Seasonal pattern of growth and regrowth of Stipa viridula Trin. as affected by fertilization and clipping

by Larry Melvin White

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Agronomy
Montana State University

Abstract:
The effects of nitrogen (N) fertilization and clipping frequency upon the performance of Stipa viridula grown in the field were studied over a 2-year period (1969-1970). Factorial combinations of N and clipping treatments were arranged in a randomized complete-block design with two replications. Nitrogen, in ammonium nitrate form, was applied at rates of 0, 70, and 140 kg/ha in November 1968. The two clipping frequency treatments were (1) nonclipped and (2) clipped five times at 21-day intervals to a 5-cm height. During 1969, measurements were made at 10-day intervals of (1) plant upstretched-leaf and head heights, (2) dry matter yield, (3) percentage of crude protein and plant phosphorus (P), (4) extraction of soil water, and (5) evapotranspiration (ET). Additional measurements made in 1969 were (1) date of tiller initiation, (2) ratio of floral to vegetative tillers, (3) plant development, (4) soil fertility, (5) total crude protein and plant P yield, (6) N fertilizer recovery, and (7) water-use efficiency, Residual effects of the 1969 treatments were determined by measuring head heights and dry matter yields in 1970.

Over half of the floral tillers present July 2, 1969, had started growth the previous autumn. Developmental stages of floral tillers initiated in the spring were reached about 4 weeks later than comparable stages of autumn-initiated tillers. The percentage of floral tillers was higher for autumn-initiated tillers than for spring-initiated tillers.

Precipitation received the last 'of June 1969 increased, during July 1969, (1) percentage of crude protein and plant P and (2) growth rate of clipped plants.

Soil and plant factors measured in 1969 and 1970 indicated that doubling the N fertilization rate (from 70 to 140 kg of N/ha) had few advantages. Nitrogen fertilization had no differential influence on dates when successive plant developmental stages occurred. On both clipped and nonclipped plots, N fertilization increased (1) dry matter yield and (2) percentage and total yield of both crude protein and plant P. Nitrogen fertilization also increased soil nitrate-nitrogen (NO_3-N), extraction of soil water., and water-use efficiency. During 1970, residual N fertilizer increased dry matter yield and head height.

Clipping reduced dry matter yield, ET, and water-use efficiency. Clipping (1) increased percentage and total yield of both crude protein and plant P and (2) extended the plant growth period. Clipping had no effect on extraction of soil water. Duping 1970, dry matter yield and head height, were reduced as a result of 1969 clipping treatment.

In presenting this thesis in partial fulfillment of the requirements for an advanced degree at Montana State University, I agree that the Library shall make it freely available for inspection. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by my major professor, or, in his absence, by the Director of Libraries. It is understood that any copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Signature Larry M. White

Date February 27, 1971

SEASONAL PATTERN OF GROWTH AND REGROWTH OF STIPA VIRIDULA TRIN.

AS AFFECTED BY FERTILIZATION AND CLIPPING

by

LARRY MELVIN WHITE

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

of

MASTER OF SCIENCE

in

Agronomy

Approved:

Head, Major Department

Co-chairman, Examining Committee

Co-chairman, Examining Committee

Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

March 1971

ACKNOWLEDGMENT

The author would like to express a sincere thanks to Drs. C. S. Cooper and J. H. Brown for their assistance in planning and reviewing this project; also for the help of the other committee members, Drs. I. K. Mills and G. F. Payne. A special thanks to the Agricultural Research Service team, Drs. A. R. Grable, F. H. Siddoway, J. R. Wight, and Mr. A. L. Black, for their assistance and suggestions in planning and reviewing this work. The author also wishes to thank the Agricultural Research Service, Soil and Water Conservation Research Division, Northern Plains Soil and Water Research Center for providing the funds to conduct this project. The author would like to thank especially his patient and understanding wife, Gail White, and secretary, M. Marilyn Potter, for their typing and corrections to this thesis.

TABLE OF CONTENTS

Table of Contents--continued

Table of Contents--continued

LIST OF TABLES

List of Tables--continued

LIST OF FIGURES

List of Figures--continued

ABSTRACT

The effects of nitrogen (N) fertilization and clipping frequency upon the performance of Stipa viridula grown in the field were studied over a 2-year period (1969-1970). Factorial combinations of N and clipping treatments were arranged in a randomized complete-block design with two replications. Nitrogen, in ammonium nitrate form, was applied at rates of 0, 70, and 140 kg/ha in November 1968. The two clipping frequency treatments were (1) nonclipped and (2) clipped five times at 21-day intervals to a 5-cm height. During 1969, measurements were made at 10-day intervals of (1) plant upstretched-leaf and head heights, (2) dry matter yield, (3) percentage of crude protein and plant phosphorus (P), (4) extraction of soil water, and (5) evapotranspiration (ET). Additional measurements made in 1969 were (1) date of tiller initiation, (2) ratio of floral to vegetative tillers, (3) plant development, (4) soil fertility, (5) total crude protein and plant P yield, (6) N fertilizer recovery, and (7) water-use efficiency. Residual effects of the 1969 treatments were determined by measuring head heights and dry matter yields in 1970.

