



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

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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 (NO₃-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.

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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


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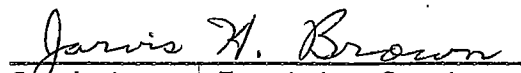
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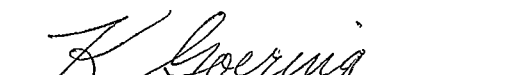
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ABSTRACT

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.

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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 viridula¹, 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

¹See 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:

<u>kg/ha-cm</u>	<u>Location</u>	<u>Researchers</u>
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 CO₂ 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 ($\% \text{ nitrogen} \times 6.25 = \% \text{ crude protein}$) 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.

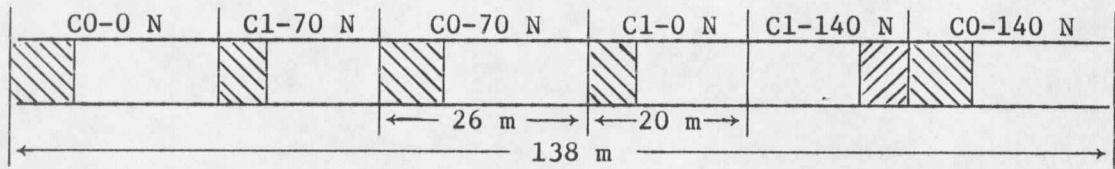
Experimental Design

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).

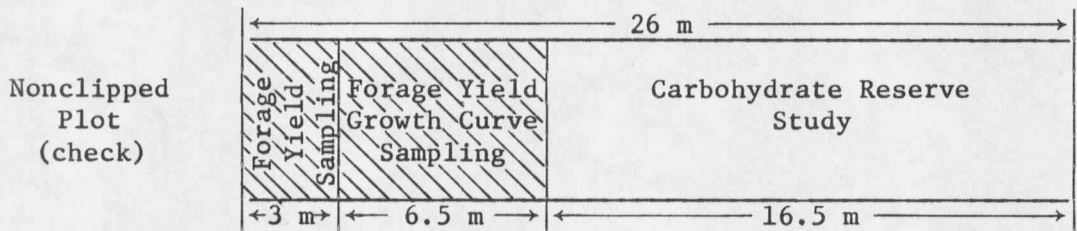
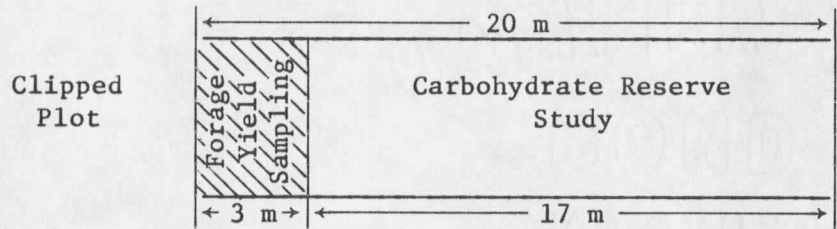
Statistical Analysis

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

Replication II



N
↑



Treatments

Clipping Frequency

CO = nonclipped (check)
C1 = clipped

Nitrogen Rate

0 N = no nitrogen (check)
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 $Y = \% \text{ soil water by volume}$ and $X = \text{soil count-shield count ratios}$.

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 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 $\frac{1}{4}$ - 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 $\frac{1}{4}$ 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 $\frac{1}{4}$ - by 4-m areas to a 5-cm height at scheduled (five) clipping dates. During August 1969, an area $\frac{1}{4}$ 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 NO₃-N in the first 7.5 cm of soil, but application of 140 kg of N/ha increase soil NO₃-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	Conduc- tivity	Organic matter	Available P (Bray-HCl)	Avail- able K	Soil texture
cm		mmhos	%	ppm	ppm	
0-7.5	7.4b	0.8ab	2.1a	23a	390a	s1
7.5-15	7.1b	0.7b	1.5b	6b	250b	s1
15-30	7.2b	0.7b	1.2c	6b	160c	s1
30-60	7.7a	1.1a	1.1c	4b	130c	s1-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 (NaHCO₃ method) by depths before and after application of 44.8 kg of P/ha.*

Depth	P fertilization		
	Before	After†	
	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 NO₃-N content (ppm) in May and August 1969: The effects of N fertilizer rates.

Depth cm	N rate, kg/ha*		
	0	70	140
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).

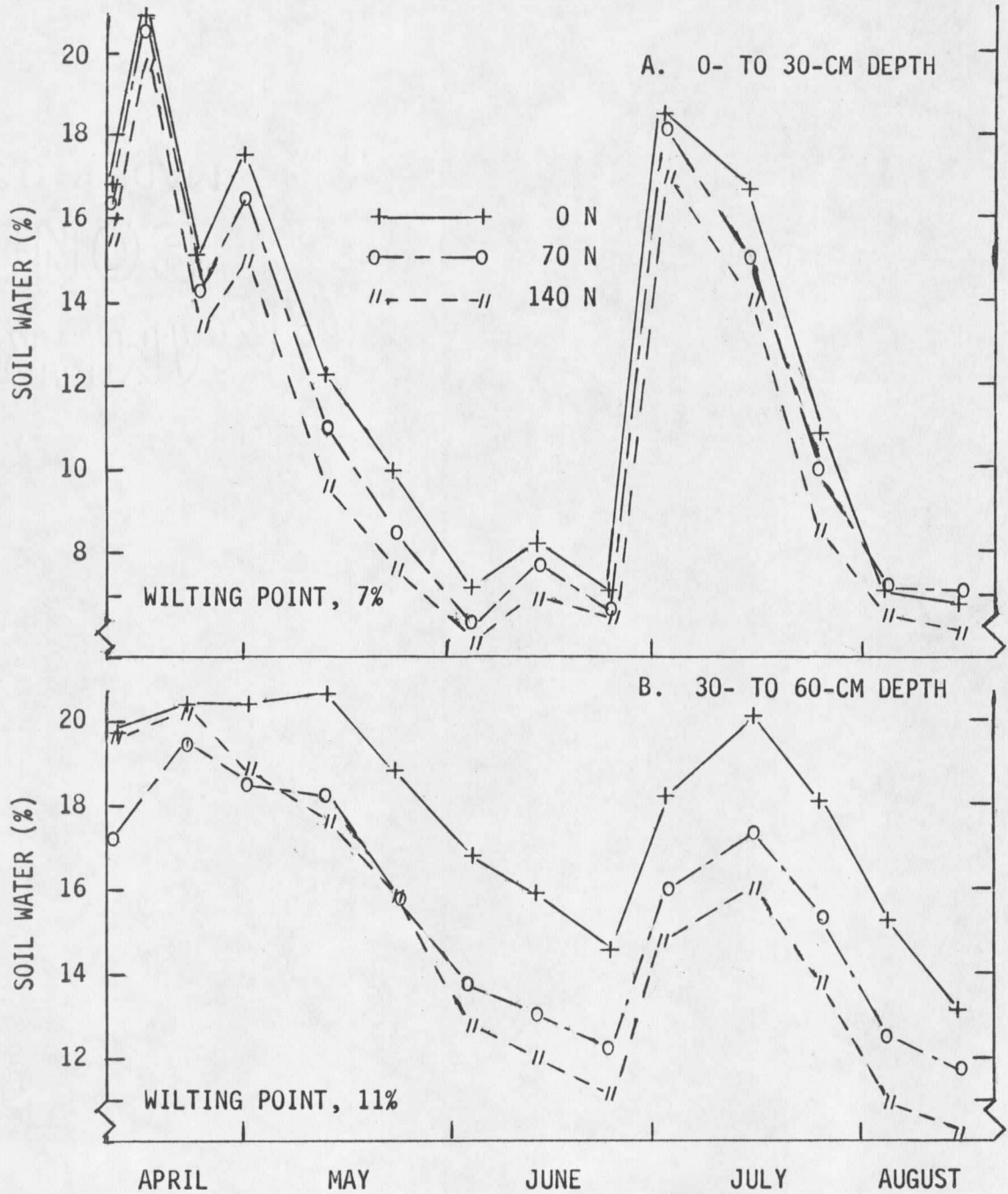


Fig. 2. Soil water percentage (by volume) for: A, 0- to 30-; B, 30- to 60-; C, 60- to 90-; D, 90- to 120-cm depths during 1969: The effects of N fertilizer rates.

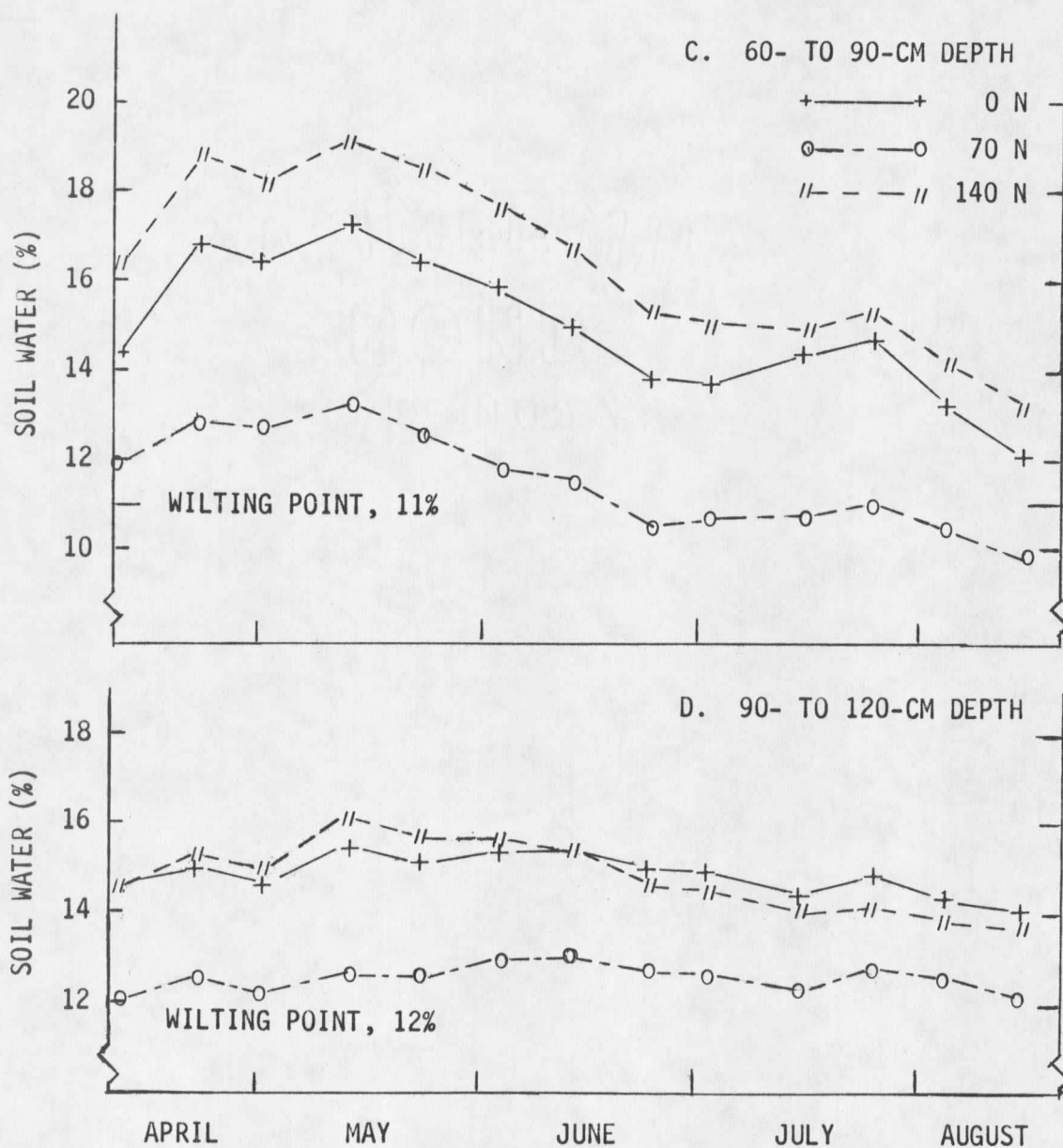


Fig. 2. Soil water percentage (by volume) for: A, 0- to 30-; B, 30- to 60-; C, 60- to 90-; D, 90- to 120-cm depths during 1969: The effects of N fertilizer rates--continued.

plots² than on all other plots. Precipitation in late June and early July supplied adequate soil water until the first of August. At this time soil water again limited plant growth.

