical treatments destroyed some clubmoss and blue grama sod. Western

5/ Smoliak, S. 1966. Personal correspondence.

wheatgrass was stimulated by the mechanical renovation.)

Reduced clubmoss cover resulting from range pitting and a sod-scalping process used in Montana range interseeding studies was reported by Ryerson et al. (1962a) and Ryerson et al. (1962b).

Fertility

Estimates of the effects of manure applications on clubmoss were also reported by the North Montana Branch Station during the treatment period (North Montana Branch Station, 1916-1937). Although a quantitative estimate of pretreatment clubmoss cover was not reported, its presence was mentioned repeatedly. At the end of the first growing season following the first treatment in 1925 total vegetative growth was reportedly stimulated on manured plots. A decrease in clubmoss was visible on manured plots at the end of the second growing season. It was stated that the manure treatments subordinated clubmoss to more vigorous stands of native grasses. Manuring was said to have improved yields of native hay more than any of the mechanical treatments.

Heady (1952) re-evaluated these treatment plots in 1947. A needle-and-thread aspect had replaced the blue grama-western wheatgrass aspect described in the early annual station reports. Although hay yields generally corresponded with those obtained from the same plots during the treatment period Heady felt that the speciation differences which existed in 1947 could not be attributed to treatments. The effects of more than four manure applications were apparent in 1947 by significant differences in culm heights of needle-and-thread. Although no specific attempt was made to evaluate the effects of the treatments on clubmoss, Heady reported the

existence of at least some clubmoss on all 16 plots.

A highly significant reduction in basal clubmoss cover resulted from each of four treatments applied to Canadian mixed prairie range (Smoliak, 1965a). The treatments consisted of 30 tons of barnyard manure per acre; 30 tons wheat-straw per acre; an inorganic fertilizer of 300# N, 150# P_2O_5, 300# K_2O per acre; and 30 tons of wheat-straw plus the mixture of inorganic fertilizer. The reduction of clubmoss was partially attributed to increased nutrients available to forage species from treatments of manure and fertilizer. However, a more dramatic decrease of clubmoss was apparent from treatments containing organic matter. A mulch effect was evidently responsible for this severe reduction.

At the end of three years of range fertilization trials in northern Montana Ryerson et al. (1962b) reported that clubmoss ground cover had been reduced as a result of fertilization. Fertilization and mechanical procedures used concurrently were more effective in destroying clubmoss than either process alone (Ryerson et al., 1962a; Ryerson et al., 1962b).

In a range fertilization study in the Palouse Prairie vegetation of southwestern Montana Ryerson and Taylor (1963) found that the response of clubmoss to applications of nitrogen and phosphorus was more erratic than its response to similar treatments at the northern Montana study. Clubmoss ground cover in fertilized plots was found to be heavier than that in the check plots.

Water

Availability of water probably influences clubmoss distribution but similar responses of the species have not always been reported. Such

factors as quantity, time and duration of applications probably affect the response.

An increase in clubmoss cover was observed by Clarke et al. (1947) in Canadian prairie vegetation after seven years of drought.

Six water spreading projects in southeastern Alberta were designed to better utilize spring runoff (Hubbard and Smoliak, 1953). The results of five of the projects disclosed that a decrease in the basal cover of clubmoss resulted from the increased availability of water. Klages and Ryerson (1965) reported an increase of clubmoss cover corresponding to applications of up to 12 inches of additional water to range in western Montana.

Chemicals

Preliminary investigations of the effectiveness of chemicals for the control of clubmoss on Montana range land have been initiated by Wagner (1966). Several chemicals have either killed all vegetation or have killed clubmoss and reduced the yield of other species. Two preparations, "AMS" and "Atrazine", appear to be effective in controlling clubmoss and may actually stimulate other vegetation. These studies are only one year old, so few conclusions can be drawn at this time. The studies are being continued.

DESCRIPTION OF THE AREA

The North Montana Branch Station, six miles southwest of Havre, is situated in the mixed prairie region of North America. This vegetational association is the most extensive of those forming the continent's grasslands. It extends from northern Alberta and Saskatchewan to the Staked Plains of Texas in the south, and from central North Dakota westward to eastern Utah (Coupland, 1961; Weaver and Albertson, 1956; Weaver and Clements, 1938).

The plots of native sod which received mechanical and manure treatments between 1925 and 1935 are located along the north side of a mixed prairie relict area which has remained relatively undisturbed since 1915 (Figures 3 and 4). This area lies in Section 32 of Township 32N, Range 15E at an elevation of about 2700 feet above sea level. The plots slope evenly and gently to the west.

Soils

At least two ice sheets have previously covered the northern Montana plains. Two distinct types of glacial till give evidence of this.

The treatment plots are located on soil classified as "Joplin clay loam, 2 to 4 percent slope" (U.S.D.A., S.C.S., 1960). A small portion of six plots overlap an area of "Joplin clay loam, 5 to 10 percent rolling" and "Devon loam, 0 to 2 percent slope" (Figure 5).

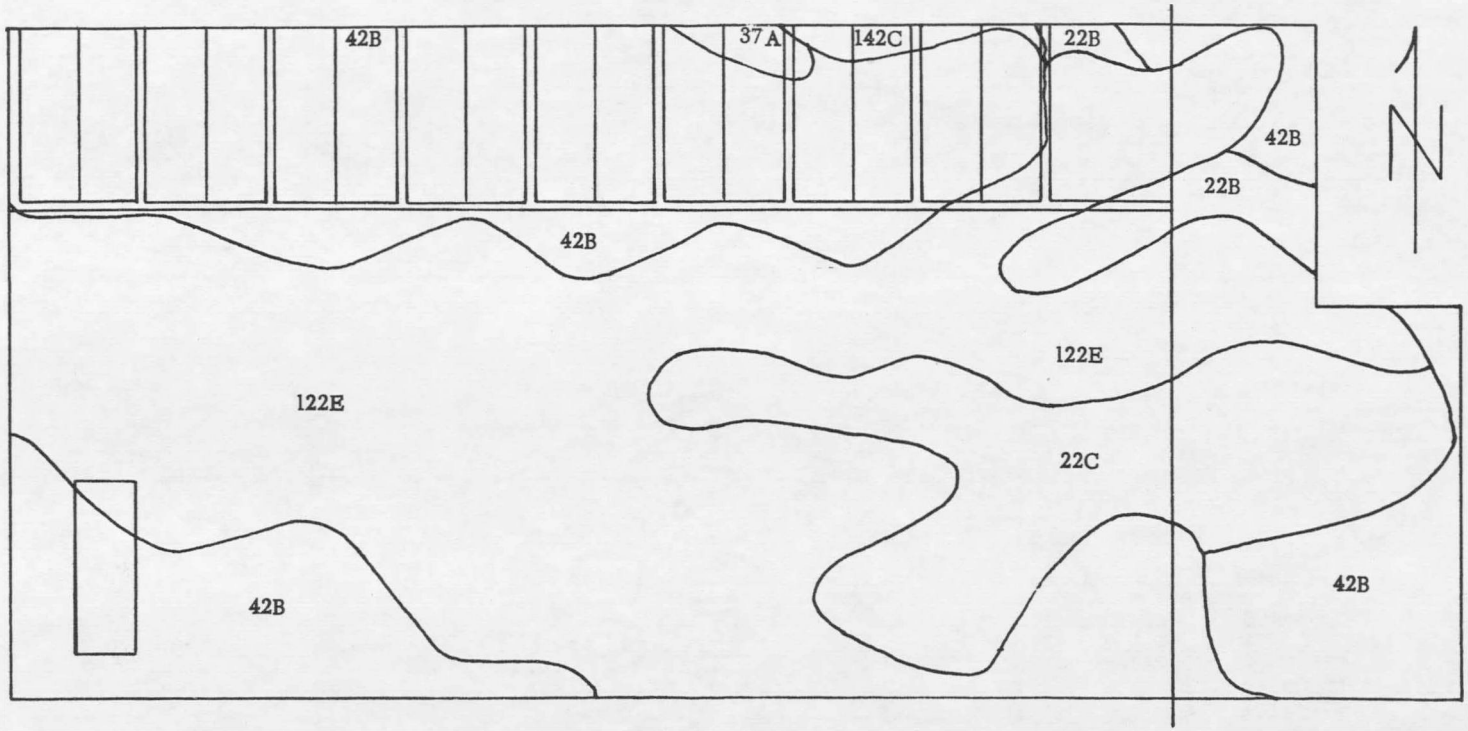
The Joplin soil series consists of an intergradation of Chestnut and Brown soils which have developed from glacial till or superglacial deposits. A high silt and fine sand content is characteristic of these parent materials. This has resulted in fine-textured soils of high moisture holding capacity. The undisturbed grassland has a grayish brown loam surface



Figure 3. Sixteen treated plots looking west. Note the light aspect of native vegetation. The darker crested wheatgrass is invading from the north.



Figure 4. Relict area looking northeast from check plot 18. Sixteen treatment plots are situated on the bench to the left.



37A: Devon loam, 0 to 2% slope
42B: Joplin clay loam, 2 to 4% slope
22B: Zahl loam, 2 to 4% slope
22C: Zahl loam, 4 to 8% slope
122E: Zahl - Sunburst clay loam, 20 to 45% slope
142C: Joplin clay loam, 5 to 10% rolling

Figure 5. Soil map of the treatment plots and relict area, North Montana Branch Station.

layer less than 3 inches deep. The subsoil is a prismatic-blocky clay loam. The Cca horizon is prominent and seldom lies at depths greater than 8 inches. The two Joplin soils occurring on the treatment plots differ chiefly in slope gradient.

Devon soils have developed from similar parent materials. They differ from Joplin soils by having a thicker solum and a Cca horizon at a greater depth. Devon soils on the treatment plots slope from 0 to 2 percent.

Climate

The severe continental climate of the high northern plains prevails at the study site. Extreme variations of weather among seasons and among years are common.

Meteorological data were collected one half mile north of the study plots in proximity to trees and buildings which have probably affected the measurements to some extent. Although similar data were collected by the U. S. Army at Fort Assinniboine since 1879 and by the U. S. Weather Bureau near Havre since 1884 these records have not been used in the preparation of the following description. Differences in instrument location and extreme variations in some of the records led to this decision. The following information and the appendix tables have been derived from climatological records of the North Montana Branch Station dating from 1916.

Precipitation

May, June and July are the months of the greatest average precipitation. Rainfall decreases as the summer progresses. The driest months are usually November through March. Table I shows the average monthly precipitation for the North Montana Branch Station.

Table I. Average monthly precipitation (North Montana Branch Station)[1/]

Month	Precipitation (inches)
January	0.40
February	0.33
March	0.47
April	0.93
May	1.63
June	2.71
July	1.38
August	1.14
September	1.11
October	0.64
November	0.41
December	0.43

1/ Forty-nine year average from N.M.B.S. climatological records.

The mean annual precipitation at the Experiment Station is 11.57 inches. Twenty-seven (55%) of the 49 years used in calculating this average were years of below average precipitation. Twenty-two years (45%) received more than average moisture. A summary of precipitation distribution by years appears in Appendix Table I.

During 1965, when the treatments to the native sod were being evaluated, 12.74 inches of precipitation had fallen by the end of August, surpassing the annual average.