Over half of the floral tillers present July 2, 1969, had started growth the previous autumn. Developmental stages of floral tillers initiated in the spring were reached about 4 weeks later than comparable stages of autumn-initiated tillers. The percentage of floral tillers was higher for autumn-initiated tillers than for spring-initiated tillers.

Precipitation received the last of June 1969 increased, during July 1969, (1) percentage of crude protein and plant P and (2) growth rate of clipped plants.

Soil and plant factors measured in 1969 and 1970 indicated that doubling the N fertilization rate (from 70 to 140 kg of N/ha) had few advantages. Nitrogen fertilization had no differential influence on dates when successive plant developmental stages occurred. On both clipped and nonclipped plots, N fertilization increased (1) dry matter yield and (2) percentage and total yield of both crude protein and plant P. Nitrogen fertilization also increased soil nitrate-nitrogen (NO_3-N), extraction of soil water, and water-use efficiency. During 1970, residual N fertilizer increased dry matter yield and head height.

Clipping reduced dry matter yield, ET, and water-use efficiency. Clipping (1) increased percentage and total yield of both crude protein and plant P and (2) extended the plant growth period. Clipping had no effect on extraction of soil water. During 1970, dry matter yield and head height were reduced as a result of 1969 clipping treatment.

INTRODUCTION

In the northern Great Plains, grazing has reduced *Stipa viridula*[1], a palatable and productive native species (20), on millions of hectares of native rangeland. The presence or absence of this species, an important component of climax vegetation, is considered a prime indicator of range condition. To increase the prevalence of this valuable species on native rangeland, more information is needed about the effects of nitrogen (N) fertilization and clipping frequency on its growth, vigor, and survival.

Fertilization is a promising method for range improvement. Rogler and Lorenz (60) stated that "two years of fertilization . . . at the 90 pound (101 kg/ha) rate of nitrogen did more to improve range condition and production than six years of complete isolation from grazing." Fertilization of native range in the northern Great Plains has resulted in variable success, however. Environment, soil fertility, and management practices often determine its effectiveness.

Major benefits could be obtained by improving range condition. Ryerson, Taylor, and Quenemoen (63) estimated that, in the eastern two-thirds of Montana, nearly 7.7 million hectares of rangeland are in the fair to poor condition class. Improvement of this rangeland to the good condition class would increase the livestock carrying capacity by

---

[1]See Table 16 (appendix) for common names of plant species mentioned.

50%, or approximately 0.25 animal unit months per hectare, and would result in about 6.6 million dollars additional income from livestock production. Improvement of range condition would also help reduce erosion and increase water infiltration.

Fertilization may or may not alleviate the effects of overgrazing. In Saskatchewan, Canada, Heinrichs and Clark (27) observed severe winterkill on frequently clipped, nonfertilized plots of Stipa viridula. With N and phosphorus (P) fertilization, however, frequent clipping decreased only ground cover. In Indiana, high rates of N fertilization caused severe stand reductions of Dactylis glomerata (57%) when clipped to a 5-cm stubble height (23). The results from clipping and fertilization experiments are variable and not well understood.

In the fall of 1968, we initiated a study to determine how frequent clipping (simulated heavy grazing) would affect the growth of Stipa viridula when fertilized with moderate rates of N. Plant growth, development, and morphology were studied throughout a growing season, and the effects of treatments on forage quality and quantity were evaluated. Residual effects of the treatments were evaluated the year following treatment.

LITERATURE REVIEW

Range Fertilization (Northern Great Plains)

The northern Great Plains extend northward from approximately the Nebraska-South Dakota border into southern Saskatchewan and Alberta. Grasses have flourished and persisted in this area for centuries. Soil fertility determines which species dominate grasslands and affects the growth and vigor of those species and their value in the diet of grazing animals.

Northern Great Plains fertilization research began in 1925 at the North Montana Branch Station at Havre (25). Barnyard manure was applied at a rate of 22.4 tons/ha to native prairie sites in various intervals of years. When measured in 1927, dry matter production was improved, and residual effects of more than four applications of manure in a 10-year period were still apparent in 1947. Dry matter yield of *Stipa comata* and *Agropyron smithii* was still increased 30 years after the last of 10 yearly applications of manure (18). At Manyberries, Alberta, application of 27 tons/ha of manure during 1928 doubled dry matter production 11 years later (14).