On certain dates N fertilization increased soil water extraction in the 0- to 60-cm depth (Fig. 2A and 2B) but did not affect water extraction below the 60-cm depth (Fig. 2C and 2D). Nitrogen fertilization increased soil water extraction in the 0- to 30-cm depth from May 13 through May 23 and on July 25 (Fig. 2A) and in the 30- to 60-cm depth from June 3 through June 24, on July 25, and from August 4 through August 15 (Fig. 2B). Black and Reitz (5) in Montana found that N fertilization caused soil water extraction patterns similar to these when Stipa viridula was grown in 76-cm rows. In North and South Dakota, researchers have reported similar soil water extraction patterns (66, 76). In North Dakota, low rates of N fertilizer increased root weight in the 0- to 30-cm depth (21, 24, 46, 47). Increases in root distribution could account for the increased soil water extraction observed in our study.

²Terms such as N fertilization and application of N (used in this study) all refer to the average effects caused by 70 and 140 N treatments. There were no differences between effects caused by 70 and 140 N treatments unless so stated.

Clipping did not affect soil water extraction patterns in the 0- to 120-cm profile (Table 4). This indicates that clipping did not decrease rooting depth as reported by Troughton (79).

Nonclipped Plant Development, Morphology, and Growth

Spring growth of Stipa viridula began in 1969 when frost left the ground (April 5), and major growth ended with seed ripening (July). Average dates for successive stages of plant development in 1969 are shown in Table 5. Early plant developmental stages occurred earlier than normal; but because of limited soil water, later plant developmental stages were delayed until near their normal date. Generally, N fertilization did not influence the time when a plant reached a developmental stage. These results support those reported by Goetz (22) in North Dakota.

It was estimated that 62% of the floral tillers present on July 2, 1969, had been initiated the previous year after the heavy August precipitation. The difference between floral tillers initiated in the autumn versus spring was easily distinguished. Spring-initiated floral tillers had four leaves; vegetative, two. On autumn-initiated floral tillers, the first of four leaves turned brown during May. Floral tillers initiated in the spring reached maturity about 4 weeks later than those initiated in the autumn. Over the winter period, autumn-initiated tillers froze back to 5 cm of green stubble. Initiation of spring tillers began about April 10, but stopped during May and early

Table 4. Soil water percentage (by volume) at different depths as determined by the neutron method during 1968 and 1969: The effects of clipping frequency.

Date	Depth, cm							
	0 to 30*		30 to 60		60 to 90		90 to 120†	
	Nonclip	Clip	Nonclip	Clip	Nonclip	Clip	Nonclip	Clip
	----- % -----							
11/13/68	11§	11	12	13	11	12	10	13
4/11/69	16	16	19	16	14	14	15	12
4/22/69	14	14	20	18	17	16	16	13
5/1/69	16	16	18	17	16	15	15	13
5/13/69	11	11	18	17	17	16	15	14
5/23/69	9	9	16	15	16	16	15	14
6/3/69	6	6	13	13	15	15	15	15
6/13/69	7	8	12	12	14	14	15	15
6/24/69	7	7	11	11	13	13	14	14
7/2/69	18	18	14	16	13	13	14	14
7/15/69	15	16	16	17	13	14	14	14
7/25/69	9	10	14	15	13	14	14	14
8/4/69	7	7	11	12	12	14	14	14
8/15/69	6	7	10	10	11	13	13	14
8/25/69	6	6	10	10	11	12	13	14
11/4/69	9	9	9	8	9	9	12	12

*Data from gravimetric samples, except dates of 4/11 and 11/4/69.

†Data of 11/13/68 used to adjust 1969 data.

§There are no differences significant at 5% level of probability between nonclip and clip at the same date and depth.

Table 5. Dates of successive plant developmental stages during 1968 and 1969 for autumn-initiated (1968) floral tillers (nonclipped).

Developmental stages	Date
Tillers started growth	15 August 1968
Emergences of first leaf*	September 1968
Over wintering	Winter 1968-69
Start of spring growth	5 April 1969
Emergence of second leaf	22 April 1969
Emergence of third leaf	12 May 1969
Head in boot	26 May 1969
First head appearance	29 May 1969
Emergence of fourth leaf	2 June 1969
First anthesis	9 June 1969
Full anthesis	13 June 1969
Seed, milk	17 June 1969
Seed, soft dough	24 June 1969
Seed, hard dough	7 July 1969
First seed ripe	7 July 1969
Start of seed dissemination	7 July 1969
Completion of seed dissemination	26 July 1969

*Leaf collar appears.

June because of limited soil water. Application of 140 N caused the most tiller initiation (not significant) after the late June precipitation (Table 6), but these made little growth because of limited soil water during August (Fig. 2A and 2B).

Mature Stipa viridula plants on nonfertilized plots had 32% floral and 68% vegetative tillers (Table 6). Nitrogen fertilization increased vegetative tillers from 68 to 74% and total tillers (Table 7) by 54%, from 860 to 1325 tillers/m² (not significant). Therefore, 15% of N-initiated tillers were floral.

Apparently more floral tillers (Table 6) had second heads (20% in 1969) when fertilized with 140 N (not significant). Second heads were not produced during 1970 on any of the N treatments. Stipa viridula normally produces one head at the terminal end of the stem. Under more favorable conditions, a second head is produced from the node of the fourth leaf.

Nitrogen did not affect upstretched-leaf height of floral tillers from April 11 until June 13, but did decrease leaf height from June 24 to July 15 (Fig. 3). Maximum upstretched-leaf height of floral tillers was reached by June 13 on N fertilized plots but not until June 24 on nonfertilized plots. Mean maximum upstretched-leaf height was 65 cm on nonfertilized plots, but only 54 cm on N fertilized plots. Mean maximum head height occurred by July 15 on N fertilized plots and was still increasing on July 29 on nonfertilized plots (Fig. 3). Mean

Table 6. Morphological characteristics of *Stipa viridula* tillers on July 2 and 29, 1969: The effects of N fertilizer rates.

Sampling date	N rate, kg/ha			Mean*
	0	70	140	
	<u>% new heads of floral tillers</u>			
7/2	37.5	30.5	34.0	34.0A
7/29†	<u>13.6</u>	<u>19.9</u>	<u>13.7</u>	15.7B
Mean	25.6a	25.2a	23.8a	
	<u>% old heads of floral tillers</u>			
7/2	62.5	69.5	66.0	66.0B
7/29	<u>86.4</u>	<u>80.1</u>	<u>86.3</u>	84.3A
Mean	74.4a	74.8a	76.2a	
	<u>% floral tillers with two heads</u>			
7/2	0	0	0	0 B
7/29	<u>4.7</u>	<u>10.0</u>	<u>20.1</u>	11.6A
Mean	2.3a	5.0a	10.1a	
	<u>% total tillers which were floral</u>			
7/2	30.3	25.2	25.8	27.1A
7/29	<u>32.3</u>	<u>26.4</u>	<u>28.4</u>	29.0A
Mean	31.3a	25.8b	27.1b	
	<u>% total tillers which were vegetative</u>			
7/2	69.7	74.8	74.2	72.9A
7/29	<u>67.7</u>	<u>73.6</u>	<u>71.6</u>	71.0A
Mean	68.7b	74.2a	72.9a	
	<u>Total number of tillers/sample area§</u>			
7/2	46.5	65.5	42.3	51.4B
7/29	<u>46.5</u>	<u>68.3</u>	<u>56.3</u>	57.0A
Mean	46.5a	66.9a	49.3a	
	<u>% increase of tiller number between sampling dates</u>			
7/2 to 7/29	0 a	2.5a	37.0a	13.2

* All interactions of N by date were nonsignificant, and means within each characteristic followed by the same letter (N means, lower case; dates means, upper case) are not significantly different (P = .05).

† New heads which were not present on July 2.

§ Sample area were individual plants.

Table 7. Tiller number and weight (August 26, 1969) on nonclipped plots when harvested above 5-cm height: The effects of N fertilizer rates.

Clipping frequency	N rate, kg/ha			Mean
	0	70	140	
	<u>Number of tillers/m²*</u>			
Nonclipped	860a	1300a	1350a	1170
	<u>Weight/tiller, g*</u>			
Nonclipped	0.08a	0.11a	0.13a	0.11