Hail storms of varying intensity are a common summertime phenomenon in northern Montana. Sturm (1954) reported hail which accumulated to a depth of six inches on the relict area during one June hail storm. Physical damage to the vegetation is a real possibility during such storms.

Total annual snowfall averages about 36 inches. The quantity of moisture in a given snow depth varies considerably. Late winter snows usually deliver more moisture than do earlier storms. January, February and March are normally the months of heaviest snowfall but snow cover usually does

not remain all winter. Warm "Chinook" winds can melt even heavy snow cover in a day or two. Wind can also physically remove snow and the area evaluated in this paper is often blown free of snow before the snow melts[6/]. Usually no snow remains after the first week in April.

Temperature

The 48 year mean annual temperature at the Experiment Station was 42.3° F. The maximum mean annual temperature recorded for one year was 54.7°. The minimum was 29.8°. Maximum average for one growing season (May-August) was 77.3°; minimum for a growing season, 49.3°. The mean growing season temperature is 63.3°. July, the hottest month, has a mean temperature of 70.0° with a record maximum average of 84.9° for the month. A record maximum of 111.0° was recorded on August 8, 1963. January, with a mean temperature of 14.8°, is the coldest month. The lowest monthly average recorded for that month was 4.2°. The record minimum temperature at the Station was -48.0° set during February 1936.

Frost-free Period

The average annual frost-free period for 48 years was 126 days. This period varied from a maximum of 172 to a minimum of 93 days.

May 14 was the date of the average last spring frost (32° F.) while the average first fall frost occurred on September 19. The record earliest and latest dates for the last spring frost were April 21 and June 5, respectively. The extreme dates recorded for the first frost of fall were August 31 and October 22.

6/ Windecker, C., Superintendent, North Montana Branch Station. 1965. Personal communication.

Wind Velocity

The annual average hourly wind velocity, determined from a four cup anemometer at a height of two feet, was 6.2 m.p.h. The velocity averaged somewhat less during the growing season. Appendix Table II lists the 48 year average monthly wind velocity.

Highest wind velocities tend to occur from November through March. The highest velocity recorded was a November 1962 wind of 62.7 m.p.h. Although there is a tendency for high winter winds they may occur at any season. Winds have sustained a 15 m.p.h. average for a five-day period on several occasions. Winds most frequently come from the southwest although westerly and northwesterly winds are also common.

Evaporation

Measurement of evaporation from an above ground free water surface was begun in 1949 at the North Montana Branch Station. The present tank is four feet in diameter. Prior to 1949 a larger, sunken tank was used in which the water surface was maintained at about soil surface level. Differences between the two methods led to the decision to consider only data from the presently used method in this summary.

Evaporation is measured from April through September. The 15-year average evaporation for this six month period is 52.2 inches. High summer temperatures, low relative humidity and frequent air movements help maintain evaporation at this high level. Average monthly evaporation rates appear in Appendix Table III.

History of Use

The proximity of the study area to Beaver Creek and to the Milk River

may have caused it to support greater numbers of animals in prehistoric times than similar areas further from water. Sturm (1954) reported that the area was a favored hunting place for Indians coming from as far as the Cypress Hills of southern Alberta and Saskatchewan. He stated that he had counted rock tepee rings numbering in the hundred in the vicinity which indicated large encampments. Horses therefore must have grazed the area at intervals. Good hunting suggests an abundance of wildlife, probably including the grazing animals of the plains.

Land north of the Missouri River remained largely uninfluenced by white men until 1888 when the Great Northern Railroad was built through the Milk River Valley in Hill County (DeYoung et al., 1932). At that time the permanent settlement of agricultural lands began along the railroad and watercourses. Both sheep and cattle became important grazing influences.

Public grazing probably did not influence the study site at that time since the area was established as a part of Fort Assinniboine in 1879. Since the Fort maintained a large cavalry unit and because the study site is only one half mile from the post buildings it is probable that the site was subjected to heavy grazing by army horses and mules.

In 1911 the Fort was abandoned. Trespass grazing probably occurred from then until 1915 when, by an act of Congress, the buildings and 2,000 acres of the military reservation were transferred to the State of Montana for educational purposes.

An area, including the relict area, was fenced for agronomic experiments in about 1915. The relict was not plowed because of its relatively rough topography. Evidence of the ruts of a road is visable cutting across

the relict from the northeast to the southwest. Stone piles along the north side of a swale within the area testify that it served as a dump for rocks when the experimental fields were being cleared. This also indicates that the north side of the relict, which was treated as native sod in 1925, was possibly disturbed if it was repeatedly traversed during the clearing operations. Since this site bordered the experimental agronomy fields it may also have been used as a headland for turning and clearing farm implements.

Such visible signs of disturbance as the rock piles indicate that the relict area was probably not considered a relict and protected as such until relatively recently.

A prairie fire burned over the relict area in the early spring of 1925 before work commenced on the treatments to the native sod.

EARLY RANGE IMPROVEMENT STUDIES AT NORTH MONTANA BRANCH STATION

Preliminary Work

Attempts to increase the productivity of rangeland on the North Montana Branch Station began four years after the Station's inception. A proposal to seed several half acre plots of native pasture to various introduced forages following some cultivation was made in 1919. Dry weather prevented implementation of this plan until 1920.

This preliminary trial was made on an area across Beaver Creek from the site of the following renovation study. Results were inconclusive and no reference was made to clubmoss in either of the two annual Station reports which mentioned the experiment.

1925-1935 Treatments to Native Sod

Eight 132 x 200 foot plots were established along the north side of the relict area in 1925. These plots corresponded in size, orientation and identification number with adjacent agronomic plots to the north. The plot to the east was identified as II. The numbers advanced westward to plot IX.

Plots II, III and IV each received 10 tons of barnyard[7/] manure in 1925. A similar application of manure was made on plot V in addition to two disking treatments. Plots VI and VII each received the double disking treatment and plot VII received an additional pass with a spring-tooth harrow. The east and west halves of plots VIII and IX were designated as "a" and "b" respectively. The west half (b) of each of these plots remained untreated to serve as a control area. The east half (a) of each plot was

7/ This designation is used throughout the records of the Experiment Station in reference to these applications. Whether this indicates cattle manure or a mixture of cattle and horse manure is not known. Both classes of livestock were maintained at the Station.

disked twice. Area "a" of plot VIII was seeded (probably drilled) to yellow sweetclover at locally recommended rates. Area "a" of plot IX was similarly sown to crested wheatgrass in 1925.

The manure applications were repeated on plots III and IV in 1926, and again on plot IV in 1927.

In 1928 all of the plots were divided into parts "a" and "b" as were plots VIII and IX in 1925. From 1928 through 1935 treatments were applied only to part "a", the east half of each plot. This effectively created 16 plots from the original eight. Chronological treatments are shown diagrammatically in Figure 6. In the diagram the plots are numbered 1 through 16 from west to east, and in the interest of clarity will be referred to in this manner for the remainder of the paper.

The sod was mechanically worked on about April 1 of each treatment year. The soil was reported as being reasonably moist at this time. Manure applications and seeding were accomplished at a "somewhat later date".

A description of the early vegetative responses to these treatments appears in the section of the literature review concerning factors influencing the local distribution of clubmoss.



Figure 6. Diagram of chronological treatment schedule.

METHODS

Pre-sampling Procedures

In the summer of 1965, forty years after the treatments to native sod were begun and 30 years since the last treatment had been applied, the long-term effects of these practices on clubmoss as well as other vegetation were evaluated.

Plot Relocation

The original wooden plot markers had rotted and disappeared by 1965. With the assistance of Mr. Claude Windecker, Station Superintendent and Mr. Harold Houlton, Assistant Soil Scientist, the original eight plots were relocated and permanently marked with steel fence posts. Plot locations were verified by Station records and plot boundaries were aligned with agronomic plots in the adjacent agronomy plot field. On several occasions portions of old markers were encountered when setting the steel posts.

Plot Modification

Along the south edge of the plots crested wheatgrass had invaded ruts created by vehicles. The south edge of each plot was therefore moved 20 feet north. This eliminated the strip of disturbed vegetation from the areas to be evaluated.

Each of the eight original plots had received one treatment on the east and another on the west which essentially divided each plot in half. These sixteen 66 x 180 foot plots are now permanently marked with steel posts. A 20 foot pathway lies between each pair of plots. Plots were designated 1 through 16 from west to east (Figure 7).

No attempt had been made to replicate the treatments in 1925 which presented an obstacle for valid statistical analysis. Each plot was there-

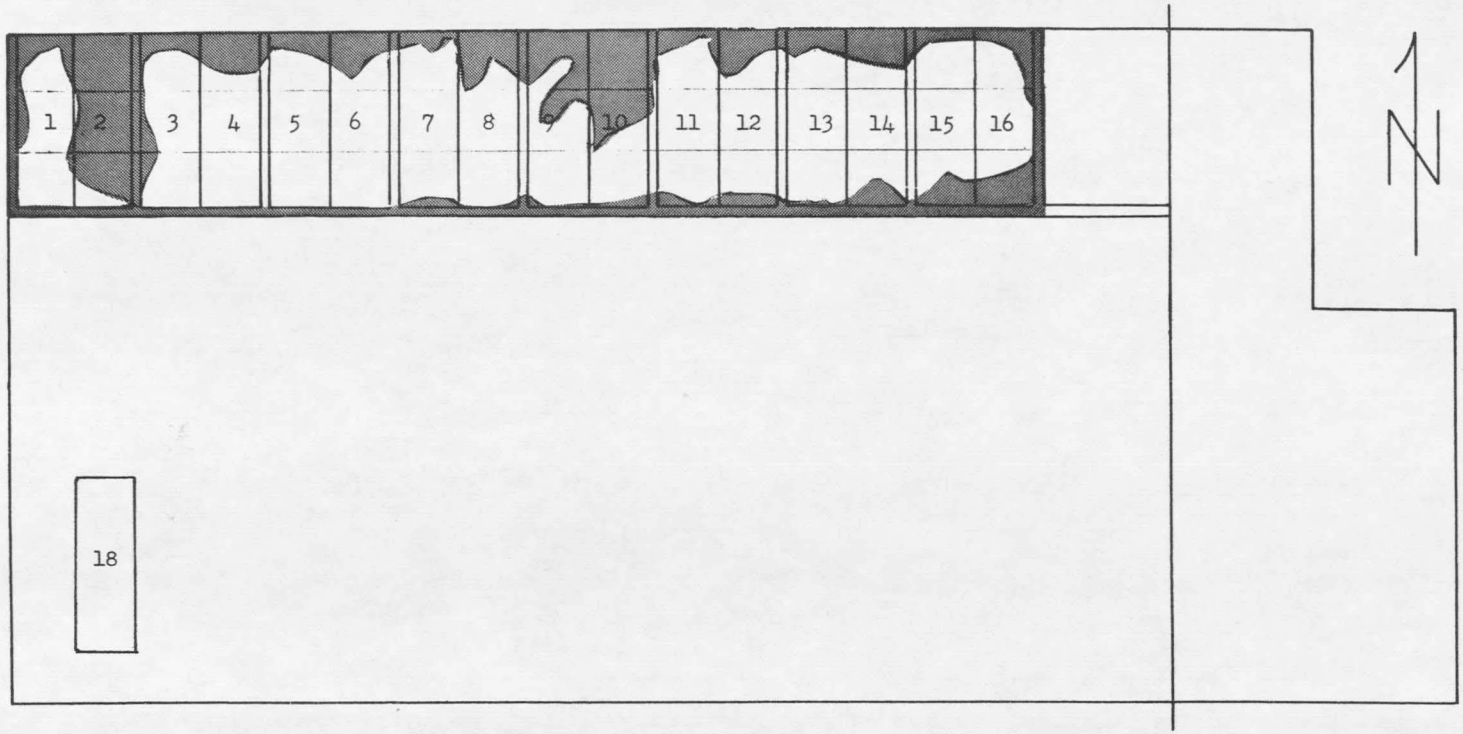


Figure 7. Vegetational aspect. Light areas depict native vegetation. Crosshatching indicates areas invaded by crested wheatgrass.

fore divided along its east-west axis into three subplots, each 60 x 66 feet. Although this subdivision did not compensate for the lack of replicated treatments it did present three separate areas from which to gather comparable data. Subplots were numbered 1 through 3, north to south and marked with steel posts.