Mineral Nutrients. Range grasses have seldom responded to applications of micronutrients. On soils from seven different parent materials in Colorado, native range vegetation did not respond to applications of micronutrients such as iron, manganese, boron, zinc, copper, molybdenum, or cobalt nor to macronutrients such as calcium, magnesium or sulfur applied alone (59).

Sulfur (S) fertilization with N on rangeland in the northern Great Plains has generally not increased dry matter yield (57). Throughout the Great Plains, analyses of the soil organic matter showed that N:S ratios varied with particular soils from 6:1 to 12:1 (72). Under normal growing conditions, soil supplies adequate S for plant growth, but high rates of N often cause a N:S ratio in plant tissue greater than 17:1--at which point S may limit plant growth (72).

Potassium increased growth of grass species grown on soils originating from granite in Colorado (59) and increased grass root growth at Mandan, North Dakota (24). However, potassium is seldom limiting in the northern Great Plains (67).

Plants growing on P-deficient soils derived from glacial till did not respond to P fertilization alone (38). Phosphorus fertilization increased the response to increasing increments of N.

Loneragan (45) stated that N fertilization ". . . is especially important because of the severity and widespread nature of nitrogen deficiency in grasslands . . . ." In his review of N fertilization, Taylor (73) concluded that N fertilization increased total dry matter yield in nearly all experiments but that economic returns were borderline between profit and loss for low to moderate rates of N application.

Species composition changes. Nitrogen fertilization may favorably or unfavorably affect species composition. It has been shown to increase growth and prevalence of cool-season grasses (e.g., Agropyron smithii) and decrease prevalence of warm-season grasses (e.g., Bouteloua gracilis) in North Dakota (60). In Alberta, Canada, N fertilization decreased Bouteloua gracilis, Stipa comata, Koeleria cristata, and Selaginella densa; and it increased Agropyron smithii, Agropyron dasystachyum, Artemisia frigida, Hordeum jubatum, and many weed species (35). Also in Alberta, Canada, N fertilization decreased Danthonia parryi and other species, while it increased Festuca scabrella (34, 69).

Forage quality. Nitrogen fertilization often increases percentage of crude protein in forage (58, 61, 70). Nitrogen fertilization alone decreased percentage of forage P (dilution) in North Dakota (67) and Colorado (39), but N-P fertilization increased both percentage of forage crude protein and P in Montana (4) and Alberta, Canada (70). In Alberta, Canada, N fertilization has frequently increased palatability of forage (35, 69) and decreased percentage of silica (3, 37). Low silica content reduces the incidence of silica urolithiasis (urinary calculi) in cattle, especially in the northern Great Plains (3). On Alberta, Canadian rangelands, Bezeau et al. (3) found that N-P fertilization had not affected the in vitro digestible cellulose of forage. Other studies have shown that N fertilization increased digestible dry matter yield, but this was due to increased dry matter yield rather than increased in vitro digestibility (10).

Nitrates may accumulate in forage and cause nitrate poisoning of livestock when high rates of N are applied (44). With a yearly application of more than 225 kg of N/ha, toxic nitrate levels (greater than 2,000 ppm) occurred in *Agropyron intermedium* forage (44). *Stipa viridula* forage has also contained toxic amounts of nitrates when grown with high rates of N (11).

Root weight and depth. A productive plant grown under dryland conditions, needs a root system capable of removing most of the available soil water. Nitrogen fertilization increases top growth and affects root growth. Troughton (79), after a thorough review of the effect of N on root growth, concluded that low N rates increased root growth but moderate to high N rates decreased root growth. Similar results were noted in the northern Great Plains. In North Dakota, annual applications of 100 kg of N/ha increased the quantity of *Agropyron cristatum* and *Elymus junceus* roots, not only in the surface 30 cm but below that depth as well (24). Also in North Dakota, *Elymus junceus* dry matter yield increased with N rates up to 450 kg/ha. Root weight, however, increased with N rates only up to 225 kg/ha, and most of the root weight increase occurred in the upper 15 cm of soil (46). With annual applications of 34 kg of N/ha to North Dakota native range, the greatest increase of total root weight also occurred in the upper 15 cm of soil, while applications of 100 kg of N/ha caused no further increase in root weight but tripled dry matter production (47, 48).

In North Dakota, N fertilization generally increases root weight in the upper 15 cm of soil, even though its effects on root weight differ with range sites (21).