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

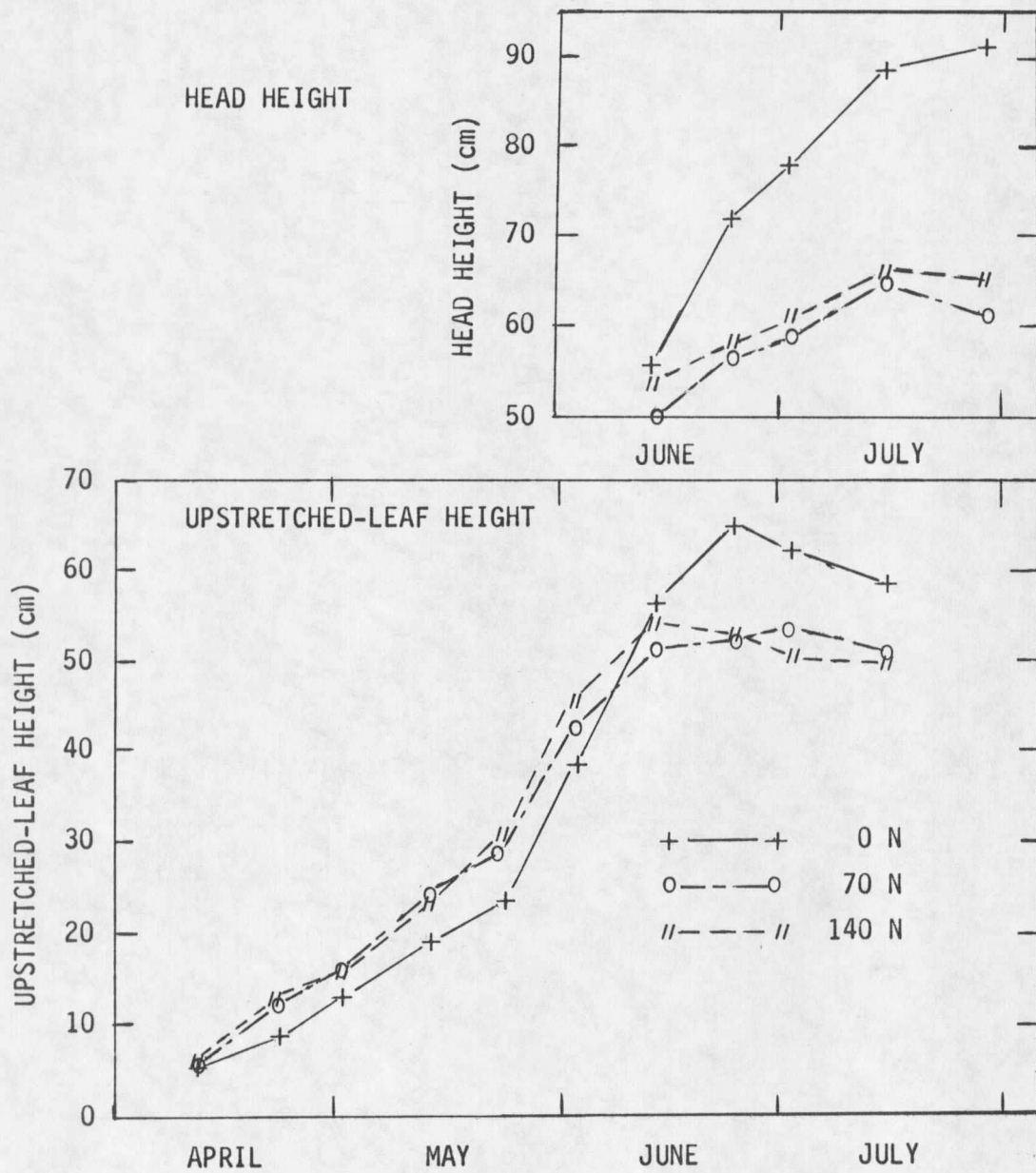


Fig. 3. Head height (upper graph) and upstretched-leaf height (lower graph) of floral tillers (nonclipped) during 1969: The effects of N fertilizer rates.

maximum head height was 91 cm on nonfertilized plots but only 66 cm on N fertilized plots. Growth of leaves and stems stopped sooner on N fertilized plots than on nonfertilized plots because of limited soil water.

Dry Matter and Quality of Nonclipped Forage

Dry matter yield accumulated most rapidly on N fertilized plots (Fig. 4). The rate of dry matter production was the same for the 70 and 140 N treatments until late June. Dry matter yield stopped increasing on the 0 and 70 N-plots the last of June but continued increasing until early July on the 140 N-plots. The increased dry matter yield on the 140 N plots during July was the result of tillers initiated after the late June precipitation. Nitrogen fertilization increased dry matter yield probably by increasing (nonsignificant) both tiller number and weight (Table 7). In North Dakota, Power and Alessi (57) reported that N fertilization increased both tiller number and weight of Agropyron cristatum.

Crude protein percentage of N fertilized forage was higher than nonfertilized forage throughout the season (Fig. 5). Nitrogen fertilization had increased percentage of crude protein 0.4-fold by the second leaf stage (April 21); but by the first of June, the increase was only 0.2-fold. Thus, percentage of crude protein decreased relatively faster in N fertilized than in nonfertilized forage. In all

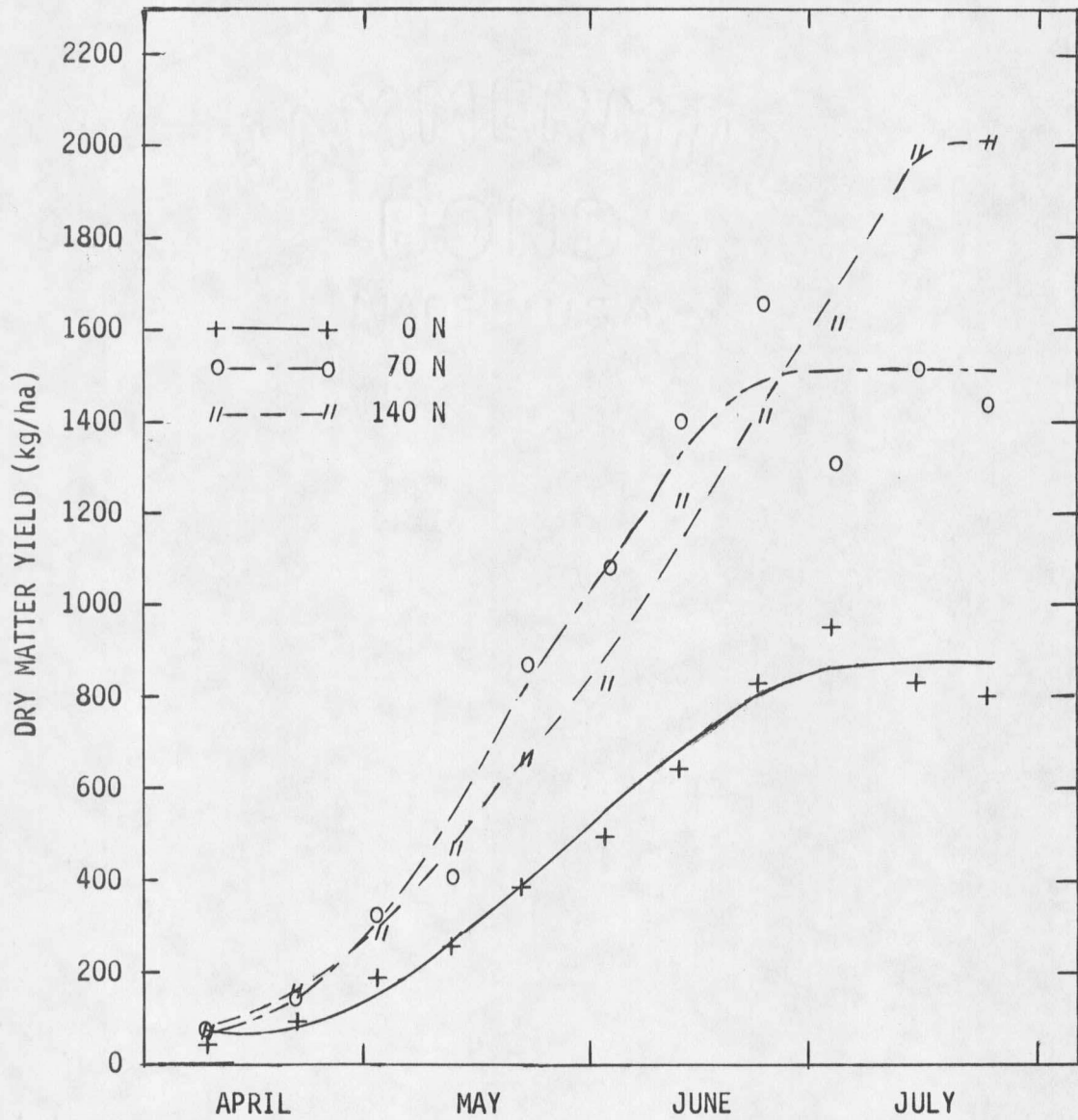


Fig. 4. Dry matter yield of nonclipped plants: Seasonal pattern during 1969 as affected by N fertilizer rates.

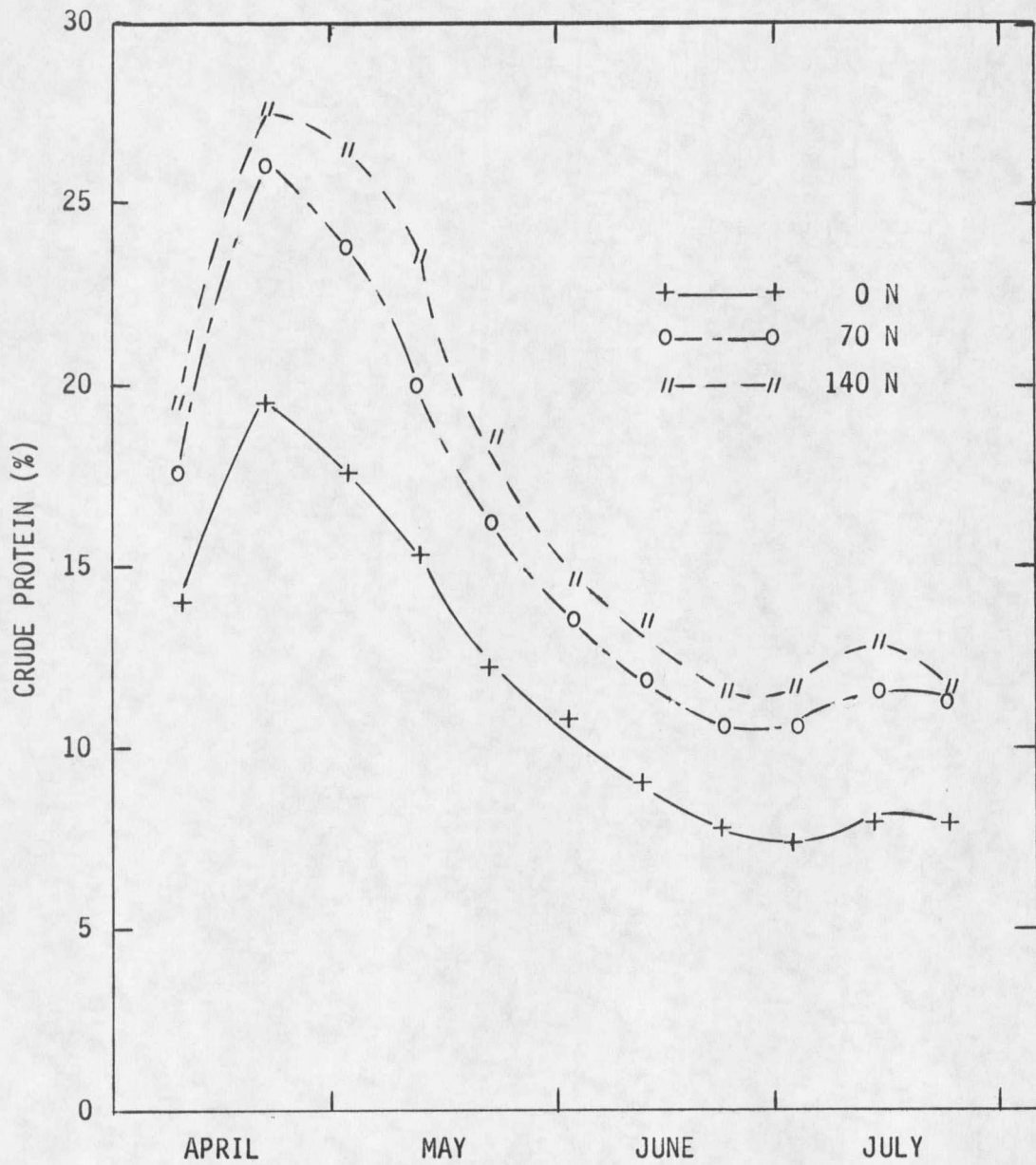


Fig. 5. Crude protein percentage of nonclipped plants: Seasonal pattern during 1969 as affected by N fertilizer rates.

treatments, late June precipitation increased available soil water which increased percentage of crude protein in forage.