Additional Check Plot

In addition to the 16 treated plots a similarly subdivided plot was established in 1965 in the undisturbed relict area (Figure 7). This plot (No. 18) was located on Joplin clay loam, 2 to 4 percent slope, soil identical with that of the treated plots, and used as a direct check for the treated plots. Although plots 1 and 3 were technically untreated both were undoubtedly influenced by their proximity to treated areas and possibly by the passage of implements over them during the renovation of neighboring plots. Plot 1 was partially destroyed by a 20 foot fenceline road on its west side. Crested wheatgrass had invaded the disturbed area.

Sampling Procedures

Estimate of Vegetative Cover

The growth characteristics of clubmoss suggested that a measurement of its ground cover would indicate its place in the plant community and response to treatments.

Basal ground cover was estimated by a method developed by Fisser and Van Dyne (1960). The technique employs a mechanical frame which supports a movable, vertical needle. This needle projects a five-foot transect across the ground surface from which cover characteristics are recorded in hundreths of feet. Use of the device and handling of resultant data have been

discussed at length by Van Dyne (1960) and Fisser (1961).

Nine transects were placed in each plot, three in each subplot. This resulted in 4,500 intercepted 0.01 foot linear units per plot. Both areas supporting native species and those dominated by crested wheatgrass appeared to be vegetatively homogeneous in individual treatment plots. In a given aspect within a plot clubmoss cover appeared especially homogeneous.

Transect Location

A system of coordinates was utilized to determine transect locations. Nine theoretical ranks six feet apart were positioned east and west. Nine similar files 6.6 feet apart were superimposed on the ranks (Figure 8).

Each coordinate intersection was a potential placement point for the number one leg of the transect device. Only eight ranks and eight files were utilized for transect placement, thereby creating a buffer zone around each plot. Thus, with the exception of limitations imposed in subplot 3 of plots 15 and 16 by a road, 64 possible transect positions were created within each subplot; 192 per plot.

A table of random permutations of nine was used to determine the rank and file of each transect position (Cochran and Cox, 1957). Positions were marked on a map of the plot area.

A map of areas dominated by crested wheatgrass (Figure 7) was consulted after the transects were randomly placed. When a disproportionate number of transects in a plot were observed on the crested wheatgrass area they were relocated so that an adequate number were placed on native vegetation.

Placement of Transects

A 7/16 inch steel rod was driven into the ground at each coordinate

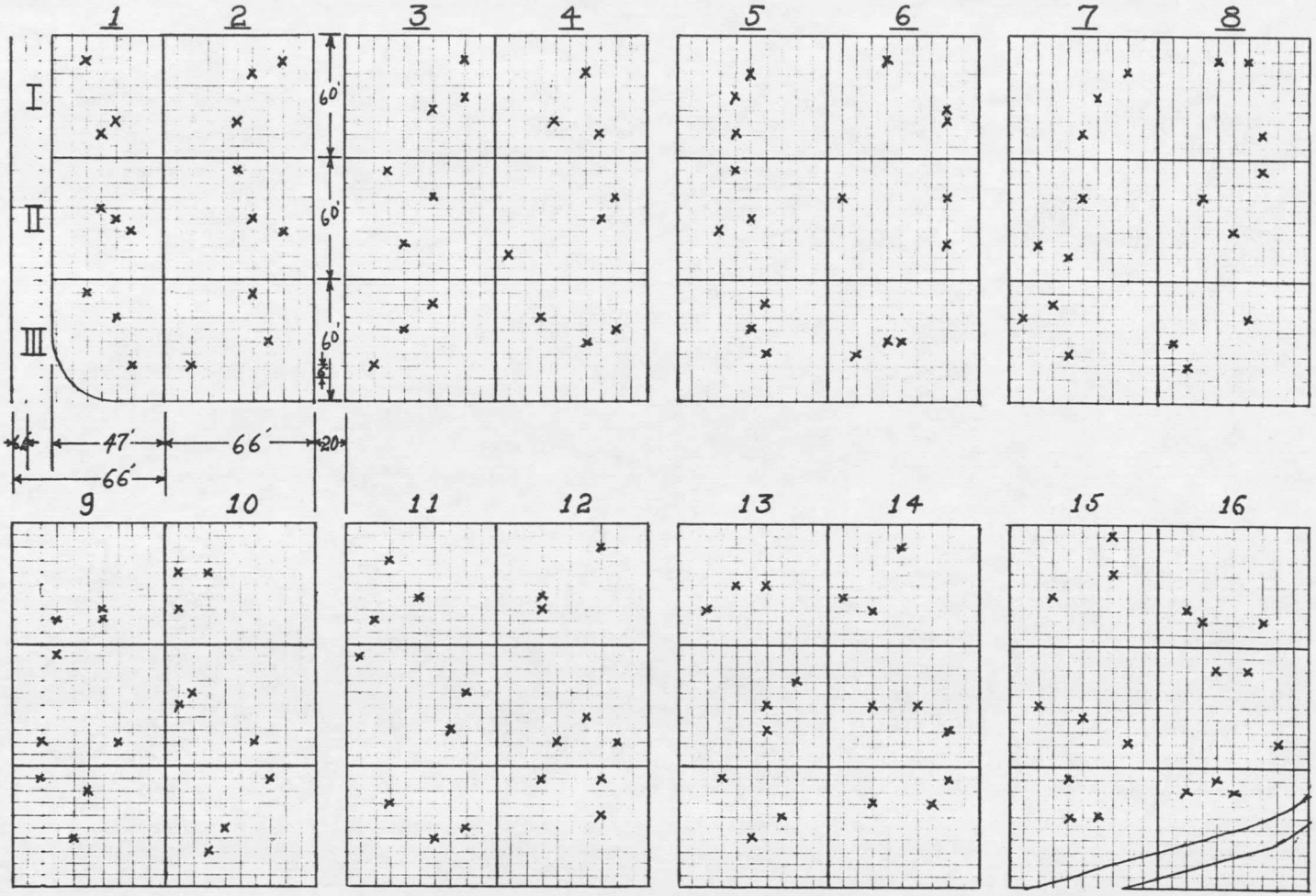


Figure 8. Diagram of transect locations.

intersect at which a transect would be placed (Appendix Table IV). These key pins, painted white to facilitate relocation, were allowed to protrude about one inch from the soil.

When the transect device was positioned before each transect reading it was aligned in an east-west direction. A hole in the number one leg of the device fitted on the key pin. Three orange colored pins of similar stock were then driven through holes in three other legs to secure the device. The resulting rectangle of one white and three orange pins if undisturbed allows for exact repositioning of the transect provided the same device is used for subsequent readings.

Collecting Intercept Data

The use of a portable tape recorder hastened the recording of intercept data (Figure 9). A five digit code was developed for transect identification in the field and during statistical analysis (Appendix Table V). After a transect was identified on the tape, intercepts were identified by type code, name of material and the point on the scale at which each was first encountered. A type code (Appendix Table VI) classified the nature of each intercepted material. Plant species were identified by using the first two letters of both the genus and species. Clubmoss was further described by a fifth letter, A or D, denoting an alive or dead appearance[8/]. Transects were read from left to right, 000 to 500 on the scale.

In all cases the transects were read with the inscribing needle set to protrude 10 inches from the holding fixture. Thus the needle was nearly

8/ Green and greenish-brown clubmoss was considered alive. Light brown and gray colored clubmoss was recorded as dead.

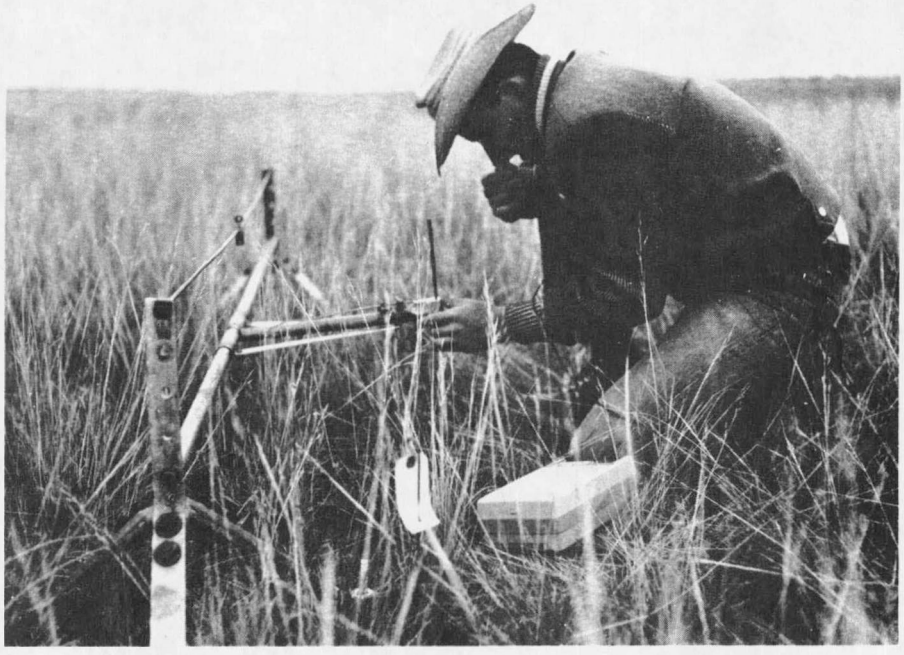


Figure 9. Reading and recording a transect.

always perpendicular to the soil surface.

Intercepted bunch grasses were measured from the point at which the needle first encountered rooted culms at ground level to the point at which the intercept at ground level changed. Ground level intercepts of different material greater than 0.01 foot within a bunch were considered as separate intercepts. Single stem grass species were given a minimum value of 0.01 foot when encountered. A colony of such stems growing less than 0.01 foot apart was regarded as one intercept until an intercept of different material greater than that distance occurred.

Only the rooted portions of erect forbs and half-shrubs were measured. Aerial encounters were disregarded. Mat forming forbs such as clubmoss and Hood's phlox were measured by recording intercepts at those points at which

any portion of the mat was encountered at ground level. Interruptions greater than 0.01 foot in the intercepted portion of the mat were recorded as new intercepts.