Water-use efficiency. Viets (80) defined water-use efficiency as weight of dry matter of marketable crop produced per unit volume of water used in evapotranspiration (ET). Total ET equals soil water depletion plus precipitation received during the period from initiation of plant growth until harvest. Increased water-use efficiency occurs when the dry matter yield increase is proportionally greater than the increase in the amount of water used.

Water use is more efficient in dryland than in irrigated crops but at much lower levels of production (80). Nitrogen fertilizer increases water-use efficiency more in low than in high fertility soils (8). Smika et al. (66) found that water-use efficiency increased as available soil water (20 to 46 cm) and N fertilization rate (0 to 160 kg of N/ha) increased. In general, N fertilization had (1) increased water use from depths lower than 60 cm (4, 60, 66, 68) and (2) increased soil water extraction in the 0- to 15-cm depth (76) and the 0- to 90-cm depth (5).

On rangeland, N fertilization usually increases water-use efficiency. For example, a water-use efficiency of 25 kg/ha-cm for check plots was increased 1.6-, 2.1, 3.5-, and 4.2-fold with the application of 22.4, 44.8, 89.6, and 179.2 kg of N/ha, respectively, on an overgrazed range in North Dakota (66). Nitrogen fertilization also increased water-use efficiency of Bromus inermis-Agropyron desertorum in South Dakota (77) and native vegetation in Alberta, Canada (36) and Montana (4).

Water-use efficiency data of native rangeland are difficult to compare because of differences in: (1) Precipitation to evaporation ratios among study locations, (2) plant species composition, and (3) responses of individual plant species to fertilizer applications. The following water-use efficiency data were reported for nonfertilized rangeland:

kg/ha-cm	Location	Researchers
18	Alberta, Canada	Johnston et al. (36)
25	North Dakota	Smika et al. (66)
84	Montana	Black (4)

Grass species differ in their water-use efficiency. In Montana, for example, water-use efficiency was 58, 98, and 101 kg/ha-cm for Stipa viridula, Elymus junceus, and Agropyron intermedium, respectively, when grown without fertilizer in 76-cm rows. Water-use efficiency of all three species increased 1.5- to 1.6-fold with the application of 45 kg of N/ha and increased 1.6- to 1.8-fold with the application of 44 kg of P/ha and 45 kg of N/ha (5).

Nitrogen recovery. Percentage of N recovery is defined as the amount of N taken up in the harvested portion of the fertilized crop, minus the amount taken up by the check crop, divided by the amount of N applied, times 100. On native rangeland, the primary factors influencing N recovery are species present, amount of P fertilizer, and total water available to the plants. Nitrogen recovery data reported in the literature are variable; most researchers did not use a P check plot to test effects of P alone on N recovery.

Fertilizer N recovery differs among grass species. In North Dakota, *Agropyron cristatum*, *Bromus inermis*, and *Elymus junceus* recovered 46, 37, and 28%, respectively, of the annual fertilizer N applied (67). In Montana, average annual N recovery by *Elymus junceus*, *Stipa viridula*, and *Agropyron intermedium* grown in 76-cm rows was 53, 38, and 33%, respectively, of the N fertilizer applied annually. With N-P fertilization, N recovery by *Agropyron cristatum* was 73% in Montana (4) and only 42% in North Dakota (67). Thus, even N recovery by the same species varies with location.

When both N and P are applied, N recovery is often increased. In South Dakota, a mixture of *Bromus inermis* and *Agropyron desertorum* recovered 46% with N fertilization and 63% with N-P fertilization (76). In Montana, P applied alone stimulated soil N uptake by 20% (4). It was theorized that added P may have increased N uptake by increasing root extension and also may have accelerated N mineralization in the severely P-deficient soil (4).

Doubling the amount of P fertilizer applied to *Agropyron smithii* in a water-spreader system in South Dakota reduced N recovery. The average N recovery, over all N rates, was 32, 51, and 44% of the N applied when 0, 39, and 78 kg of P/ha was applied, respectively.

The amount of water available to the crop affects N recovery. On a fine-textured soil in Montana, water added by spring flood irrigation to *Agropyron smithii* decreased recovery of annually applied N from 24 to 10% (65). Water added on native rangeland in North Dakota, in contrast, increased N recovery but decreased residual N fertilizer remaining in the soil (66). Differences in research methods confuse the N recovery data reported in the literature.

Clipping Effects

Results from clipping studies of mixed plant populations are difficult to interpret. In such studies, it is impossible to determine if plant response is the result of modification of competition received from associated species or a direct effect of the clipping treatment (31).

To evaluate clipping effects, one must be able to identify tiller types (vegetative or floral) and specific growth stages. During a grass plant's development, tillers continually emerge, grow, and die at different rates, which are determined by environmental conditions.