Nitrogen fertilization increased percentage of plant P (Fig. 6) 0.2-fold from the second leaf stage (April 21) until the boot stage (May 22). From the boot stage until seed dissemination, N fertilization did not affect percentage of plant P. Added soil water in late June increased percentage of plant P by 0.3-fold regardless of N treatment (July 14 vs. June 12).

Dry Matter and Quality of Clipped Forage

For clippings one through five, N fertilized plots (average of 70 and 140 N plots) produced an average of 110, 290, 150, 180, and 370 (LSD .05 = 110) kg/ha of dry matter, respectively, which represented a 0.9-, 0.9-, 0.7-, 1.6-, and 2.5-fold increase over that of the 0 N plots for each successive clipping (Fig. 7). Dry matter yield of the third and fourth clipping was limited because of insufficient water. There was not enough growth for a sixth clipping because of insufficient soil water.

Percentage of crude protein in the forage decreased during May and June and reached a minimum at the third clipping of 12.5, 15.8, and 17.4% on the 0, 70, and 140 N treatments, respectively (Fig. 8). Percentage crude protein of forage increased by the fourth clipping (July 7) for all treatments because of late June precipitation.

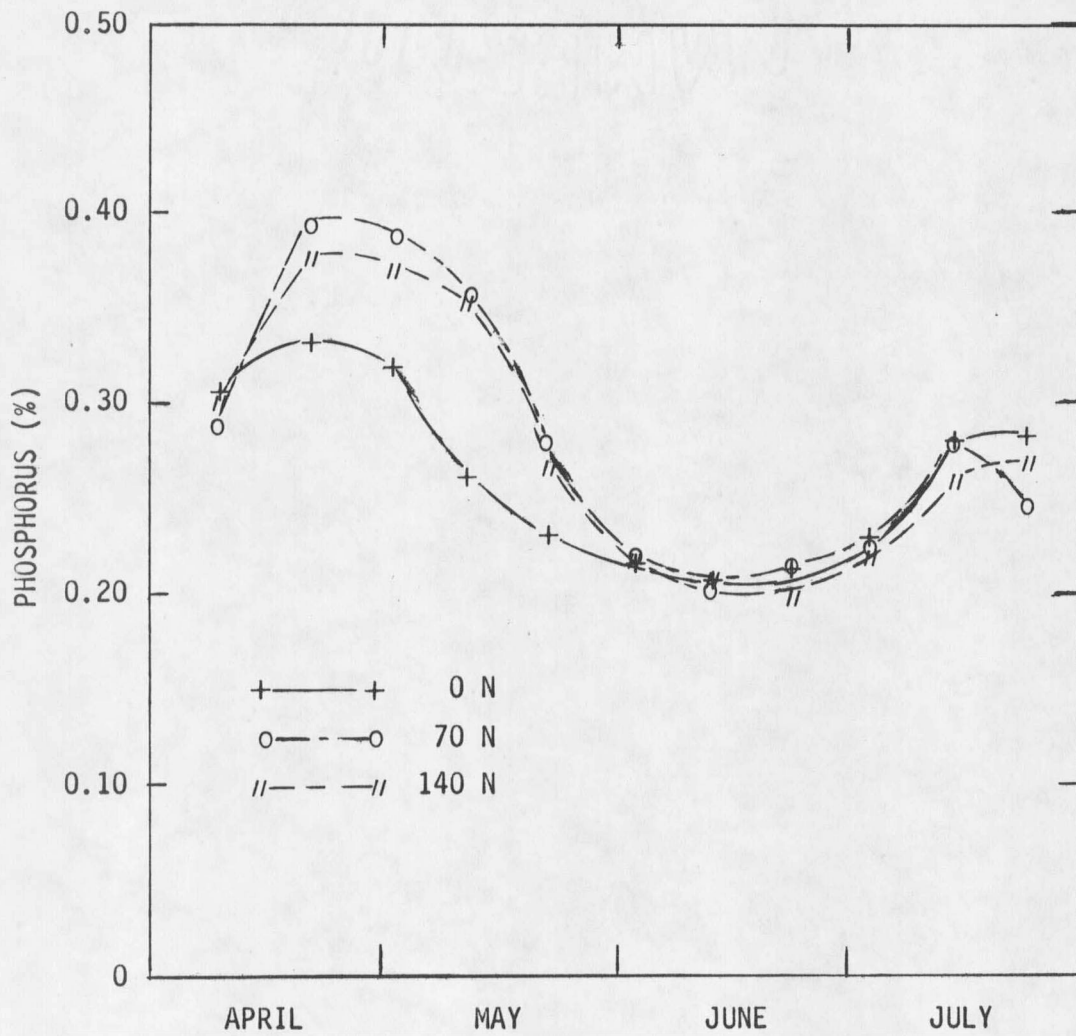


Fig. 6. Phosphorus percentage of nonclipped plants: Seasonal pattern during 1969 as affected by N fertilizer rates.

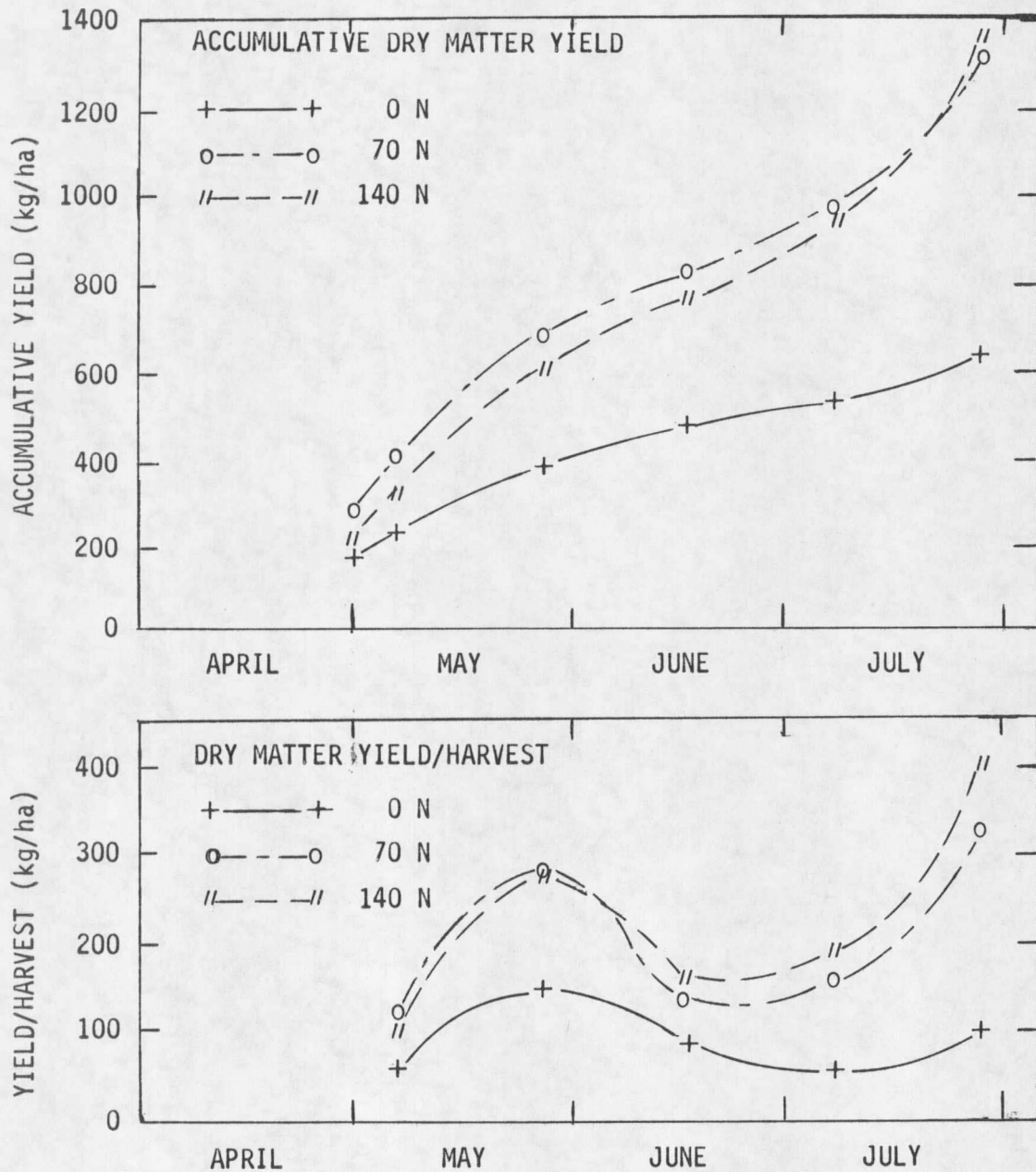


Fig. 7. Accumulative dry matter yield with stubble (upper graph) and dry matter yield at each of five harvests (lower graph) in 1969: The effect of N fertilizer rates.