Litter was recorded only when the portion encountered measured 0.01 foot or greater. Mats of litter were measured in the same fashion as mats of low growing vegetation. Litter measurements occasionally became somewhat subjective. Litter in contact with the soil was always recorded as an intercept. If litter was prevented from touching the soil it was then recorded or not recorded on the basis of dominance in a particular micro-habitat. Mass of the litter and distance above the soil were the two main considerations in determining the occurrence or length of an intercept in these cases.

Animal feces were recorded as defined in Appendix Table VI. Rabbit feces were seldom encountered while droppings from domestic livestock were absent.

Bare ground was considered to be all non-living inorganic and organic material other than litter, the individual particles of which were less than 0.01 foot in diameter. Erosion pavement consisted of pebbles 0.01 to 0.03 foot in diameter. Stones with diameters greater than 0.03 foot were recorded as rock.

Estimate of Herbage Production

Six circular plots, 9.6 square feet in area, were clipped on each treatment plot during the first week in September, 1965. Species and groups of species were separated into the following categories: needle-and-thread, blue grama, crested wheatgrass, western wheatgrass, junegrass (Koeleria

cristata), other perennial grasses, annual grasses, sedges, annual and biennial forbs, perennial forbs, fringed sagewort and winterfat.

Clip Plot Location

Clip plots were placed subjectively by the author. Areas of typical and homogeneous vegetation were selected and marked before clipping. In addition clip plots were placed on areas of native vegetation and crested wheatgrass proportionately to the relative amounts of both aspects in each treatment plot. Approximate clip plot positions may be seen in Figure 10. A five digit code, similar to that used in transect identification, was used to identify each clip plot location (Appendix Table VII).

Clipping Procedure

Vegetation was clipped at ground level by teams of two men each (Figures 11 and 12) and separated into the 12 categories mentioned previously. Each category in a given clip plot was represented by a numbered paper bag in a compartmented box carried by the clippers. Bag numbers were assigned by a centrally located man at a portable field desk and recorded in the record book (Figure 13) before the box and its complement of 12 bags were taken by the clippers.

Clipped vegetation was immediately placed into the proper bag. When the filled bags were returned to the recorder they were checked for content, stapled closed, bagged and coded according to clip plot (Figure 14). Six bags, each containing clippings from one clip plot were then consolidated into one large sack (Figure 15) representing vegetative samples from one treatment plot. The samples were then sent to the University and weighed.

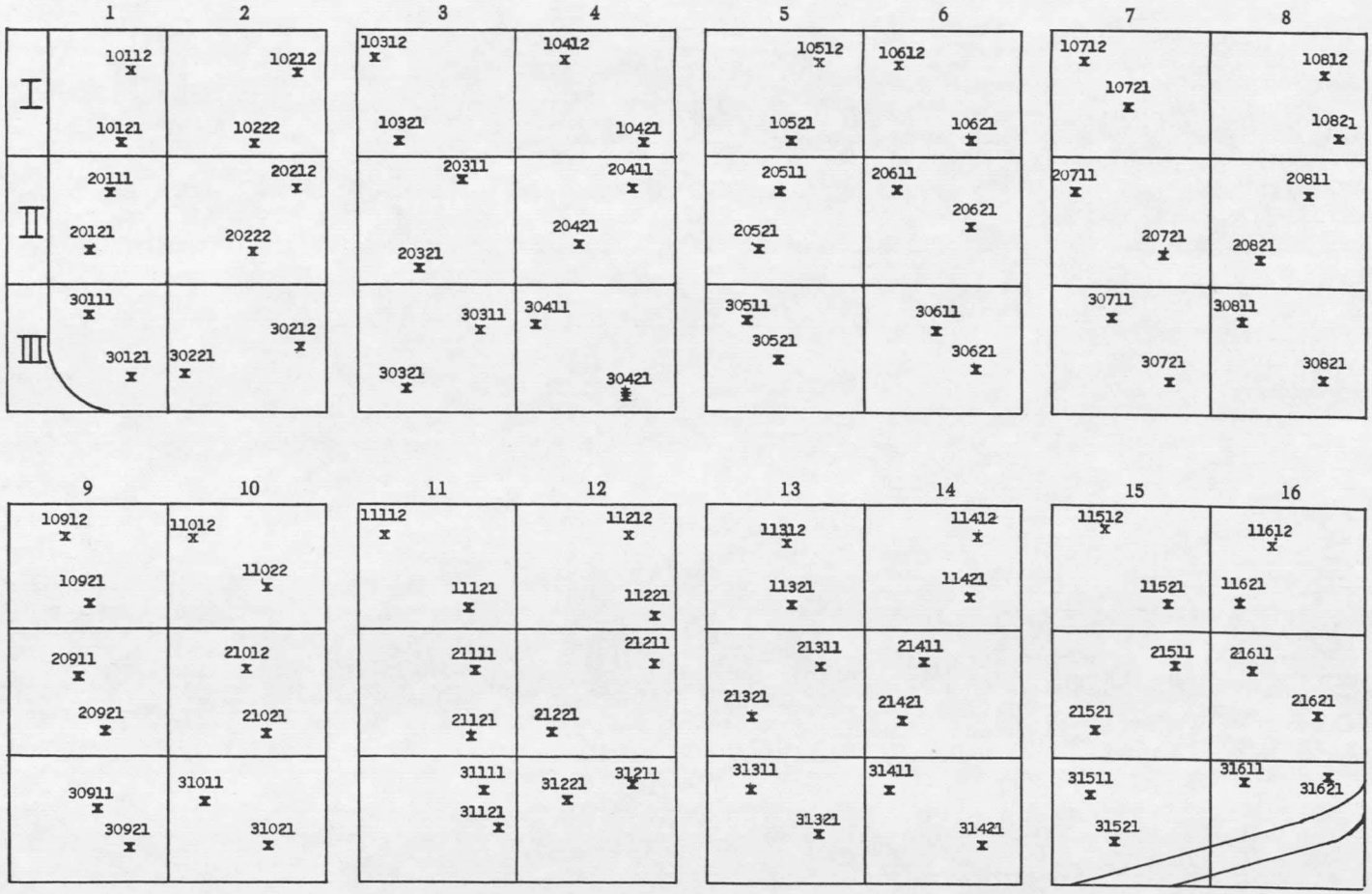


Figure 10. Diagram of clip plot locations.



Figure 11. Two clipping crews and field office. Plot 18 looking north.



Figure 12. Details of the clipping operation in native vegetation.

Treatment Code Symbol	Clip Plot Number	Sack Number	Type	Name Symbol	Gross Weight	Tare
10112	1	57426	10	STCC	10.47	10.43
		~~57475~~	~~10~~	~~AGSM~~		
		~~57477~~	~~10~~	~~KOCR~~		
		~~57503~~	~~10~~	~~BOGR~~		
		57437	10	AGCR	141.75	10.38
		~~57448~~	~~10~~	~~MISC~~		
		~~57370~~	~~11~~	~~MISC~~		
		~~57526~~	~~12~~	~~MISC~~		
		57527	13-14	MISC	10.53	10.45
		~~57497~~	~~15~~	~~MISC~~		
		~~57533~~	~~16~~	~~ARFR~~		
		~~57546~~	~~16~~	~~EULA~~		
10121	2	57547	10	STCO	159.76	10.69
		57548	10	AGSM	12.56	10.37
		57549	10	KOCR	12.54	10.32
		57550	10	BOGR	10.50	10.27
		57551	10	AGCR	13.66	10.47
		57552	10	MISC	16.98	10.48
		~~57553~~	~~11~~	~~MISC~~		
		57554	12	MISC	11.39	10.48
		~~57555~~	~~13-14~~	~~MISC~~		
		~~57556~~	~~15~~	~~MISC~~		
		~~57557~~	~~16~~	~~ARFR~~		
		57558	16	EULA	11.14	10.31
20111	1	57559	10	STCO	129.82	10.56
		~~57560~~	~~10~~	~~AGSM~~		
		57561	10	KOCR	11.78	10.37
		~~57562~~	~~10~~	~~BOGR~~		
		~~57563~~	~~10~~	~~AGCR~~		
		57564	10	MISC	11.29	10.48
		~~57565~~	~~11~~	~~MISC~~		
		57566	12	MISC	10.79	10.41
		57567	13-14	MISC	10.79	10.41
		57568	15	MISC	11.24	10.55
		~~57569~~	~~16~~	~~ARFR~~		
		~~57570~~	~~16~~	~~EULA~~		

	Workers	Date
Field Work		
Weighing		

Figure 13. Sample page from herbage yield record book.



Figure 14. Recording sack numbers at the field office.



Figure 15. Consolidating six clip plot bags into one bag representing a treatment plot.

Estimate of Litter

The same 9.6 square foot circular plot rings used for the clip plots were used for litter collection plots. Six plots were again placed in each treatment plot, three per subplot.

Each litter plot was paired with a clip plot with respect to vegetative aspect and locality. A minimum distance of six feet was imposed between such paired plots because of disturbances to the area immediately surrounding the clip plots incurred during the clipping operation. Before clipping, all litter was removed from the area to be clipped and deposited beyond the clip plot perimeter. More litter could therefore be expected around the clip plots than in other areas. In addition vegetation surrounding clip plots had been trampled. The same five digit code used to distinguish clip plots was again employed to identify litter plots.

Because of the subjectivity involved in deciding what was and what was not litter the author made all of the litter collections. All loose plant organic matter within the sampling ring was first collected (Figure 16). Then bunch grasses were combed lightly with the fingers in an effort to retrieve loose material occurring principally in the basal regions. Grass bases were not physically disturbed nor were grass culms broken. All litter was not retrieved from these bunches but an effort was made to maintain identical collection practices in all samples. Gathering mineral soil with litter was meticulously avoided.

Plant material samples from both clip plots and litter plots were opened and oven dried in their individually numbered sacks. Samples were weighed to the nearest 0.01 gram. This figure was recorded in the record book



Figure 16. Collecting litter in an area invaded by crested wheatgrass.

opposite the bag number. A record book, similar to that used for herbage yield, was used to record litter weight data (Figure 17).

Vegetation Survey of 21 Areas

Although the dominant plant species occurring on the treatment plots were encountered on the line intercepts, many other less abundant species were not recorded. A visual survey of the vegetation was therefore made. Each of the treatment plots was inspected closely in an effort to identify all species. In addition four other areas within the relict area were also inspected. The results of this survey appear in Appendix Table VIII.

Data Processing

Magnetic tapes containing the field recorded data were sent directly to the Montana State University Computing Center. Key punch operators

Plot Number	Clip Plot Code and Sack Number	Gross Weight	Tare			
1	10112	124.24	12.08			
	10121	21.48	11.43			
	20111	24.22	11.60			
	20121	31.88	11.71			
	30111	34.20	11.70			
	30121	25.83	11.59			
2	10212	68.73	12.16			
	10222	78.94	11.94			
	20212	67.10	12.11			
	20222	56.83	11.98			
	30212	66.22	11.86			
	30221	27.27	11.74			
3	10312	100.38	12.42			
	10321	21.68	10.14			
	20311	24.67	9.90			
	20321	19.56	9.99			
	30311	30.23	10.13			
	30321	40.91	10.08			
4	10412	95.57	11.94			
	10421	35.41	10.01			
	20411	38.12	10.21			
	20421	65.78	10.19			
	30411	50.28	10.36			
	30421	69.60	10.06			

Workers	Date
Field Work	
Weighing	

Figure 17. Sample page from litter record book.

equipped with tape recorders and earphones punched the recorded material directly onto IBM cards. Total intercept lengths were listed by type code and species in preparation for statistical analysis. An analysis of variance of the intercept data of each major species and species group in each treatment plot was next obtained. A Duncan's multiple range test (Duncan, 1955) was used to determine significant differences in ground cover on the treatment plots caused by the early treatments.