The growth rate of a sward depends upon the growth rate and initiation of tillers. Partial defoliation of a tiller, including the apical meristem, stops growth and the tiller soon dies. Plant regrowth then depends upon the number, extent, and type of leaves remaining on tillers having intact apical meristems (50).

The interrelationship of carbohydrate reserves, leaf area, root growth, and environmental factors complicate clipping effects.

Leaf-area index. Carbohydrate reserves no longer control rate of regrowth once adequate photosynthetic area is present. Leaf area index can control growth rate if plant growth is not limited by lack of water, fertility, or other environmental factors (9, 19).

The importance of leaf area index is more theoretical than actual. Milthorpe and Davidson (50) stated that leaf area and light interception ". . . emphasize only a part of the whole system and provide an over-simplified model on which to base management systems. The model assumes . . . that all green leaves have an equal capacity for photosynthesis, the rate depending only on the local light supply." Leaves differ in photosynthetic capacity, however, with maximum photosynthetic capacity occurring when the leaf first emerges from the sheath and decreasing as the leaf ages (33, 78). Taylor and Templeton (74) found that the life span of *Dactylis glomerata* leaves, after they reached full extension, was about 28 days. Even different parts of the leaf differ in their photosynthetic capacity. For example, in young tillers of Dactylis glomerata, sheaths have about one-third the photosynthetic capacity of the blades (17).

Growth rate and leaf area index are not always clearly related (1, 32). In Australia, leaf area index was difficult to use as a major criterion for management of a mixed species sward in an area with sporadic rainfall and an ample supply of energy (64). Thus, leaf area index, though helpful, is not the complete answer to forage management.

Root growth and nutrient uptake. Clipping will reduce root growth for varying lengths of time (7, 16, 29). In some cases, it may cause small losses of root weight (54, 71), and a single clipping may reduce root length (56). Removal of 40% or more of the foliage by one clipping has stopped apical root growth of several grass species within 24 hours (16, 17, 54).

Under certain conditions, each tiller has its own root system. Crider (16) found that defoliation of one tiller or group of tillers only stopped root growth of those roots associated with defoliated tillers. His work was confirmed by Marshall and Sagar (49), who found that leaves of Lolium multiflorum fed labelled CO_2 transported labelled assimilates through the tiller to its own root system. However, clipping only part of the tillers changed this pattern. Where a single undefoliated tiller remained, it initially supplied defoliated tillers with labelled carbon products, thus reintegrating a system of apparently independent tillers (49). This could explain differences that sometimes exist between clipping and grazing effects on root growth.

Clipping of forage also affects time and amount of nutrient uptake by roots. Davidson and Milthorpe (17) found that following severe clipping labelled P uptake was reduced as long as 8 days later. In another study uptake of labelled P, injected into the soil at different depths immediately following clipping, did not occur until new roots reached the labelled P zone (54). Clipping *Stipa pulchra* foliage stopped new root hair development for 1 month (55). Lack of new root hair development may explain lack of nutrient uptake after clipping. An extensive review of effects of forage removal on root growth and root weight has been published by Troughton (79).

Forage yield. Generally, clipping has reduced dry matter yield when a single species rather than a mixture of species was clipped; and the more frequent and severe the clipping, the more dry matter yield was depressed (31).

Protein yield. The most common expression for forage quality is percentage of protein (62). Crude protein (% nitrogen x 6.25 = % crude protein) decreases as a forage plant matures (26). Frequent clipping usually increases percentage of protein and forage digestibility but decreases percentage of lignin of regrowth forage (40). Other researchers found that frequent clippings have decreased dry matter yield but increased protein yield (27, 52, 82). However, Thaine (75) found that frequent clipping of *Elymus junceus* increased both dry matter and crude protein yield.

Combined Fertilization and Clipping Effects

Application of 90 kg of N/ha to grazed pastures in North Dakota caused the death of some *Agropyron cristatum* plants (62). In Indiana, high rates of N fertilization severely reduced stands of *Dactylis glomerata* (57%) when clipped to a 5-cm stubble height (23). In contrast, Heinrichs and Clark (27) reported that, in Saskatchewan, Canada, nonfertilized plants of *Stipa viridula*, clipped frequently the previous year, winterkilled more readily than those fertilized with N and P. With N-P fertilization, frequent clipping only decreased ground cover of *Stipa viridula* (27).