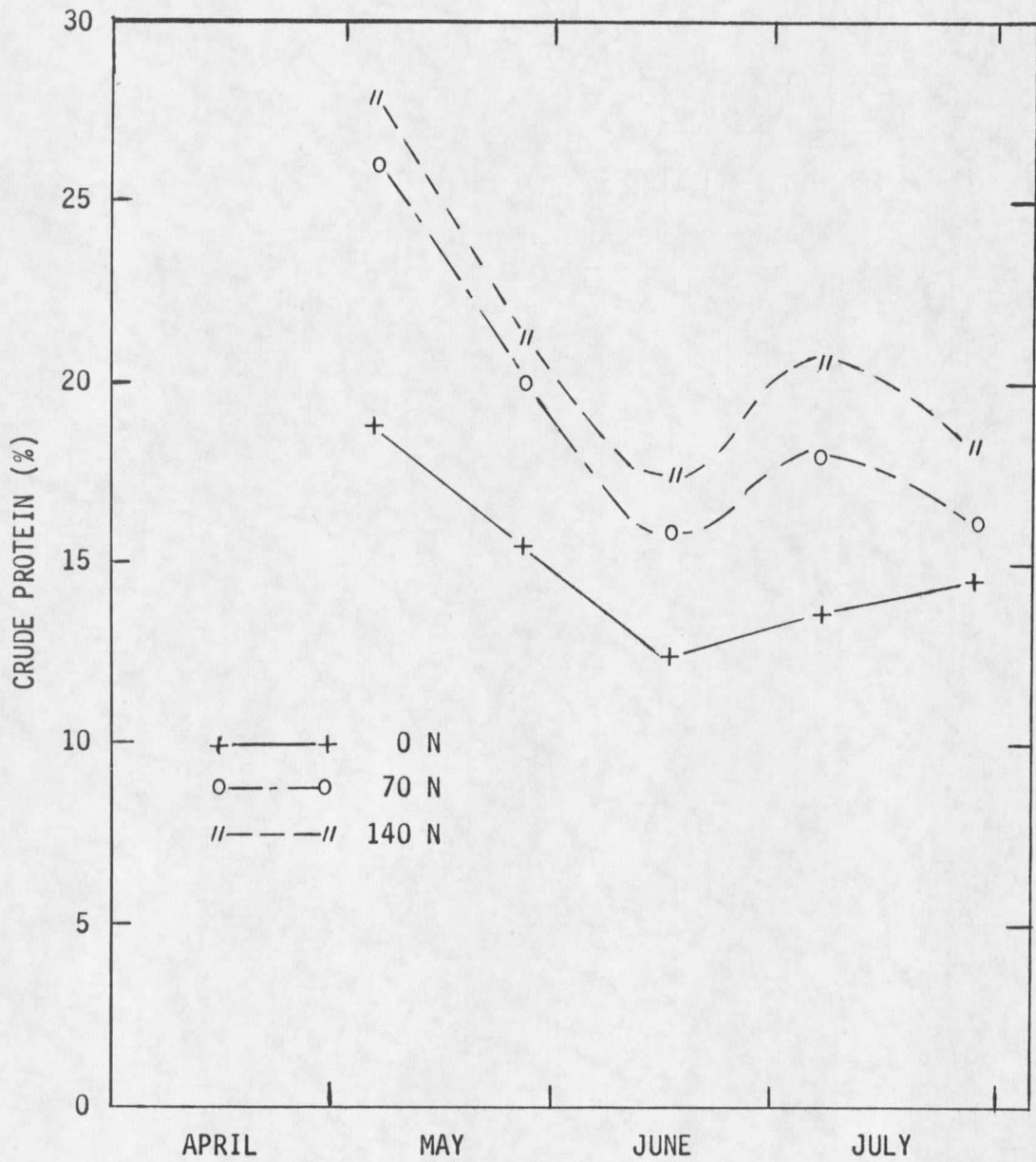


Fig. 8. Crude protein percentage of forage at each of five harvests in 1969: The effects of N fertilizer rates.

Nitrogen increased crude protein percentage 0.4-fold for the first, second, third, and fourth clippings, but only 0.2-fold for the fifth clipping. The following interactions among percentage of crude protein in the forage on N fertilized and nonfertilized plots were significant: (1) Between the first and second clipping, protein percentage decreased at a slower rate on nonfertilized plots; and (2) between the fourth and fifth clipping, protein percentage increased on nonfertilized plots but decreased on N fertilized plots.

Nitrogen fertilization increased percentage of plant P by 0.25-fold at the first clipping only (Fig. 9). In North Dakota, studies have shown moderate rates of N fertilization to increase the amount of roots in the 0- to 30-cm depth (21, 24, 46, 47). An increase in root distribution may be the reason for the higher P percentage of forage from N fertilized plots than from nonfertilized plots for the first clipping.

The percentage of plant P varied with clipping date (Fig. 9). Limited soil water instead of increased dry matter yield probably caused the decrease in percentage of plant P between the second and third clipping for N fertilized plots. Late June precipitation probably increased the percentage of plant P in the fourth clipping forage on N fertilized plots. However, the increase in dry matter yield from the fourth to the fifth clipping did not change the plant P percentage.

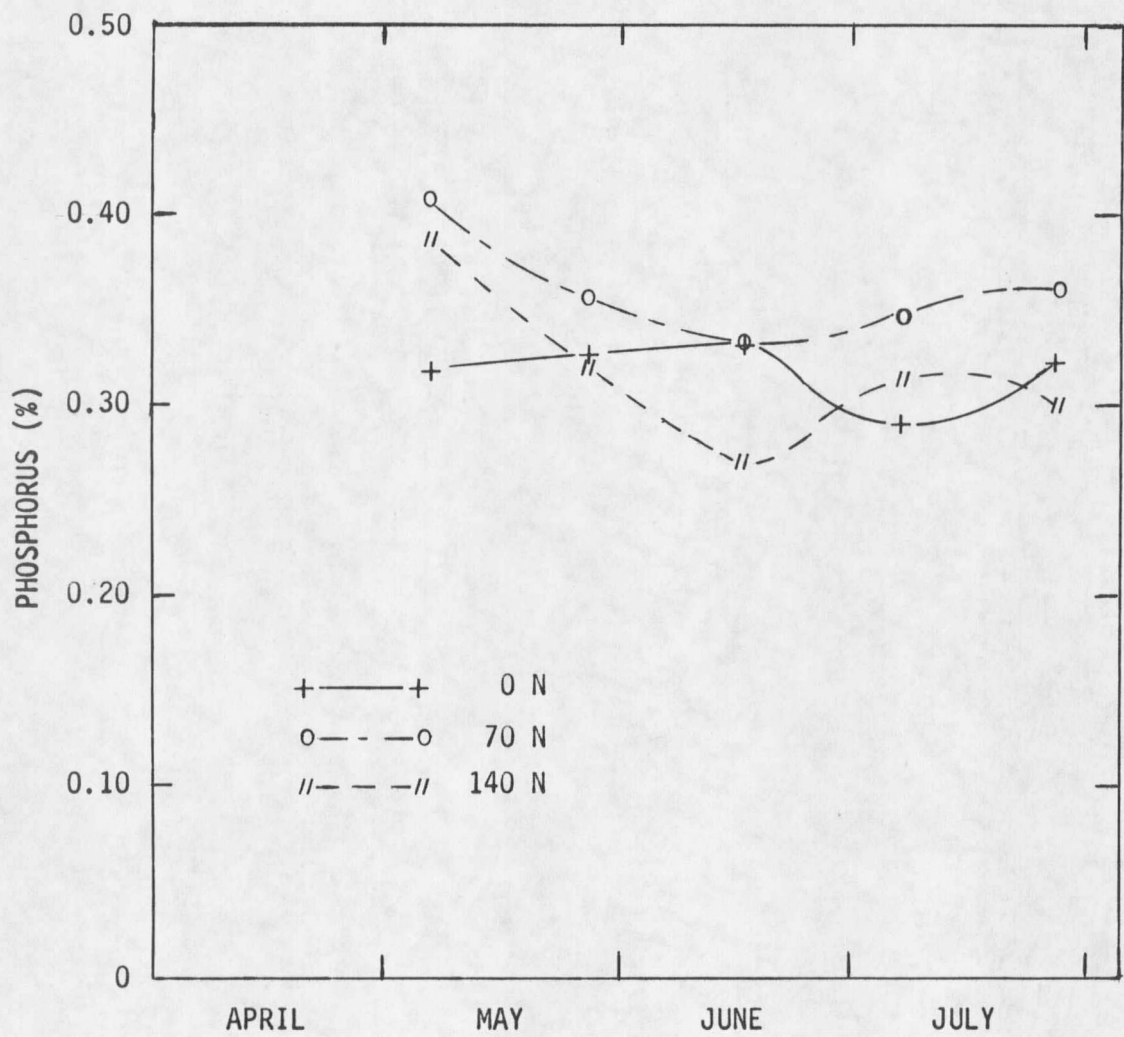


Fig. 9. Phosphorus percentage of forage at each of five harvests in 1969: The effects of N fertilizer rates.

There were two significant interactions in percentage P of forage from N fertilized and nonfertilized plots (Fig.9). First, between the first and second clipping, the dry matter yield increase (Fig. 7) was sufficient to decrease percentage of P on N fertilized plots but not on nonfertilized plots. Second, between the third and fourth clipping, adequate soil water allowed a moderate increase in plant growth, and thus increased both dry matter yield and percentage P of forage on N fertilized plots. However, on nonfertilized plots, lack of soil N probably delayed plant growth until after the fourth clipping, thus causing a slight decrease in dry matter yield and a moderate decrease in percentage of P.

Dry Matter and Quality of Forage from One Clipping vs. Five Clippings

Effects of nitrogen fertilization. Application of N caused similar dry matter yield responses on both clipped and nonclipped plots (Table 8). The mean dry matter yield increased 90% with 70 N fertilization and increased only an additional 23% with 140 N fertilization. In southern Saskatchewan, Canada, a study on Stipa viridula showed that application of 43 kg of N/ha plus 24.4 kg of P/ha increased total dry matter yield 40, 40, 50, and 85% on plots clipped one, two, three, five times per year, respectively (27). In Montana, Black and Reitz⁷ (6) reported that 22 kg of N/ha applied annually to nonclipped Stipa viridula plants grown in 76-cm rows increased dry matter yield 20% and

Table 8. Total dry matter yield during 1969: The effects of N fertilizer rates and clipping frequency.

Clipping frequency	N rate, kg/ha			Mean*
	0	70	140	
	----- kg/ha -----			kg/ha
Nonclipped†	780	1420	2000	1400A
Clipped	<u>630</u>	<u>1300</u>	<u>1360</u>	1095B
Mean*	715c	1360b	1680a	

*Nitrogen x clipping interaction is not significant (P = .05). Means followed by the same letter (N means, lower case; clipping means, upper case) are not significantly different (P = .05).

†Dry matter yield of 7/24 sampling date.

application of either 45 or 67 kg of N/ha increased dry matter yield 60%.

Application of N caused similar responses of total crude protein yield on both clipped and nonclipped plots. Mean total crude protein yield increased 1.5-fold with 70 N fertilization and increased only an additional 0.3-fold with 140 N fertilization (Table 9). Black and Reitz (6) reported that total crude protein yield increased 0.7-fold when 22 kg of N/ha was applied to nonclipped Stipa viridula plants grown in 76-cm rows and crude protein yield increased 1.3-fold when 45 or 67 kg of N/ha was applied

Application of 70 N increased the mean plant P yield 0.8-fold and application of 140 N caused no additional increase over that of the 70 N treatment (Table 10). Black and Reitz (6) reported that total plant P yield increased 0.7- and 0.9-fold when 45 and 67 kg of N/ha were applied with 22 kg of P/ha, respectively.

Effects of clipping frequency. In this study, dry matter yield (average of all plots) of Stipa viridula plants clipped five times per year were 22% less than those clipped once at the seed ripening stage (Table 8). Similar results were obtained in southern Saskatchewan, Canada, where clipping nonfertilized Stipa viridula plants two, three, and five times per year reduced the 3-year mean dry matter yield 18, 35, and 37%, respectively, compared with one clipping (27). Also in another study in southern Saskatchewan, Canada, conducted

Table 9. Total crude protein yield during 1969: The effects of N fertilizer rates and clipping frequency.

Clipping frequency	N rate, kg/ha			Mean*
	0	70	140	
	----- kg/ha -----			kg/ha
Nonclipped†	63	154	230	149B
Clipped	<u>84</u>	<u>221</u>	<u>256</u>	187A
Mean*	74c	188b	243a	

*Nitrogen x clipping interaction is not significant (P = .05). Means followed by the same letter (N means, lower case; clipping means, upper case) are not significantly different (P = .05).

†Crude protein yield of 7/24 sampling date.

Table 10. Total plant P yield during 1969: The effects of N fertilizer rates and clipping frequency.

Clipping frequency	N rate, kg/ha			Mean*
	0	70	140	
	----- kg/ha -----			kg/ha
Nonclipped†	2.3	3.4	5.4	3.7A
Clipped	<u>2.0</u>	<u>4.5</u>	<u>4.1</u>	3.5A
Mean*	2.2b	3.9a	4.8a	

*Nitrogen x clipping interaction is not significant (P = .01). Means followed by the same letter (N means, lower case; clipping means, upper case) are not significantly different (P = .01).