It was impractical to arbitrarily assign relative values to treatment intensities due to the confounding effects of climatic variations among years of partial treatments. Therefore correlations between treatment intensity and vegetational responses were not attempted. Correlation coefficients were obtained, however, for paired ground cover categories throughout all treatment plots to indicate relationships among categories.

Weight data were transferred directly from the record books to IBM cards. Each separate species sample from a clip plot was identified by location and species on one card together with the weight. Weight summary sheets were then prepared from these cards prior to statistical analysis. Analysis of variance, Duncan's multiple range tests and correlation coefficients were used as with the intercept data.

Estimate of Forage Protein Content

The weighed vegetation from each of the treatment plots was separated into grass and non-grass categories. Sedges (Carex spp.) were included in the non-grass category. Grinding in a Wiley mill resulted in a well-mixed flour which was then analyzed for crude protein by the Montana Grain Inspection Laboratory (MacMasters, 1962).

RESULTS AND DISCUSSION

Introduction

Although the primary purpose of this study was to evaluate the effects of various renovation practices on clubmoss, quantitative measurements were made of all vegetation encountered on the treatment plots. Complex interspecific relationships within the plant community make complete assessment of all interrelationships difficult.

It is not clearly understood whether the decrease in clubmoss ground cover observed in certain plots resulted directly from the initial treatments or occurred as a secondary response. Therefore all pertinent data collected during the treatment evaluation are presented. Perhaps at some later date, when the ecology of clubmoss is better understood, further inferences can be developed from these data.

Throughout the following discussion the various treatments are compared with check plots. Plot number 1 has been influenced by the road crossing it and can not be equated with the other two check plots. Since it was designated a check plot in 1925 it has been included as a matter of historical interest.

In several of the following tables (III, VI, VII and VIII) the treatment plots have been grouped as check plots, mechanically treated plots and manured plots. The plots within each group have been ranked in an order of increasing treatment intensity (Figure 6).

Response of Clubmoss to Renovation Practices

Significant differences of clubmoss cover occurred among treatments (Tables II and III). Thus, it may be assumed that certain treatments affected the live, dead and combined live and dead clubmoss ground cover.

Cover differences of clubmoss among some treatment plots actually may be seen at certain plot boundary lines.

Live Clubmoss

Live clubmoss ground cover on check plots 3 and 18 did not differ significantly. Check plot 18 had a heavier cover of live clubmoss than any mechanically treated plot while live clubmoss cover on check plot 3 was greater than that on any of the four most intensively cultivated plots. No significant decrease appeared between check plot 3 and either of the least intensively cultivated treatment plots.

It is apparent from the intercept data that as the intensity of mechanical treatment increased the percentage of ground cover of the live clubmoss decreased. The implications of this become especially striking when it is realized that the treatment sequence began 40 years ago and that no plot has been treated for 30 years.

With the exception of plot 13, which received two 10-ton manure applications, all manured plots had significantly less live clubmoss ground cover than either check plot 3 or 18. An apparent decreasing (but non-significant) trend was noted in percent ground cover of the species as manuring intensity increased.

Dead Clubmoss

The two check plots 3 and 18 were again consistent in that no significant difference existed in the amount of dead clubmoss encountered on them.

More dead clubmoss was present on check plots 3 and 18 than all but one of the mechanically treated and one of the manured plots, neither of which was intensively treated. A significant trend of less dead clubmoss

Table II. Summary of analysis of variance tests on ground cover.

Variable	Mean square		
	Error	Among treatments	Among subplots, within treatments
Live clubmoss	2,270.60	26,907.89 * *	3,836.78 *
Dead clubmoss	4,407.69	65,060.39 * *	7,918.54 *
All clubmoss	10,091.00	174,109.00 * *	20,892.32 * *
Needle-and-thread	115.32	331.79 *	144.06
Blue grama	12.74	17.63	13.86
Crested wheatgrass	115.74	361.22	186.59 *
All grass species	162.55	406.77	249.45
Sedges	2.07	3.11	3.23
Perennial forbs	0.15	0.24	0.15
All vegetation (except clubmoss)	164.64	374.16	214.26
All attached veg.	10,222.90	163,231.00 * *	20,295.38 * *
Litter	8,874.06	127,392.50 * *	15,126.50 *
Bare soil	410.54	3,242.08 *	1,342.59 *

* Significant at the .05 probability level.
* * Significant at the .01 probability level.

Table III. Percent ground cover by species.

Treatment intensity	Treatment plot	Live clubmoss	Dead clubmoss	All clubmoss	Needle-and-thread
check	18	34.38 a [1]	49.09 a	83.46 a	2.22 cde
	3	26.07 ab	40.02 a	66.08 ab	2.04 cde
	1 [2]	6.04 def	7.80 cd	13.84 ef	4.62 ab
mechanical	7	15.60 bcd	22.96 b	38.54 cd	1.93 cde
	5	20.38 bc	37.07 a	57.44 bc	1.60 de
	4	14.29 cde	20.38 bc	34.66 de	2.09 cde
	2	0.89 f	1.13 d	2.02 f	0.53 e
	8	1.04 f	0.00 d	1.04 f	2.09 cde
	6	4.09 ef	4.60 d	8.68 f	2.33 bcde
manure	15	5.76 def	13.42 bcd	19.16 def	3.91 abc
	9	0.06 f	0.40 d	0.46 f	2.02 cde
	13	25.58 ab	43.24 a	68.82 ab	2.93 bcd
	11	4.84 ef	7.89 cd	12.72 ef	2.60 bcd
	16	1.02 f	0.78 d	1.80 f	5.73 a
	10	0.08 f	0.47 d	0.54 f	2.04 cde
	14	2.80 f	13.13 bcd	15.92 ef	3.24 bcd
	12	1.33 f	0.69 d	2.02 f	2.84 bcd

1/ Identical letters indicate no significant ground cover difference within a given species or other category at the .05 probability level according to the Duncan's multiple range test.

2/ Plot 1 is included as a matter of historical interest. It has been disturbed since being designated a check plot and should not be equated with the other two check plots.

Table III. Percent ground cover by species. (continued)

Treatment intensity	Treatment plot	Blue grama	Crested wheatgrass	All grass species	Sedges	Perennial forbs
check	18	0.18 ab	0.00 b	2.49 e	0.13 abcd	0.00 b
	3	0.75 a	0.13 b	2.95 de	0.13 bcd	0.07 ab
	1	0.75 a	0.22 b	5.91 abc	0.29 abcd	0.00 b
mechanical	7	0.67 ab	0.00 b	2.87 de	0.44 a	0.04 ab
	5	0.27 ab	0.35 b	2.22 e	0.20 abcd	0.02 b
	4	0.40 ab	0.60 b	3.24 bcde	0.31 abc	0.07 ab
	2	0.27 ab	4.15 a	5.04 abcd	0.07 cd	0.00 b
	8	0.78 a	0.91 b	3.89 bcde	0.22 abcd	0.11 a
	6	0.02 b	1.09 b	3.67 bcde	0.27 abcd	0.02 b
manure	15	0.40 ab	0.04 b	4.44 abcde	0.07 bcd	0.02 b
	9	0.00 b	0.80 b	3.09 de	0.15 abcd	0.00 b
	13	0.18 ab	0.00 b	3.20 cde	0.07 bcd	0.00 b
	11	0.13 ab	0.24 b	3.11 de	0.22 abcd	0.00 b
	16	0.62 ab	0.24 b	6.75 a	0.02 d	0.00 b
	10	0.00 b	3.95 a	6.04 ab	0.09 bcd	0.00 b
	14	0.13 ab	1.40 b	5.20 abcd	0.27 abcd	0.00 b
	12	0.13 ab	0.95 b	4.02 abcde	0.35 ab	0.00 b

Table III. Percent ground cover by species. (continued)

Treatment intensity	Treatment	Treatment plot	All vegetation (except clubmoss)	All attached vegetation	Litter	Bare soil
↓	check	18	2.71 ef	86.16 a	6.22 j	0.69 cde
		3	3.18 def	69.26 ab	20.44 ij	5.60 b
		1	6.29 abc	20.12 def	55.67 def	12.89 a
	mechanical	7	3.40 def	41.94 cd	41.00 fgh	1.93 bcde
		5	2.44 f	59.88 bc	30.47 ghi	4.13 bcde
		4	4.84 abcdef	39.50 cd	49.31 efg	1.62 bcde
		2	5.11 abcde	7.12 ef	67.13 bcde	12.29 a
		8	4.31 abcdef	5.34 ef	69.95 bcd	2.51 bcde
		6	4.71 abcdef	13.40 ef	65.73 bcde	1.00 cde
	manure	15	4.53 abcdef	23.70 de	57.42 cdef	4.93 bc
		9	3.69 bcdef	4.14 f	65.67 bcde	4.47 bcd
		13	3.31 def	72.12 ab	24.84 hi	0.40 e
		11	3.60 cdef	16.32 ef	72.31 abcd	1.73 bcde
		16	6.78 a	8.56 ef	80.40 ab	0.55 de
		10	6.38 ab	6.92 ef	77.78 abc	4.09 bcde
		14	5.47 abcd	21.40 def	73.78 abcd	1.02 cde
		12	4.55 abcdef	6.56 ef	91.55 a	0.60 de

was noted as the intensity of mechanical disturbance increased. Such a trend was less distinguishable and non-significant in the manured plots.

As was noted with regard to live clubmoss, plot 13 unaccountably exhibited high dead clubmoss cover. In both instances this cover was comparable with that of check plots 3 and 18.

All Clubmoss

The sum of live and dead clubmoss ground cover reacted essentially the same as both categories considered separately. As mechanical treatments intensified the total clubmoss cover decreased significantly. With one exception, plot 13, all manured plots had significantly less total clubmoss than check plots 3 and 18. However, manuring intensity seemed to have little differential effect upon total clubmoss cover.

Differences of clubmoss cover among subplots within treatments are shown in Table II. The severe reduction of clubmoss cover in areas invaded by crested wheatgrass may explain this. More crested wheatgrass and less clubmoss were encountered on the northern-most row of subplots than on either of the other two rows of subplots.

Significant inverse relationships occurred between total clubmoss cover, and the yield of all clipped vegetation and total vegetative cover, excluding clubmoss (Table IV). Clubmoss cover was also inversely proportional to crested wheatgrass cover and litter cover.

Response of Needle-and-Thread

Ground Cover

None of the mechanically treated plots differed significantly from check plots 3 and 18. Plot 16, which received four 10-ton manure applica-

tions, had a denser needle-and-thread cover than either of the two check plots. However, no discernible trend was found between manuring intensity and ground cover of the species.

A direct relationship was found between needle-and-thread ground cover and the cover contributed by all vegetation, except clubmoss.

Table IV. Correlation coefficients showing the relationships between some major categories estimated from 17 treatment plots.