Lawrence (41) reported that, in Saskatchewan, Canada, N fertilization increased winterkill of *Agropyron intermedium* following long periods of drought. Lawrence and Ashford (43) later reported that N fertilization rates did not significantly increase winterkill of *Agropyron intermedium*. They found that plants were winterkilled more readily when clipped at low (3.8-cm) than at high 7.6- or 15.2-cm) stubble heights and when clipped at 2- or 3-week intervals than at less frequent intervals (42). After a long drought period in Colorado, Klipple and Retzer (39) reported that N fertilization increased death loss of Bouteloua gracilis and other grasses.

Results of clipping fertilized grass are variable and not well understood. Time of clipping and carbohydrate reserve levels probably are important for predicting winterkill. Lawrence and Ashford (42) reported that plant development stage at clipping did not influence winter injury of Agropyron intermedium in Saskatchewan, Canada, but frequency and height of clipping had a direct effect. In general, these factors have not been studied.

STUDY AREA

This study was conducted during 1969 and 1970 on a solid stand of Stipa viridula which was planted in 1961. The site was located on the Soil and Water Conservation District research farm, 11 km north of Culbertson, Montana. The soil is a Williams loam derived from glacial till, sloping from 4 to 6% to the south. Range site classification for the area, according to the Soil Conservation Service classification system, is a sandy 25.4- to 35.6-cm precipitation zone range site. Prior to 1969, Stipa viridula forage was harvested annually for hay when the first seeds ripened.

Weeds in the stand, primarily volunteer Medicago sativa, were controlled by spraying with 1.1 kg/ha active ingredient 2,4-D amine on May 12, 1969. During 1969 and 1970, leaf spot disease, Alternaria tenuis, infected the entire second leaf and the distal half of the third leaf during the middle of May causing light to moderate damage. Subsequent infections did not occur during the growing season of either year.

Based on a 62-year record, average annual precipitation for this area is 32.6 cm, and average growing season (April through September) precipitation is 26.0 cm (Table 17). Average frost-free period is 114 days, extending from May 22 to September 13. Based on a 50-year record, mean annual temperature is 5.2 C (Table 17).

METHODS

Treatments

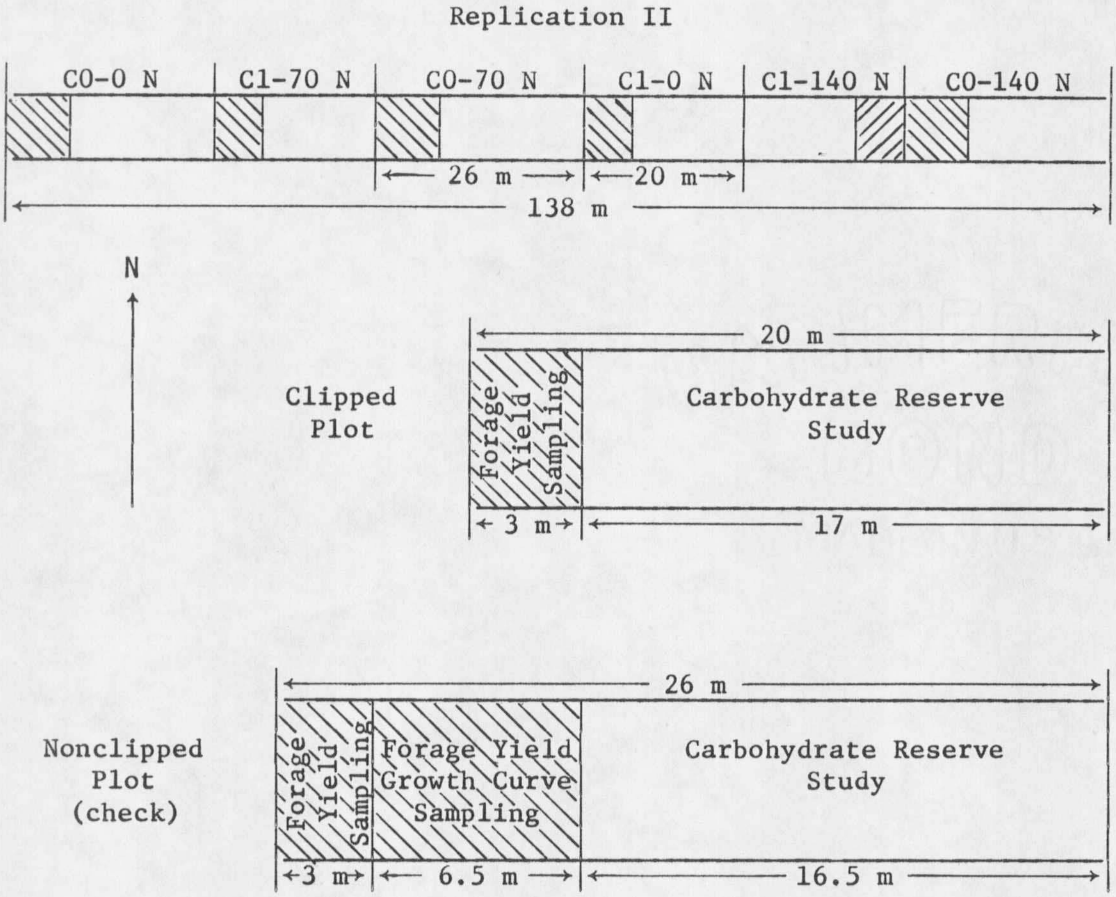
Treatments consisted of three N fertilization rates and two clipping frequencies. Nitrogen, as ammonium nitrate, was broadcast during November 1968 at 0, 70, and 140 kg/ha rates, hereafter referred to as 0 N, 70 N, and 140 N treatments. Clipping frequency treatments in 1969 consisted of (1) nonclipped and (2) clipped five times, May 6 and 27, June 16, July 7 and 28, to a 5-cm height. These dates were approximately 21-day intervals.