†Plant P yield of 7/24 sampling date.

for 5 years, clipping Stipa viridula plants three times per year caused 30% less total dry matter yield than one clipping (12). In a 6-year study in North Dakota, clipping Stipa viridula plants only twice a year caused 15% less dry matter yield than clipping once (82).

Clipping not only decreased total dry matter yield, but it also extended the duration of dry matter production by 26 days. A comparison of seasonal dry matter yield curves for N fertilized clipped and non-clipped plots is shown in Fig. 10. Nonclipped plots produced 90% of their dry matter before July, but clipped plots produced one-third of their dry matter during July. Accumulative dry matter yield of clipped plots without the late June precipitation would have been limited to less than 60% of that produced by nonclipped plots. June and July precipitation affects dry matter yield more on clipped plots than on nonclipped plots.

Clipped forage contained a higher percentage of crude protein (Fig. 8) and thus more relative nutritive value than nonclipped forage (Fig. 5) throughout the growing season. For example, clipping on N fertilized plots steadily increased percentage of crude protein from the second to the fifth clipping; and by the fifth clipping, clipped forage contained 0.35-fold more crude protein than nonclipped forage. In North Dakota, when Stipa viridula plants were clipped three times a year, the forage contained 55% more crude protein than forage from plants clipped only once a year (82).

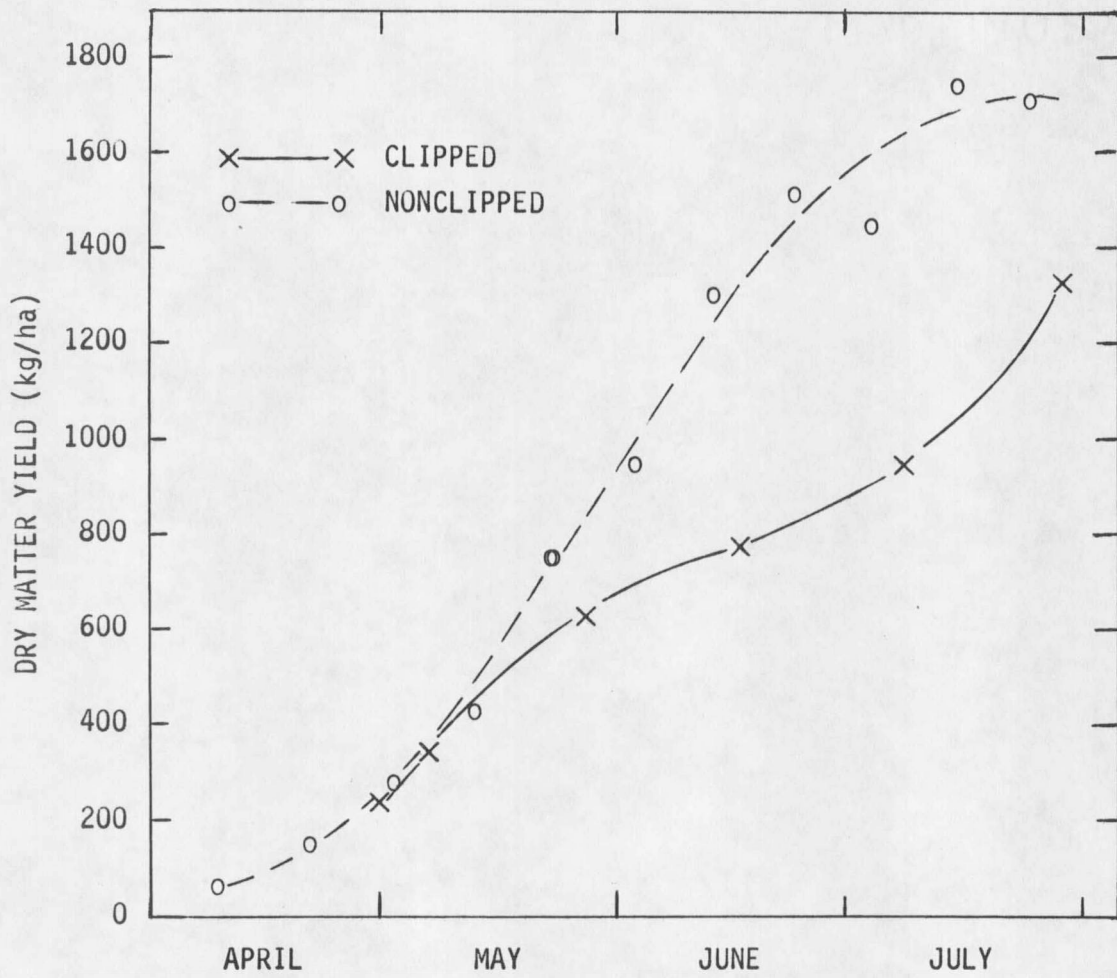


Fig. 10. Accumulative dry matter yield of plants clipped five times or once during 1969 on N fertilized plots.

Forage from clipped plots always contained adequate crude protein to meet the minimum requirement of 9.2% set by the National Research Council (51) for beef cows nursing calves (first 3 to 4 postpartum months). In contrast, on fertilized nonclipped plots, forage harvested for hay after June 11 contained less than 9.2% protein.

Clipping decreased total dry matter yield by 22% (Table 8) and increased total crude protein yield by 25% (Table 9). Clipping increased total crude protein yield by extending the duration of the plant growth period 26 days. Other studies have shown that clipping more than once per season increases percentage of crude protein and total crude protein yield. In Saskatchewan, Canada, Stipa viridula plants clipped two, three, and five times per year produced 35, 15, and 30%, respectively, more total crude protein yield than those clipped once a year (27). In North Dakota, Stipa viridula plants clipped twice a year produced 45% more crude protein than plants clipped only once year (82).

Clipping increased percentage plant P content 0.36-fold for the second through fifth clipping dates. Clipped forage during June contained more than 0.28% P. This is above the minimum requirement (0.22%) for beef cows nursing calves (first 3 to 4 postpartum months) set by the National Research Council (51). Nonclipped forage contained slightly less than 0.22% P. Adequate or nearly adequate P in forage resulted from the application of 44.8 kg of P/ha in 1968. Black and

Reitz (5) in Montana and Clarke and Tisdale (13) in Saskatchewan, Canada, reported that without N-P fertilization Stipa viridula forage contained only 0.15% P at the seed ripening stage. Clipping had no effect on yield of plant P.

Nitrogen Recovery

Neither N fertilization rate nor clipping frequency significantly affected N fertilizer recovery (Table 11). The N recovery from the 70 N clipped treatment (30%) appeared to be more than any of the other treatments (20%). In Montana, Black and Reitz (6) found that nonclipped Stipa viridula plants, grown in 76-cm rows with annual application of 67 kg of N/ha in combination with 22 kg of P/ha, recovered 40, 30, 70, and 25% of the N applied during 1965 through 1969, respectively. Their N recovery values differed among years because of differing growing conditions, especially limited soil water.

Residual Effects of Nitrogen Fertilization and Clipping

Application of 70 N in the autumn of 1968 doubled (505 kg/ha) dry matter yield during 1970 (Table 12). Application of 140 N increased dry matter yields an additional 32% (330 kg/ha) over the 70 N rate. Heads were 12 cm (15%) taller on plots fertilized with 140 N than on those fertilized with 70 N or nonfertilized (Table 13).

Table 11. Recovery* of fertilizer N (%) by plants during 1969: The effects of N fertilizer rates and clipping frequency.

Clipping frequency	N rate, kg/ha			Mean†
	0	70	140	
	-----	%	-----	%
Nonclipped§	--	21	19	20A
Clipped	--	<u>31</u>	<u>20</u>	25A
Mean†		26a	19a	

$$*\% \text{ N recovery} = \frac{(\text{N uptake from N+P plot}) - (\text{N uptake from P only plot})}{\text{Total N applied}} \times 100$$

†Nitrogen x clipping interaction is not significant (P = .05). Means followed by the same letter (N means, lower case; clipping means, upper case) are not significantly different (P = .05).

§N recovery of 7/24 sampling date.

Table 12. Dry matter yield (July 30, 1970): The residual effects of N fertilizer rates (autumn 1968) and clipping frequency (1969) when harvested above 5-cm height.

Clipping frequency	N rate, kg/ha			Mean*
	0	70	140	
	----- kg/ha -----			kg/ha
Nonclipped	640	1130	1525	1100A
Clipped	<u>400</u>	<u>920</u>	<u>1185</u>	835B
Mean*	520c	1025b	1355a	

*Nitrogen x clipping interaction is not significant (P = .05). Means followed by the same letter (N means, lower case; clipping means, upper case) are not significantly different (P = .05).

Table 13. Head height (June 24, 1970): The residual effects of N fertilizer rates (autumn 1968) and clipping frequency (1969).

Clipping frequency	N rate, kg/ha			Mean*
	0	70	140	
	----- cm -----			cm
Nonclipped	80	78	91	83A
Clipped	<u>61</u>	<u>62</u>	<u>73</u>	65B
Mean*	70b	70b	82a	

*Nitrogen x clipping interaction is not significant (P = .05). Means followed by the same letter are not significantly different (P = .05).

Clipping Stipa viridula plants five times during 1969 reduced dry matter yield and head height the following year. Clipping decreased dry matter yield by 25% (265 kg/ha) and head height by about 20% (18 cm). In 1970, dry matter yield reductions caused by clipping five times in 1969 were overcome by the 1968 N fertilization treatment; head height reduction was not overcome.

Evapotranspiration

ET varied throughout the growing season (Fig. 11). ET averaged about 1.9 cm/10-day period from April 11 to June 18, but increased in late June and July when precipitation increased. ET on July 8 reached a high of 3.9 cm/10-day period. ET on August 20 was restricted to 1.0 cm/10-day period as a result of limited soil water during August.

The dominant factors affecting ET rate were amount of precipitation received and availability of soil water. Nitrogen fertilization did not affect ET rate (Fig. 11) nor total ET on either clipped or non-clipped plots (Table 14). Frequent clipping appeared to decrease (not significant) ET rate an average of 0.35 cm/10-day period from May 18 to July 8 (Fig. 12). Frequent clipping, as of July 2, had decreased total ET by 15% (Table 14). Plant growth ceased on nonclipped plots before July 15, which caused ET rate to decrease to the same rate as that of the clipped plots. In North Dakota, Smika et al. (66) reported that when dry matter growth of native grasses ceased, ET rate was not affected.