Relationship between		Correlation coefficient
All clubmoss cover	and All clipped veg. (yield)	-.538 *
" " "	and All veg. cover (no SEDE)	-.697 * *
" " "	and Needle-and-thread yield	-.241
" " "	and Needle-and-thread cover	-.184
" " "	and Blue grama cover	.113
" " "	and Crested wheatgrass cover	-.491 *
" " "	and Litter cover	-.954 * *
" " "	and Bare soil	-.203
Needle-and-thread yield	and All clipped veg. (yield)	.835 * *
" " " cover	and All veg. cover (no SEDE)	.531 *
" " " "	and Needle-and-thread yield	.500 *
" " " yield	and Litter cover	.433
" " " "	and Bare soil	-.683 * *
Litter cover	and All clipped veg. (yield)	.728 * *
" "	and All veg. cover (no SEDE)	.689 * *
" "	and Bare soil	.010
Bare soil	and All clipped veg. (yield)	-.470

* Significant at the .05 probability level.
* * Significant at the .01 probability level.

Weight

Only plot 2, which was seeded to crested wheatgrass, yielded significantly less needle-and-thread than check plot 18 (Tables V and VI). However, no distinct yield pattern evolved from the mechanical treatments. Only plot 12, which received the highest level of manure exhibited a significantly heavier yield of needle-and-thread than check plot 1. Its yield of 1,631 pounds per acre of needle-and-thread was not significantly different from

that of check plot 18. A significantly heavier yield per acre of the species was realized from the most intensively manured plot than from the plot least intensively manured.

As the yield of needle-and-thread increased the yield of all vegetation increased significantly and bare soil decreased.

Response of Blue Grama

Blue grama appeared in all treatment plots. Apparently neither ground cover nor yield of the species was affected by the treatments. Several of the treated plots had less cover contributed by blue grama than check plot 3 but no evident pattern existed. The least intensively mechanically treated plot yielded significantly more blue grama than two of the most heavily manured plots.

Response of Crested Wheatgrass

Ground Cover

Plots 2 and 10 had significantly more crested wheatgrass ground cover than the other plots. This difference reflects the number of transects located in areas dominated by the species. Eight of the nine transects established in plot 2 were located in the crested wheatgrass community while five of the transects of plot 10 were so placed. Very little crested wheatgrass was found on areas exhibiting a needle-and-thread aspect. Crested wheatgrass was encountered neither on the transects nor clip plots on plot 18, the check plot located in the relict area.

Plot 2 was seeded to crested wheatgrass and, except for one small portion, that species dominated the plot. The plot boundaries were virtually defined by the crested wheatgrass aspect (Figure 7).

Table V. Summary of analysis of variance tests on herbage yield.

Variable	Mean Square		
	Error	Among treatments	Among subplots, within treatments
Needle-and-thread	375,750.78	715,174.37	375,149.70
Blue grama	502.08	479.13	451.65
Crested wheatgrass	348,187.94	287,476.81	366,839.67
Western wheatgrass	5,293.84	18,178.83	9,791.49 *
Junegrass	247.30	292.71	301.23
Other perennial grasses	427.99	662.05 *	306.24
Annual grasses	289.33	261.91	336.80
Sedges	163.26	217.30	251.07
Annual and biennial forbs	246.70	1,032.99 * *	348.43
Perennial forbs	481.49	660.90	823.65 *
Fringed sagewort	1,950.08	2,228.15	1,761.65
Winterfat	62.50	82.41	48.88
All clipped veg.	80,991.90	700,165.00 * *	162,028.82 *
Litter	87,822.56	1,763,581.50 * *	144,906.00

* Significant at the .05 probability level.
* * Significant at the .01 probability level.

Table VI. Herbage yield in pounds per acre by species.

Treatment intensity	Treatment plot	Needle-and-thread	Blue grama	Crested wheatgrass	Western wheatgrass	Junegrass
check	18	996.3 abc 1/	5.2 ab	0.0 c	67.5 bc	6.0 ab
	3	640.1 bcd	14.1 ab	243.6 abc	16.3 bc	17.0 ab
	1 2/	804.0 bcd	13.6 ab	235.3 abc	3.6 c	6.4 ab
mechanical	7	890.5 abc	33.2 a	183.1 bc	30.3 bc	11.1 ab
	5	615.8 cd	13.9 ab	246.2 abc	0.7 c	7.6 ab
	4	724.5 bcd	24.7 ab	235.6 abc	22.7 bc	12.9 ab
	2	154.4 d	9.8 ab	977.5 a	0.4 c	0.2 b
	8	1,086.0 abc	25.2 ab	192.0 bc	27.0 bc	11.2 ab
	6	1,011.9 abc	12.0 ab	298.5 abc	33.9 bc	3.4 ab
manure	15	784.7 bcd	16.6 ab	225.6 abc	64.2 bc	16.4 ab
	9	1,025.9 abc	5.4 ab	237.7 abc	53.8 bc	21.7 a
	13	1,003.4 abc	12.1 ab	342.3 abc	51.2 bc	7.3 ab
	11	1,297.8 abc	6.5 ab	259.8 abc	106.8 b	0.0 b
	16	1,329.8 abc	25.0 ab	198.6 bc	65.4 bc	0.0 b
	10	847.0 abcd	1.1 b	692.1 ab	26.2 bc	0.0 b
	14	1,386.7 ab	2.1 b	312.2 abc	227.4 a	0.0 b
	12	1,631.3 a	14.3 ab	313.7 abc	99.9 b	0.0 b

1/ Identical letters indicate no significant yield difference within a given species or other category at the .05 probability level according to the Duncan's multiple range test.

2/ Plot 1 is included as a matter of historical interest. It has been disturbed since being designated a check plot and should not be equated with the other two check plots.

Table VI. Herbage yield in pounds per acre by species. (continued)

Treatment intensity	Treatment plot	Other perennial grasses	Annual grasses	Sedges	Annual and biennial forbs	Perennial forbs
check	18	23.8 abc	0.2 a	11.0 abcd	7.0 cd	10.5 abc
	3	2.3 bc	0.0 a	9.7 abcd	0.1 d	9.2 abc
	1	23.2 abc	0.0 a	16.2 abc	0.7 cd	25.3 abc
mechanical	7	17.9 abc	1.7 a	8.8 abcd	4.1 cd	8.5 abc
	5	4.5 bc	0.0 a	7.8 bcd	0.7 d	27.4 ab
	4	32.5 a	19.5 a	24.9 a	12.1 bcd	15.4 abc
	2	2.0 bc	0.0 a	10.4 abcd	0.1 d	1.2 bc
	8	1.7 bc	11.7 a	10.9 abcd	17.1 bcd	35.9 a
	6	18.1 abc	2.2 a	18.3 ab	20.7 bc	9.5 abc
manure	15	6.1 abc	0.0 a	1.8 cd	11.5 bcd	10.2 abc
	9	25.4 ab	5.1 a	3.8 bcd	29.3 b	4.2 bc
	13	5.2 abc	0.0 a	10.6 abcd	11.3 bcd	12.5 abc
	11	0.6 c	0.0 a	7.3 bcd	14.7 bcd	0.9 bc
	16	6.7 abc	0.1 a	11.3 abcd	17.5 bcd	1.4 bc
	10	1.7 bc	7.3 a	0.2 d	6.2 cd	1.0 bc
	14	1.6 bc	2.1 a	4.7 bcd	9.5 bcd	1.2 bc
	12	4.2 bc	19.2 a	8.4 abcd	52.7 a	0.3 c

Table VI. Herbage yield in pounds per acre by species. (continued)

Treatment intensity	Treatment	plot	Fringed sagewort	Winterfat	All clipped veg.	Litter
	check	18	0.0 b	1.6 b	1,129.3 ef	243.7 f
		3	0.0 b	14.1 a	957.9 f	291.2 ef
		1	0.0 b	1.3 b	1,129.9 ef	319.5 ef
	mechanical	7	0.0 b	0.0 b	1,189.5 def	309.6 ef
		5	0.2 b	0.0 b	925.1 f	288.6 ef
		4	0.0 b	0.0 b	1,125.0 ef	486.6 cdef
		2	0.0 b	7.0 ab	1,163.3 def	488.8 cdef
		8	35.2 ab	0.0 b	1,454.4 cde	545.4 cdef
		6	73.4 a	0.0 b	1,502.4 cd	626.3 cde
	manure	15	0.0 b	0.0 b	1,137.3 def	322.1 ef
		9	0.0 b	0.0 b	1,412.7 cde	805.9 bcd
		13	0.0 b	0.0 b	1,456.5 cde	414.9 def
		11	0.0 b	0.0 b	1,694.8 bc	857.2 bc
		16	0.0 b	0.0 b	1,655.8 bc	1,109.8 b
		10	0.0 b	0.0 b	1,583.1 bc	1,144.8 b
		14	0.1 b	0.0 b	1,948.0 ab	848.1 bc
		12	0.0 b	0.0 b	2,144.4 a	2,460.8 a

No explanation of the extensive crested wheatgrass invasion in plot 10 can be given with certainty. This plot received the most intensive mechanical treatment combined with manure applications in four separate years.

At least one transect in subplot 1 of each treatment plot was located in an area of crested wheatgrass aspect. This probably explains the significant difference in ground cover of the species found among subplots, within treatments.

Weight

Treatment plots yielded crested wheatgrass proportionally to the number of clip plots placed in areas dominated by the species. Only plot 18, from which no crested wheatgrass was harvested, yielded significantly less crested wheatgrass than plots 2 and 10. The great yield variation required to indicate valid differences among treatments is probably the result of variation in the crested wheatgrass harvested among the clip plots in areas of native species and crested wheatgrass aspect.

Response of Western Wheatgrass

One of the most intensively manured plots produced significantly heavier yields of western wheatgrass than any other treatment plot. The remaining treatments did not differ significantly from one another with respect to yield of the species. No distinct pattern between treatment and yield became apparent.

Western wheatgrass was encountered erratically along the transects which suggests an insufficient number of transects to adequately sample this rhizomatous grass.

Response of Annual and Biennial Forbs

Increased intensity of both mechanical and manure treatments apparently favored increased numbers of annual and biennial forbs. Highly significant differences in the weight of these forbs among treatments was indicated in the preliminary analysis of variance and "F" test (Table V). Plot 12, which received the most manure, supported significantly more such forbs than any other treatment plot (Table VI). The lack of forbs on plot 10 can be ascribed to the massive invasion of crested wheatgrass on that plot. In such invaded areas forbs were notably absent.

Response of Other Species

No junegrass appeared in any of the clip plots of the five most intensively manured treatment plots. The species was present in the yield clips of all other treatment plots.

Ground cover contributed by all grass species appeared to increase as treatment intensity increased. Higher but non-significant yields of annual grasses were realized from the more intensively treated plots. No trends were noted in either intercept or yield data of the sedges as a result of treatment.

Perennial forbs produced heaviest yields on the check plots and least intensively treated plots. No perennial forbs were encountered on transects in the seven most intensively manured treatment plots. In addition, no perennial forbs were intercepted on two of the check plots nor on one of the mechanically treated plots. This may reflect only the relatively small basal area contributed by perennial forbs and thus a low probability of basal interception by the transects.

Considerably heavier yields of fringed sagewort (Artemisia frigida) were obtained from the two plots which received the most intensive mechanical treatments. While check plot 3 produced significantly more winterfat than any other plot, only the check plots and one mechanically treated plot yielded any winterfat from the clip plots.