Experimental Design

Factorial combinations of the three N fertilization treatments and two clipping frequency treatments were randomly assigned to *Stipa viridula* plots in a randomized complete-block design with two replications. Plot dimensions were 9.5 by 5 m for the nonclipped treatment and 3 by 5 m for the clipped treatment (Fig. 1).

Statistical Analysis

Standard analyses of variance were used to determine if treatment differences were significant. Unless otherwise stated, differences at the 5% level were considered significant. When the F-test was significant at the 5% level and more than two treatments existed, Duncan's Multiple Range Test (P = .05) was used to determine which



<u>Treatments</u>

<u>Clipping Frequency</u>	<u>Nitrogen Rate</u>
C0 = nonclipped (check)	0 N = no nitrogen (check)
C1 = clipped	70 N = 70 kg N/ha
	140 N = 140 kg N/ha

Fig. 1. Plot diagram (Rep. II).

treatments were significant.

When measurements were repeated over time, time was considered an additional factor; therefore, data were analyzed as a split in time. When interaction was significant at the 5% level, analysis of variance was made for each date.

Soil Fertility

Soil samples were collected during July 1968 (before fertilizer application) and analyzed for pH, conductivity, organic matter, available P (Bray-HCl method), available K, and soil texture class by the Soil Testing Laboratory, Montana State University. Soil samples were taken again from each plot during May and August of 1969 and analyzed for available P by the $NaHCO_3$ method (53) with color developed by Murphy-Riley method (81) and nitrate (30). Soil P was determined from samples taken at the 0- to 7.5-, 7.5- to 15-, 15- to 30-, and 30- to 60-cm depths; soil nitrate, at the same depths plus the 60- to 90- and 90- to 120-cm depths.

Soil Water

Soil water was determined at 10-day intervals from April through August 1969 and once in November 1969. Soil water content in both the 0- to 15- and 15- to 30-cm depth was determined by the gravimetric method from three subsamples per plot at each sampling date. Soil water in the 30- to 120-cm depth was determined with a neutron 100-mc ^{241}Am-Be probe. Measurements were taken at the 45-, 75-, and 105-cm depths in one access tube within each plot.

The neutron probe was calibrated by comparing soil count-shield count ratios with percent soil water by volume determined from gravimetric-bulk density samples taken when access tubes were installed in November 1968. Percent soil water (volume) was related to neutron readings in the following manner: $Y = -3.07 + 39.86 X$ ($r^2 = .90$), where Y = % soil water by volume and X = soil count-shield count ratios.

Evapotranspiration was determined from soil water content changes in the 0- to 120-cm profile measured at 10-day intervals, plus precipitation received, assuming no runoff or deep percolation. Water-use efficiency in this study is defined as kilograms of dry matter produced per hectare per hectare-cm of total water used (ET).

Plant Development, Morphology, and Growth

During 1969, the date that each of the following plant development stages occurred on nonclipped plots was recorded: (1) Emergences of first, second, third, and fourth (flag) leaves (appearance of leaf collar); (2) heads in boot; (3) first head appearance; (4) first anthesis; (5) milk, soft dough, and hard dough stages of seed; (6) first seed ripening; (7) start of seed dissemination; (8) completion of seed dissemination; and (9) initiation of tillers. Tiller counts on July 2 and 29, 1969, helped determine kind of tillers present and date of growth initiation.

Upstretched-leaf height and head height (when visible) of *Stipa viridula* plants on nonclipped plots were measured at 10-day intervals from April through July 1969 as an index of growth rate. Head height was measured again during June 1970 on all plots. Upstretched-leaf height is the distance from the the soil surface to tip of longest upstretched leaf. Head height is the distance from the soil surface to tip of head.