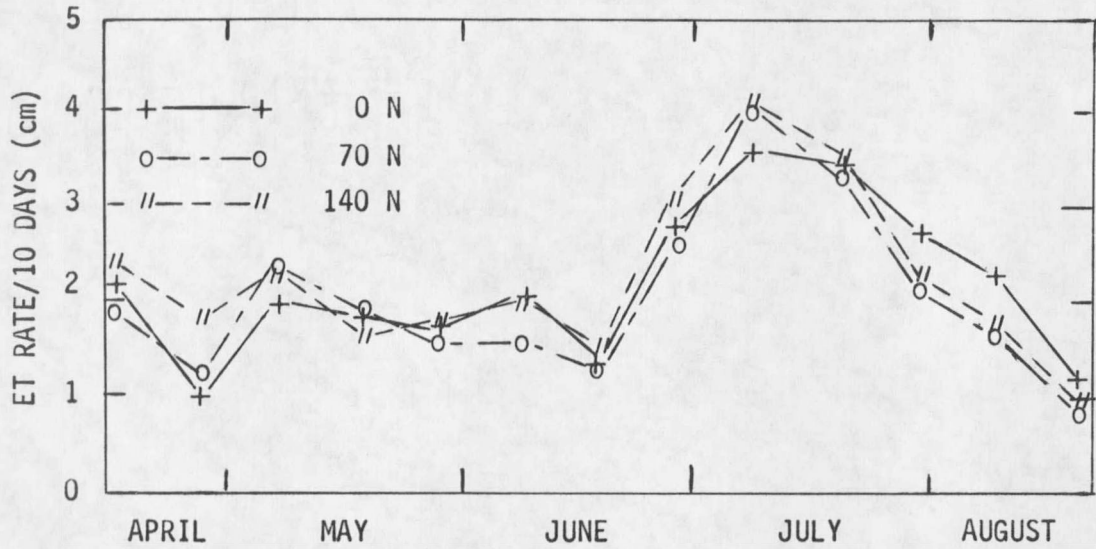


Fig. 11. The ET rates during 10-day periods in 1969: The effects of N fertilizer rates.

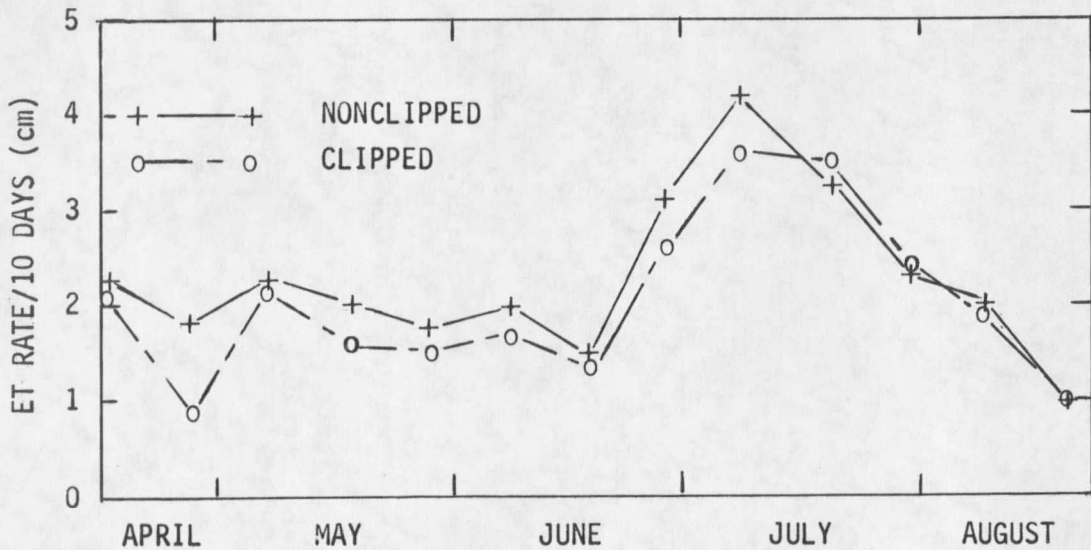


Fig. 12. The ET rates during 10-day periods in 1969: The effects of clipping frequency.

Table 14. Total ET during 1969: The effects of N fertilizer rates and clipping frequency.

Clipping frequency	N rate, kg/ha			Mean*
	0	70	140	
	<u>ET (4/11 to 7/2)†, cm</u>			
Nonclipped	16.5	15.7	18.4	16.9A
Clipped	<u>13.8</u>	<u>14.0</u>	<u>15.2</u>	14.3B
Mean*	15.1a	14.8a	16.8a	
	<u>ET (4/11 to 7/28)*, cm</u>			
Clipped	22.0a	23.0a	24.7a	23.2

*Means followed by the same letter (N means, lower case; clipping means, upper case) are not significantly different (P = .05).

†Nitrogen x clipping interaction is not significant (P = .05).

Water-Use Efficiency

Accumulative ET from April 11 to July 2 increased in a linear manner as the season progressed ($Y = 0.447 + 0.196X$, $r^2 = 0.997$). In North Dakota, Smika et al. (66) also reported that accumulative ET increased in a linear manner. Accumulative dry matter on nonclipped plots from April 9 to July 3, increased in a cubic manner as the season progressed on both N fertilized and nonfertilized plots

$$\text{(nonfertilized, } Y = 7.73 - .406X + 3.76 \times 10^{-2}X^2 - 2.58 \times 10^{-4}X^3 \text{);}$$

$$\text{(N fertilized, } Y = 6.98 - .165X + 5.63 \times 10^{-2}X^2 - 3.87 \times 10^{-4}X^3 \text{).}$$

ET and dry matter yield on both N fertilized (Fig. 13) and nonfertilized plots (Fig. 14) was closer related during the first part of the growing season than the last part. Nitrogen fertilization did not affect the accumulative ET curve, but it increased dry matter yield at a faster rate than ET.

Water-use efficiency for both N fertilized (Fig. 14) and non-fertilized (Fig. 13) plots increased as the growing season progressed. Nitrogen fertilization steadily increased the water-use efficiency as the growing season progressed over that of the nonfertilized plots. Application of 70 N increased the mean total water-use efficiency 90%, and application of 140 N caused no significant additional increase over that of the 70 N treatment. The increase in water-use efficiency resulted from increased dry matter yield and not from decreased total ET. In Montana, Black and Reitz (5) reported similar water-use

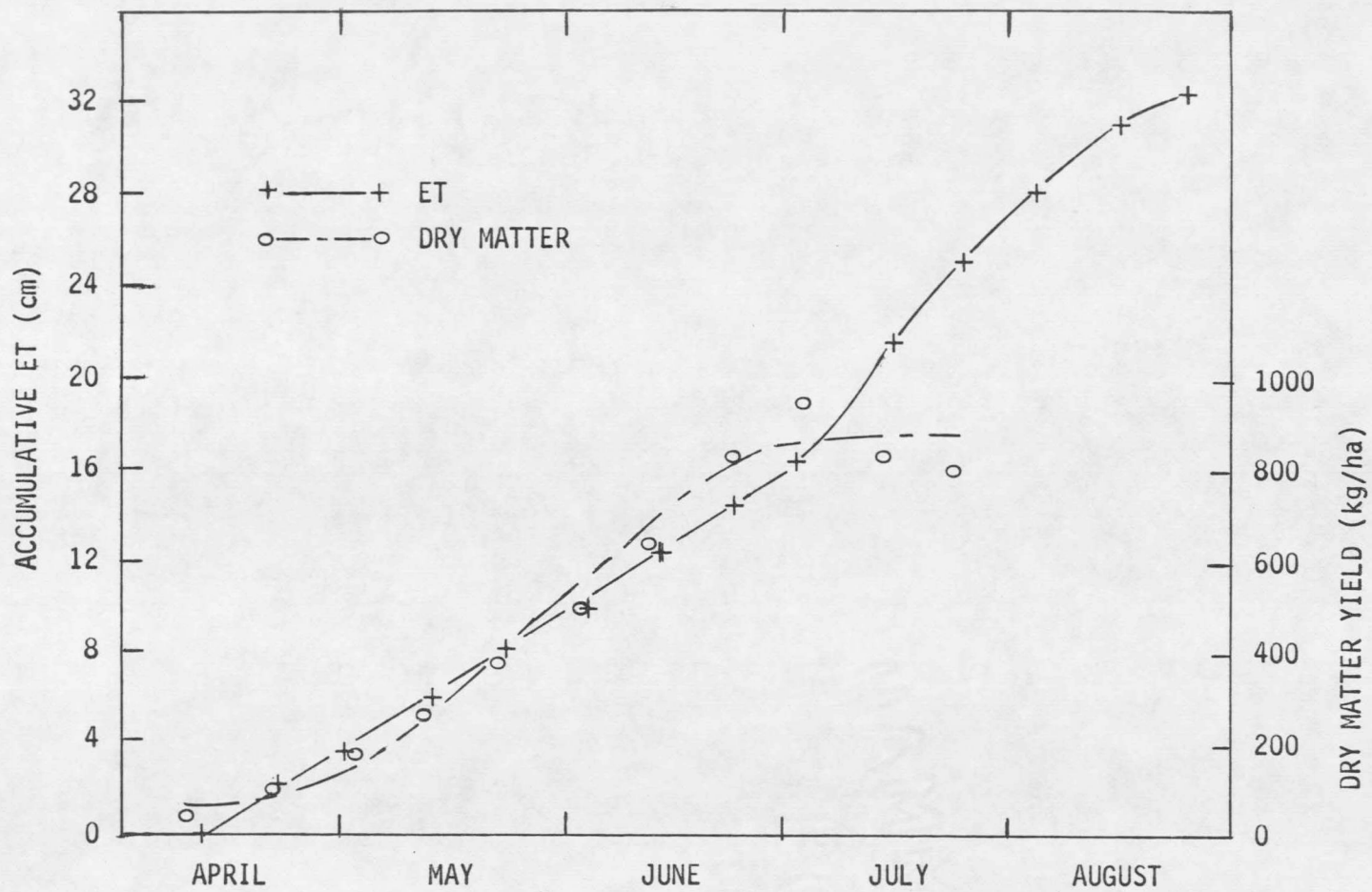


Fig. 13. Accumulative ET (cm) and accumulative dry matter yield (kg/ha): Seasonal patterns during 1969 on nonfertilized nonclipped plots.