Response of Total Vegetation

A distinct and significant increase of the weight of all vegetation, (excluding clubmoss) occurred as treatment intensity increased. A similar but non-significant trend appeared to be indicated by ground cover data. When all vegetation, including clubmoss, was compared the reverse situation occurred. As treatment intensity increased the ground cover contributed by total attached vegetation decreased significantly.

Herbage yields per individual plot during five of the years in which treatments were being applied and in 1947 and 1965 appear in Table VII. Yield data among years are probably not comparable due to differences in harvesting methods. During the treatment period mowing occurred at some height above ground level while clip plots were harvested at ground level in 1965. Low-growing species may have therefore contributed proportionately more to the 1965 clippings than to the earlier yields.

Litter

The presence or absence of plant litter above the soil can greatly affect a plant community. Litter might indicate relative amounts of material potentially useful for incorporation into new vegetation. Soil structure and water loss by runoff and evaporation are directly affected by litter. Extreme microhabitat temperatures are modified and periods of seed

Table VII. Herbage yield in pounds dry matter per acre.

Treatment intensity		Treatment plot	1927	1929	1932	1933	1935	1947	1965
↓	check	18 1/							1,129
		3	395	23	69	26	47	564	958
		1	180	23	59	23	30	168	1,130
	mechanical	7	620	83	158	66	33	300	1,190
		5	940 2/	248	383	132	64	312	925
		4	740	182	541	238	69	456	1,125
		2	295	92	383	337	111	429	1,163
		8	620	158	449	188	44	540	1,454
		6	940	356	739	350	61	588	1,502
	manure	15	760	99	119	73	125	360	1,137
		9	2,230	403	323	178	42	396	1,413
		13	1,550	310	152	109	50	336	1,457
		11	2,540	1,069	832	429	136	996	1,695
		16	760	162	525	264	327	486	1,656
		10	2,230	1,010	1,241	495	108	870	1,583
		14	1,550	614	686	409	185	870	1,948
		12	2,540	1,023	1,538	620	228	1,092	2,144

1/ Plot 18 was set aside in 1965 as a check plot.
2/ Yields from paired plots 5 and 6 through 15 and 16 were not separated in 1927.

germination and plant growth changed according to the amount of litter present (Daubenmire, 1962; Dyksterhuis and Schmutz, 1947; Humphrey, 1962 and Weaver and Rowland, 1952). Litter accumulation can therefore affect speciation as well as herbage yield.

Ground Cover

Highly significant differences in litter cover among treatments were found. As treatment intensity increased litter cover tended to increase.

A direct relationship was found between litter cover and yield of all clipped vegetation and all vegetative cover, excluding clubmoss.

Weight

Litter weight also varied directly with intensity of treatment. The weight of litter from heavily manured plots was significantly greater than litter yields from less intensively manured plots.

Bare Soil

The amount of bare soil intercepted by the transects varied considerably. Significant differences were indicated among treatments and among subplots within treatments. No particular relationship between the amount of bare soil and treatment intensity became evident.

Protein Content of the Vegetation

Crude protein of the combined grasses ranged from 4.5 to 5.8 percent (Table VIII). Non-grass species in the treated plots contained from 6.4 to 8.8 percent crude protein. There appears to be no pattern between the protein content of the vegetation and treatment.

Table VIII. Crude protein content of grass and non-grass species (percent).

Treatment intensity		Treatment plot	All grass species	All non-grass species
	check	18	5.8	7.9
		3	5.3	8.1
		1	5.0	6.4
	mechanical	7	5.4	7.6
		5	5.2	7.0
		4	5.2	6.9
		2	4.5	6.9
		8	5.3	6.6
		6	4.9	7.0
	manure	15	5.2	7.3
		9	5.3	6.8
		13	5.3	6.6
		11	5.5	9.0
		16	5.7	8.3
		10	4.8	6.8
		14	5.6	8.8
↓		12	4.7	5.7

SUMMARY AND CONCLUSIONS

After 30 years the effects of mechanical treatments to native range could still be observed by reduced live and dead clubmoss ground cover. Less clubmoss was present on plots which received the most intensive mechanical treatments. Manure applications reduced live and dead clubmoss cover but treatment intensity did not produce significant differences among manured plots.

A significant and inverse relationship occurred between clubmoss cover present on all treated areas and the yield and ground cover contributed by all other vegetation.

An erratic pattern occurred between needle-and-thread ground cover and treatments. Heaviest yields of needle-and-thread were realized from the treatment plots which received the heaviest applications of manure. Direct, significant correlations occurred between yield of needle-and-thread and total yield, and between needle-and-thread cover and cover contributed by all vegetation, excluding clubmoss. As the yield of needle-and-thread increased the occurrence of bare soil decreased significantly.

No significant yield or cover differences of blue grama occurred as a result of treatment.

Crested wheatgrass exhibited no significant increased yield resulting from increased treatment intensity, but a significant inverse relationship was found between crested wheatgrass cover and clubmoss cover.

Western wheatgrass responded favorably to three of the most intensive manure treatments.

As treatment intensity increased the yield of annual and biennial forbs increased.

No junegrass occurred on any of the five most intensively manured plots although it was present in the herbage samples of every other treatment plot.

Highly significant increases in litter cover and yield were found with increased treatment intensity. This increased litter was associated with increased forage productivity.

Treatment did not affect the protein content of the vegetation.

Since the data showed reduced clubmoss cover and increased forage production even 30 years after the last treatment was applied, such renovation practices appear promising in areas where clubmoss is a problem. The long-term response of clubmoss and range in general to such treatments under grazing should now be investigated. The ecological and economical implications of such long-term studies are obvious.

APPENDIX

Appendix Table I. Yearly precipitation distribution at North Montana Branch Station since 1916.

Precipitation (inches)	Year	Total years
7.01 - 8.00	1919, 1935, 1936, 1949, 1961	5
8.01 - 9.00	1918, 1926, 1930, 1931, 1952, 1960, 1963	7
9.01 - 10.00	1934, 1946, 1948, 1956	4
10.01 - 11.00	1922, 1937, 1939, 1944, 1945, 1947, 1957, 1962	8
11.01 - 12.00	1916, 1917, 1920, 1928, 1943, 1955, 1958, 1964	8
12.01 - 13.00	1929, 1940, 1950, 1953	4
13.01 - 14.00	1921, 1924, 1941, 1951	4
14.01 - 15.00	1942, 1954, 1959	3
15.01 - 16.00	1932, 1933, 1938	3
16.01 - 17.00	1923	1
17.01 - 18.00	1925	1
18.01 - 19.00		0
19.01 - 20.00	1927	1

Appendix Table II. Average monthly wind velocity (N. M. B. S.)[1/].

Month	Velocity (M. P. H.)
January	7.1
February	6.6
March	6.6
April	7.0
May	6.5
June	5.8
July	5.2
August	5.0
September	5.4
October	5.9
November	6.4
December	6.9

1/ Forty-eight year average from N. M. B. S. climatological records.

Appendix Table III. Average monthly evaporation (N. M. B. S.)[1/].

Month	Evaporation (inches)
April	4.8
May	9.3
June	9.7
July	10.2
August	11.2
September	6.9

1/ Fifteen year average from a free water surface at N. M. B. S.

Appendix Table IV. Transect locations.

Plot	Subplot	Transect	Coordinates		Distance from NW corner		Code
			Rank	File	Feet S.	Feet E.	
1	1	1	2	5	12	33.0	1 0 1 1 2
		2	7	7	42	46.2	1 0 1 2 1
		3	8	6	48	39.6	1 0 1 3 1
	2	1	4	6	24	39.6	2 0 1 1 3
		2	5	7	30	46.2	2 0 1 2 3
		3	6	8	36	52.8	2 0 1 3 3
	3	1	1	5	6	33.0	3 0 1 1 1
		2	3	7	18	46.2	3 0 1 2 1
		3	7	8	42	52.8	3 0 1 3 1
2	1	1	2	8	12	52.8	1 0 2 1 2
		2	3	6	18	39.6	1 0 2 2 2
		3	7	5	42	33.0	1 0 2 3 2
	2	1	1	5	6	33.0	2 0 2 1 2
		2	5	6	30	39.6	2 0 2 2 2
		3	6	8	36	52.8	2 0 2 3 2
	3	1	1	6	6	39.6	3 0 2 1 2
		2	5	7	30	46.2	3 0 2 2 2
		3	7	2	42	13.2	3 0 2 3 1
3	1	1	2	8	12	52.8	1 0 3 1 2
		2	5	8	30	52.8	1 0 3 2 1
		3	6	6	36	39.6	1 0 3 3 1
	2	1	1	3	6	19.8	2 0 3 1 1
		2	3	6	18	39.6	2 0 3 2 1
		3	7	4	42	26.4	2 0 3 3 1
	3	1	2	6	12	39.6	3 0 3 1 1
		2	4	4	24	26.4	3 0 3 2 3
		3	7	2	42	13.2	3 0 3 3 3

Appendix Table IV. Transect locations. (continued)

Plot	Subplot	Transect	Coordinates		Distance from NW corner		Code
			Rank	File	Feet S.	Feet E.	
4	1	1	3	6	18	39.6	1 0 4 1 2
		2	7	4	42	26.4	1 0 4 2 1
		3	8	7	48	46.2	1 0 4 3 1
	2	1	3	8	18	52.8	2 0 4 1 1
		2	5	7	30	46.2	2 0 4 2 3
		3	8	1	48	6.6	2 0 4 3 1
	3	1	3	3	18	19.8	3 0 4 1 3
		2	4	8	24	52.8	3 0 4 2 3
		3	5	6	30	39.6	3 0 4 3 3
5	1	1	3	5	18	33.0	1 0 5 1 2
		2	5	4	30	26.4	1 0 5 2 1
		3	8	4	48	26.4	1 0 5 3 1
	2	1	1	4	6	26.4	2 0 5 1 1
		2	5	5	30	33.0	2 0 5 2 1
		3	6	3	36	19.8	2 0 5 3 1
	3	1	2	6	12	39.6	3 0 5 1 1
		2	4	5	24	33.0	3 0 5 2 1
		3	6	6	36	39.6	3 0 5 3 1
6	1	1	2	4	12	26.4	1 0 6 1 2
		2	6	8	36	52.8	1 0 6 2 1
		3	7	8	42	52.8	1 0 6 3 1
	2	1	3	1	18	6.6	2 0 6 1 1
		2	3	8	18	52.8	2 0 6 2 1
		3	7	8	42	52.8	2 0 6 3 1
	3	1	5	4	30	26.4	3 0 6 1 1
		2	5	5	30	33.0	3 0 6 2 1
		3	6	2	36	13.2	3 0 6 3 3

Appendix Table IV. Transect locations. (continued)