Forage Yield

Dry matter yield of nonclipped *Stipa viridula* was determined by clipping a ¼- by 4-m area per plot at 10-day intervals from April through July 1969. Plants were clipped at ground level from a different sample area each date. During August 1969, an area ¼ by 4 m was clipped to a 5-cm height from nonclipped plots, and number of tillers taller than 5 cm and weight per tiller were determined.

Initial dry matter yield and regrowth rate were determined by clipping two permanent ¼- by 4-m areas to a 5-cm height at scheduled (five) clipping dates. During August 1969, an area ¼ by 4 m was harvested on clipped plots to determine dry matter yield remaining below the clipping height (5 cm). Dry matter yields were determined during 1968 and 1970 at the seed ripening stage.

Chemical Analysis of Plant Material

Forage from clipped and nonclipped plots was harvested and dried in a forced-air oven at 65 C until it reached constant weight. Samples were then ground to pass through a 10-mesh screen in a Wiley mill and were analyzed for N by the Kjeldahl method (30) and for total P content by the colorimetric method following wet oxidation of the plant tissue (2).

In this study, percentage of N recovery is defined as the amount of N taken up in the harvested portion of the N-P fertilized plants, minus the amount taken up by the P alone fertilized plants, divided by the amount of N applied, times 100.

Environmental Characteristics

Weather station records at the Soil and Water Conservation District research farm were used to determine normality of the 1968, 1969, and 1970 climate.

RESULTS AND DISCUSSION

Soil Fertility

Before fertilizer application, the soil contained adequate potassium but was low in organic matter and available P (Table 1). The soil contained only 5 ppm of available P at a depth of 0 to 7.5 cm and less than 2 ppm below 7.5 cm (Table 2). Restricted plant growth usually occurs when the first 15 cm of soil contains less than 5 ppm of available P (53). After application of 44.8 kg of P/ha, the soil contained over 5 ppm of available P to a depth of 30 cm (Table 2).

Application of 70 kg of N/ha in November 1968 did not significantly increase soil NO_3-N in the first 7.5 cm of soil, but application of 140 kg of N/ha increase soil NO_3-N in the 0- to 7.5- and 15- to 30-cm depths (Table 3). Soil nitrate had not leached through the profile by August 1969.

Soil Water Extraction

Because of lack of precipitation during May and June, soil water in the 0- to 30-cm depth was limited during June. Plants used little water from the 60- to 90-cm depth (Fig. 2C) and little or no water from the 90- to 120-cm depth (Fig. 2D). During June and August on nonclipped plots, *Stipa viridula* leaves rolled during the hottest part of the day even though soil water was available in the 30- to 60-cm depth(Fig. 2B). Plant leaves rolled more on nonclipped N fertilized

Table 1. Summary of soil analysis data (July 1968) before application of N-P fertilizer.*

Depth	pH	Conductivity	Organic matter	Available P (Bray-HCl)	Available K	Soil texture
cm		mmhos	%	ppm	ppm	
0-7.5	7.4b	0.8ab	2.1a	23a	390a	sl
7.5-15	7.1b	0.7b	1.5b	6b	250b	sl
15-30	7.2b	0.7b	1.2c	6b	160c	sl
30-60	7.7a	1.1a	1.1c	4b	130c	sl-cl†

* Means within each column followed by the same letter are not significantly different (P = .05).

†Sandy loam-clay loam.

Table 2. Available soil P ($NaHCO_3$ method) by depths before and after application of 44.8 kg of P/ha.*

	P fertilization		
	Before	After†	
Depth	Summer 1968	May 1969	August 1969
cm	ppm	ppm	ppm
0-7.5	5.0	52.7a	51.6a
7.5-15	1.6	9.1a	15.0a
15-30	1.4	6.8a	5.6a
30-60	1.1	3.7b	4.6a

*Nitrogen treatments had no significant effects (P = .05) therefore means for only sampling dates were reported.

†Means within each depth followed by the same letter are not significantly different (P = .05).

Table 3. Soil NO_3-N content (ppm) in May and August 1969: The effects of N fertilizer rates.

	N rate, kg/ha*		
Depth	0	70	140
cm	----------------	ppm	----------------
0-7.5	1.3b	2.1b	5.5a
7.5-15	1.4a	1.4a	1.9a
15-30	1.2b	1.2b	3.0a
30-60	1.1a	1.2a	4.0a
60-90	1.1a	1.1a	1.5a
90-120	1.1a	1.4a	1.5a

*Means within each depth followed by the same letter are not significantly different (P = .05).