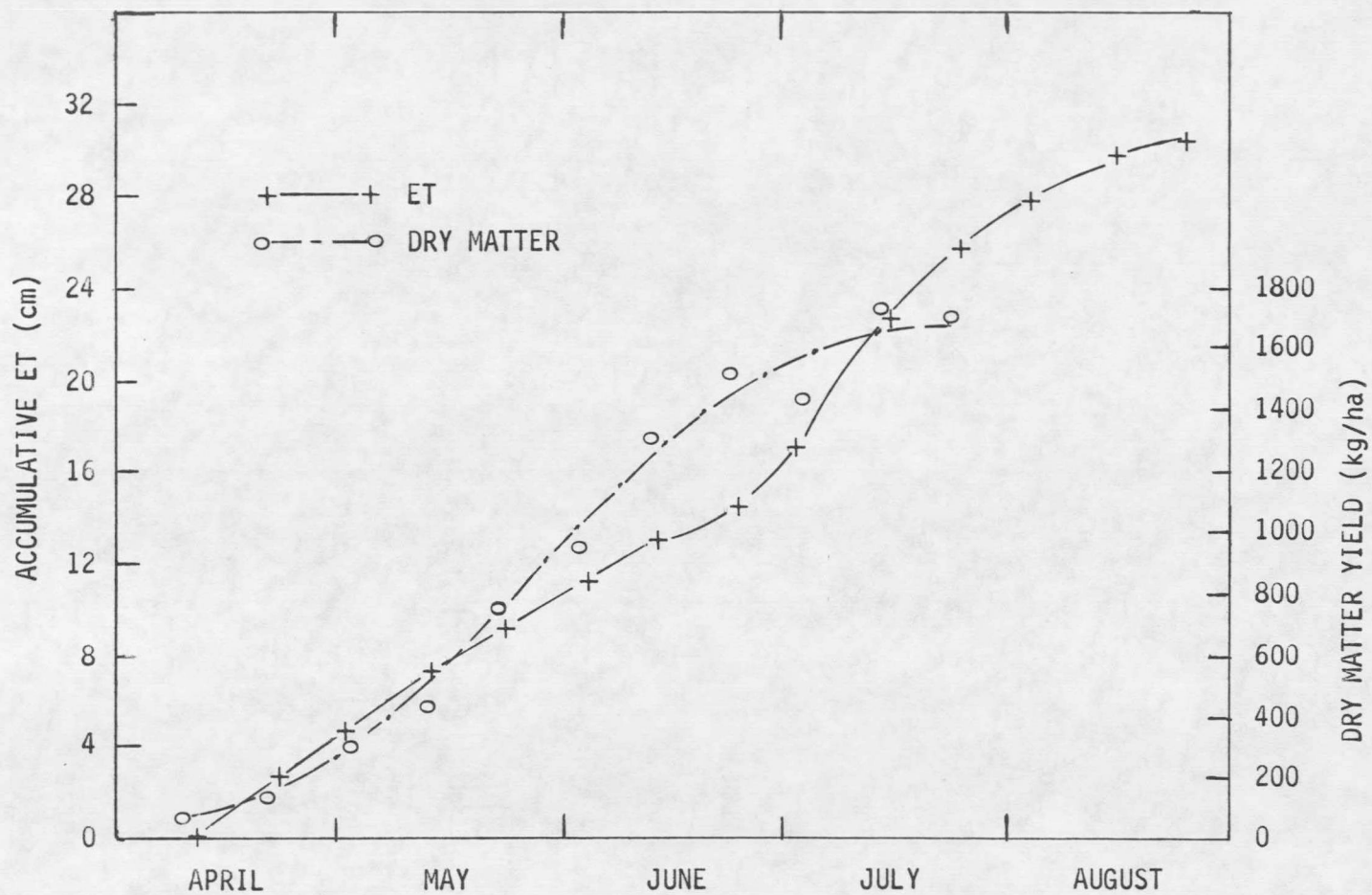


Fig. 14. Accumulative ET (cm) and accumulative dry matter yield (kg/ha): Seasonal patterns during 1969 on N fertilized nonclipped plots.

efficiency data for this same species when grown in 76-cm rows with various N fertilization rates.

Nonclipped plants produced maximum dry matter by July 2 (average over N treatments) and used 16.9 cm of water as ET (Table 14). However, clipped plants required 26 more days to produce maximum dry matter and, by this time, had used 35% (6.3 cm) more water as ET than nonclipped plants. Thus, the total water-use efficiency of clipped plants was 43% less than nonclipped plants (Table 15). Hölmen et al. (28), in North Dakota, reported that clipping Bromus inermis decreased water-use efficiency because it decreased dry matter yield faster than it decreased ET.

Table 15. Water-use efficiency* during 1969: The effects of N fertilizer rates and clipping frequency.

Clipping frequency	N rate, kg/ha			Mean†
	0	70	140	
	----- kg/ha-cm -----			kg/ha-cm
Nonclipped‡	50	90	109	83A
Clipped¶	<u>28</u>	<u>57</u>	<u>55</u>	47B
Mean†	39b	74a	82a	

*Water-use efficiency = forage produced (kg) /soil water used + seasonal precipitation (cm)

†Nitrogen x clipping interaction is not significant (P = .05). Means followed by the same letter (N means, lower case; clipping means, upper case) are not significantly different (P = .05).

‡Harvested 7/2.

¶Harvested 7/28.

SUMMARY AND CONCLUSIONS

The effects of 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 P, (4) extraction of soil water, and (5) 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 1969 treatments were determined by measuring head heights and dry matter yields in 1970.

Plant Growth Characteristics

Over 62% of the floral tillers present July 2, 1969, on non-fertilized plots had started growth the previous autumn. Developmental stages of floral tillers initiated in the spring were about 4 weeks

behind those initiated in the autumn. At maturity, spring-initiated floral tillers had four green leaves, while autumn-initiated floral tillers had only three green leaves remaining because the first leaf had turned brown during May. Autumn-initiated tillers consisted of 32% floral and 68% vegetative tillers, while spring-initiated tillers consisted of 15% floral and 85% vegetative tillers at maturity.

Percentage crude protein and P content of forage from both clipped and nonclipped plots was highest during the last of April and decreased as the season progressed (maturity approached). Precipitation the last of June increased percentage of both crude protein and plant P; however, they started decreasing again by the last of July.

Nitrogen Fertilization Effects

Doubling the N fertilization rate (from 70 to 140 kg of N/ha) caused additional increases of the following soil and plant factors: (1) In 1969, it increased soil NO₃-N in the 0- to 7.5- and 15- to 30-cm depths, total dry matter yield 23%, and total crude protein yield 0.3-fold; and (2) during 1970, it increased head height 17% and total dry matter yield 32%. These additional increases were one-third or less over those produced by the 70 N rate, and probably do not justify the application of 140 N instead of 70 N on a solid stand of Stipa viridula, unless significant residual effects occur 3 or 4 years after application.

Nitrogen fertilization (average of 70 and 140 N rates) had no differential influence on the date when successive plant developmental stages occurred, but it did affect plant morphology and growth. Application of N decreased leaf-growth period by 10 days and the head-growth period by 15 days, which shortened leaf height by 11 cm and head height by 25 cm.

On nonclipped plots, N fertilization increased percentage of crude protein 0.4-fold during the first part of the growing season but only 0.2-fold during the last part. Only during May did N fertilization increase percentage of plant P.

On clipped plots, application of N increased dry matter, crude protein, and plant P. Dry matter yield of each clipping, first through fourth, was increased an average of 100% (90 kg/ha); for the fifth clipping, 250% (270 kg/ha). The total increase from all five clippings was 110% (700 kg/ha). Nitrogen fertilization increased percentage of crude protein 0.4-fold for the first through fourth clippings and 0.2-fold for the fifth clipping. The total crude protein increase was 180% (155 kg/ha). Only for the first clipping did N fertilization increase plant P percentage (0.25-fold).

On both clipped and nonclipped plots, application of 70 N increased dry matter yield 90% (645 kg/ha), crude protein yield 1.5-fold (114 kg/ha), and total plant P yield 0.8-fold (1.7 kg/ha).

Nitrogen fertilization increased soil water extraction in the 0- to 60-cm depth on various dates. However, N fertilization did not affect ET rate or accumulative ET pattern. Application of N increased water-use efficiency more as the growing season progressed. At final harvest, N fertilization had increased the mean water-use efficiency by 90% (35 kg/ha-cm).

During 1970 (second year), residual 70 N fertilizer doubled dry matter yield (505 kg/ha) but had no effect on head height. Residual 140 N fertilizer increased dry matter yield 32% (330 kg/ha) and head height by 15% (12 cm) over that of the 70 N rate.

Clipping Frequency Effects

Clipping affected both dry matter yield and nutrient content of forage. Clipping during 1969 reduced dry matter yield 22% (300 kg/ha). Clipping extended the duration of dry matter production by 26 days. Plants from clipped plots produced one-third of their total dry matter during July.

The clipping treatment gradually increased the percentage crude protein from the second to the fifth clipping; and by the fifth clipping, clipped forage contained 0.35-fold more crude protein than nonclipped forage. Clipping increased the mean total crude protein yield 25% (38 kg/ha) and had no significant effect on fertilizer N recovery. Clipping also increased plant P content 0.36-fold for the

second through fifth clipping.

Clipped forage always contained adequate crude protein and plant P to meet the minimum nutritional requirements for beef cows nursing calves (first 3 to 4 postpartum months). In contrast, nonclipped forage harvested after June 11 contained nearly adequate plant P, but inadequate crude protein.

Clipping did not affect extraction of soil water in the 0- to 120-cm profile when analyzed by 30-cm increments, and thus provided no evidence that clipping affected rooting depth. However, clipping decreased ET 0.35 cm/10-day period from May 18 until July 8 (not significant), resulting in 2.6 cm less water used as ET as of July 2. However, clipped plants required 26 additional days (after July 2) to produce their maximum dry matter. Plants from clipped plots used 6.3 cm more water than plants from nonclipped plots. Clipping decreased water-use efficiency 43% (36 kg/ha-cm), because it decreased dry matter production and increased ET.

The 1970 residual effects of the 1969 clipping treatment were reduction of dry matter yield 25% (265 kg/ha) and reduction in head height 20% (18 cm).

APPENDIX

Table 16. Botanical and common names of plant species mentioned.

Botanical name	Common name
<u>Agropyron cristatum</u> (L.) Gaertn.	Crested wheatgrass
<u>Agropyron dasystachyum</u> (Hook.) Scribn.	Thickspike wheatgrass
<u>Agropyron desertorum</u> Fisch.	Crested wheatgrass
<u>Agropyron intermedium</u> (Host) Beauv.	Intermediate wheatgrass
<u>Agropyron smithii</u> Rydb.	Western wheatgrass
<u>Artemisia frigida</u> Willd.	Fringed sagewort
<u>Bouteloua gracilis</u> (HBK.) Lag. ex Steud.	Blue grama
<u>Bromus inermis</u> Leyss.	Smooth brome
<u>Dactylis glomerata</u> L.	Orchardgrass
<u>Danthonia parryi</u> Scribn.	Parry oatgrass
<u>Elymus junceus</u> Fisch.	Russian wildrye
<u>Festuca scabrella</u> Torr. in Hook.	Rough fescue
<u>Hordeum jubatum</u> L.	Foxtail barley
<u>Koeleria cristata</u> (L.) Pers.	Prairie junegrass
<u>Lolium multiflorum</u> Lam.	Italian ryegrass
<u>Medicago sativa</u> L.	Alfalfa
<u>Selaginella densa</u> Rydb.	Dense clubmoss
<u>Stipa comata</u> Trin. & Rupr.	Needleandthread
<u>Stipa pulchra</u> Hitchc.	Purple needlegrass
<u>Stipa viridula</u> Trin.	Green needlegrass

Table 17. Temperature and precipitation recorded during 1968, 1969, and 1970 at the Soil and Water Conservation District research farm, Culbertson, Montana.

Month	Normal*	1968	1969	1970
Mean temperature, C				
April	5.9	4.7	8.8	4.0
May	12.7	10.7	11.9	12.1
June	17.0	15.6	13.8	18.9
July	21.4	19.9	18.7	21.2
August	20.1	17.2	21.4	20.2
September	14.0	13.3	14.3	13.3
Precipitation, cm				
April	2.38	0.22	4.59	8.30
May	4.06	2.26	1.93	7.87
June	8.53	10.26	8.86	5.28
July	4.54	3.32	6.24	12.54
August	3.78	11.73	2.64	3.88
September	<u>2.74</u>	<u>2.54</u>	<u>2.89</u>	<u>4.92</u>
Total	26.03	30.33	27.15	42.79

*Temperature normal based on town of Culbertson 50-year record; precipitation, 62-year record.
Town of Culbertson data used; farm record not available.

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