Plot	Subplot	Transect	Coordinates		Distance from NW corner		Code
			Rank	File	Feet S.	Feet E.	
7	1	1	3	8	18	52.8	1 0 7 1 1
		2	5	6	30	39.6	1 0 7 2 1
		3	8	5	48	33.0	1 0 7 3 1
	2	1	3	5	18	33.0	2 0 7 1 1
		2	7	2	42	13.2	2 0 7 2 1
		3	8	4	48	26.4	2 0 7 3 1
	3	1	2	3	12	19.8	3 0 7 1 1
		2	3	1	18	6.6	3 0 7 2 1
		3	6	4	36	26.4	3 0 7 3 2
8	1	1	2	4	12	26.4	1 0 8 1 2
		2	2	6	12	39.6	1 0 8 2 2
		3	8	7	48	46.2	1 0 8 3 1
	2	1	1	7	6	46.2	2 0 8 1 3
		2	3	3	18	19.8	2 0 8 2 1
		3	6	5	36	33.0	2 0 8 3 1
	3	1	3	6	18	39.6	3 0 8 1 1
		2	5	1	30	6.6	3 0 8 2 1
		3	7	2	42	13.2	3 0 8 3 1
9	1	1	7	6	42	39.6	1 0 9 1 3
		2	8	3	48	19.8	1 0 9 2 3
		3	8	6	48	39.6	1 0 9 3 3
	2	1	1	3	6	19.8	2 0 9 1 3
		2	8	2	48	13.2	2 0 9 2 1
		3	8	7	48	46.2	2 0 9 3 1
	3	1	1	2	6	13.2	3 0 9 1 3
		2	2	5	12	33.0	3 0 9 2 1
		3	6	4	36	26.4	3 0 9 3 1

Appendix Table IV. Transect locations. (continued)

Plot	Subplot	Transect	Coordinates		Distance from NW corner		Code
			Rank	File	Feet S.	Feet E.	
10	1	1	4	1	24	6.6	1 1 0 1 2
		2	4	3	24	19.8	1 1 0 2 2
		3	7	1	42	6.6	1 1 0 3 2
	2	1	4	2	24	13.2	2 1 0 1 2
		2	5	1	30	6.6	2 1 0 2 2
		3	8	6	48	39.6	2 1 0 3 3
	3	1	1	7	6	46.2	3 1 0 1 1
		2	5	4	30	26.4	3 1 0 2 1
		3	7	3	42	19.8	3 1 0 3 1
11	1	1	3	3	18	19.8	1 1 1 1 2
		2	6	5	36	33.0	1 1 1 2 3
		3	8	2	48	13.2	1 1 1 3 3
	2	1	1	1	6	6.6	2 1 1 1 1
		2	4	8	24	52.8	2 1 1 2 1
		3	7	7	42	46.2	2 1 1 3 1
	3	1	3	3	18	19.8	3 1 1 1 1
		2	5	8	30	52.8	3 1 1 2 1
		3	6	6	36	39.6	3 1 1 3 1
12	1	1	2	7	12	46.2	1 1 2 1 2
		2	6	3	36	19.8	1 1 2 2 3
		3	7	3	42	19.8	1 1 2 3 3
	2	1	6	6	36	39.6	2 1 2 1 3
		2	8	4	48	26.4	2 1 2 2 1
		3	8	8	48	52.8	2 1 2 3 1
	3	1	1	3	6	19.8	3 1 2 1 1
		2	1	7	6	46.2	3 1 2 2 1
		3	4	7	24	46.2	3 1 2 3 1

Appendix Table IV. Transect locations. (continued)

Plot	Subplot	Transect	Coordinates		Distance from NW corner		Code
			Rank	File	Feet S.	Feet E.	
13	1	1	5	4	30	26.4	1 1 3 1 1
		2	5	6	30	39.6	1 1 3 2 3
		3	7	2	42	13.2	1 1 3 3 1
	2	1	3	8	18	52.8	2 1 3 1 1
		2	5	6	30	39.6	2 1 3 2 1
		3	7	6	42	39.6	2 1 3 3 1
	3	1	1	3	6	19.8	3 1 3 1 1
		2	4	7	24	46.2	3 1 3 2 1
		3	6	5	36	33.0	3 1 3 3 1
14	1	1	2	5	12	33.0	1 1 4 1 2
		2	6	1	36	6.6	1 1 4 2 1
		3	7	3	42	19.8	1 1 4 3 1
	2	1	5	3	30	19.8	2 1 4 1 1
		2	5	6	30	39.6	2 1 4 2 1
		3	7	8	42	52.8	2 1 4 3 1
	3	1	1	8	6	52.8	3 1 4 1 1
		2	3	3	18	19.8	3 1 4 2 1
		3	3	7	18	46.2	3 1 4 3 1
15	1	1	1	7	66	46.2	1 1 5 1 2
		2	4	7	24	46.2	1 1 5 2 1
		3	6	3	36	19.8	1 1 5 3 1
	2	1	5	2	30	13.2	2 1 5 1 1
		2	6	5	36	33.0	2 1 5 2 1
		3	8	8	48	52.8	2 1 5 3 1
	3	1	1	4	6	26.4	3 1 5 1 1
		2	4	4	24	26.4	3 1 5 2 1
		3	4	6	24	39.6	3 1 5 3 1

Appendix Table IV. Transect locations. (continued)

Plot	Subplot	Transect	Coordinates		Distance from NW corner		Code
			Rank	File	Feet S.	Feet E.	
16	1	1	7	2	42	13.2	1 1 6 1 1
		2	8	3	48	19.8	1 1 6 2 1
		3	8	7	48	46.2	1 1 6 3 3
	2	1	2	4	12	26.4	2 1 6 1 1
		2	2	6	12	39.6	2 1 6 2 1
		3	8	8	48	52.8	2 1 6 3 1
	3	1	1	4	6	26.4	3 1 6 1 1
		2	2	2	12	13.2	3 1 6 2 1
		3	2	5	12	33.0	3 1 6 3 1
18	1	1	2	3	12	19.8	1 1 8 1 1
		2	6	5	36	33.0	1 1 8 2 1
		3	7	2	42	13.2	1 1 8 3 1
	2	1	4	4	24	26.4	2 1 8 1 1
		2	6	1	36	6.6	2 1 8 2 1
		3	8	7	48	46.2	2 1 8 3 1
	3	1	1	1	6	6.6	3 1 8 1 1
		2	5	8	30	52.8	3 1 8 2 1
		3	6	6	36	46.2	3 1 8 3 1

Appendix Table V. Transect coding key.

1st Digit	Subplot 1 - North 3 - South
2nd & 3rd Digits	Plot 01 - West 16 - East 18 - Check
4th Digit	Transect Number 1 - North 3 - South
5th Digit	Vegetative Aspect 1 - Native Vegetation 2 - Crested Wheatgrass 3 - Ecotone (Between native vegetation and crested wheatgrass)

Appendix Table VI. Intercept type code.

Type	Description	
10	Perennial grasses	
11	Annual grasses	
12	Sedges, rushes, and grass-like plants	
13	Annual forbs	
14	Biennial forbs	
15	Perennial forbs	
16	Half-shrubs	
17	Shrubs	
18	Trees	
19	Miscellaneous vegetation	
	SEDE-A	Live clubmoss
	SEDE-D	Dead clubmoss
	Lich	Lichens
	HYME	Toadstools
	M	Moss
	L	Litter
21	Feces	
22	Cow feces	
23	Sheep feces	
24	Horse feces	
25	Rodent and rabbit feces	
31	Bare soil	
32	Erosion pavement	
33	Rock	

Appendix Table VII. Clip plot coding key.

1st Digit	Subplot 1 - North 3 - South
2nd & 3rd Digits	Plot 01 - West 16 - East 18 - Check
4th Digit	Clip plot Number 1 - North 2 - South
5th Digit	Vegetative Aspect 1 - Native Vegetation 2 - Crested Wheatgrass

Appendix Table VIII. Presence of species in 21 areas [1/].

Species	Areas																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Selaginella densa																					
Sod of native species	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sod of crested wheatgrass	X	X	X	X	X	X	X	X		X			X	X	X	X					
GRASS																					
Agropyron cristatum	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X		
Agropyron smithii	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Agropyron spicatum																	X		X		
Andropogon scoparius																			X		
Bouteloua gracilis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Bromus tectorum	X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
Calamagrostis montanensis			X	X				X										X	X		
Calamovilfa longifolia																			X		
Festuca octoflora						X		X			X	X			X	X					
Koeleria cristata	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Muhlenbergia cuspidata	X	X								X							X		X	X	
Poa pratensis																					X
Poa secunda	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Sitanion hystrix										X			X		X				X		X
Stipa comata	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Stipa viridula												X									X

1/ Areas 1 through 16 and 18 correspond to the treatment plots of the same number.
Area 17: an area of Zahl loam, 4 to 8 percent slope within the relict.
Area 19: a 30 percent north-facing slope of Zahl-Sunburst clay loam.
Area 20: a 25 percent south-facing slope of Zahl-Sunburst clay loam.
Area 21: swale bottom of Zahl-Sunburst clay loam.

Appendix Table VIII. Presence of species in 21 areas. (continued)

Species	Areas																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
SEDGES																					
Carex eleocharis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Carex filifolia																	X	X	X	X	
FORBS																					
Achillea millefolium								X											X		X
Alyssum alyssoides	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Antennaria rosea	X				X				X		X		X				X	X	X	X	
Artemisia ludoviciana																			X	X	X
Aster canescens																			X		X
Astragalus pectinatus		X													X			X	X	X	
Astragalus purshii			X		X		X	X	X						X		X	X	X		
Chenopodium album	X			X	X	X	X	X		X	X	X		X	X	X	X	X		X	
Chrysopsis villosa										X	X								X	X	
Cirsium undulatum																			X	X	
Comandra umbellata																	X		X		
Glycyrrhiza lepidota																					X
Grindelia squarrosa																					X
Haplopappus spinulosus	X				X	X	X						X		X	X	X	X	X		
Hedeoma hispida																			X		
Lactuca ludoviciana	X		X	X		X	X	X	X	X	X	X	X	X	X	X				X	X
Liatris punctata																X	X	X	X	X	
Linum lewisii	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	
Lygodesmia juncea	X																			X	
Mamillaria vivipara		X																X			
Melilotus officinalis																			X		
Opuntia polycantha	X	X	X	X	X		X	X	X	X		X	X	X		X	X	X		X	

Appendix Table VIII. Presence of species in 21 areas. (continued)

Species	Areas																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
FORBS																					
Penstemon radicosus																			X		
Petalostemon purpureum	X																		X		
Phlox hoodii	X	X	X	X	X	X	X	X	X				X		X	X	X	X	X	X	
Phlox longifolia																			X		
Plantago purshii	X		X	X	X	X	X	X			X		X		X		X	X		X	
Potentilla concinna																			X		
Psoralea argophylla	X																		X	X	
Salsola kali	X			X				X		X		X	X		X	X	X		X	X	
Sisymbrium altissimum			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
Solidago missouriensis																			X		X
Solidago occidentalis																					X
Sphaeralcea coccinea	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	
Tragopogon dubius	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Townsendia hookeri																			X		
Urtica dioica																					X
Vicia americana																	X	X			
HALF-SHRUBS																					
Artemisia drancunculus																	X				
Artemisia frigida	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Eurotia lanata	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X			
Gutierrezia sarothrae	X																		X		
SHRUBS																					
Artemisia cana		X											X			X	X	X	X	X	X

Appendix Table VIII. Presence of species in 21 areas. (continued)

Species	Areas																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
SHRUBS																					
Atriplex nuttallii			X						X	X						X	X	X			
Juniperus horizontalis																			X		
Rosa arkansana																	X		X		
Rosa sp.																					X
Symphoricarpos occidentalis																					X

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