



Effects of clipping on carbohydrate reserves and dry matter yields of basin wildrye
by Lawrence Joseph Perry

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in Crop and Soil Science
Montana State University
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Abstract:

After establishment, spaced basin wildrye plants were clipped to 10 or 30 cm at three developmental stages in 1971. Total nonstructural carbohydrates (TNC) were measured 1, 2, 3, and 10 weeks following the initial clipping and after a regrowth clipping which was three weeks after each initial clipping. Seasonal TNC trends of unclipped plants were also determined. In an additional experiment, the effect of clipping to 45, 30, or 15 cm at three, six, and nine week intervals at three starting dates on total seasonal dry matter production of spaced basin wildrye plants in 1970 was studied. The same treatments were imposed in 1971 with three additional starting dates, earlier than in 1970.

Seasonal TNC levels of unclipped plants declined rapidly during June when many developmental events were occurring. After this time, TNC levels increased through the summer, except for a decline in mid-August associated with the following year's tiller development. TNC of plants clipped once or twice to 10 cm was significantly lower than plants clipped to 30 cm for all developmental stages at all dates following clipping with a greater decline associated with plants clipped twice to 10 cm. A restoration of TNC occurred within three weeks with plants clipped to 30 cm, but only a slight restoration occurred with plants clipped to 10 cm. TNC levels of clipped plants ten weeks after the initial clipping were generally lower in plants clipped to 10 cm than in unclipped plants or plants clipped to 30 cm.

Total seasonal dry matter yields were greatly reduced due to clipping, particularly at the later starting dates, during one year's clipping. The amount of regrowth following clipping appeared directly related to growing point removal. The dry matter yields during the second year of clipping were markedly lower on plants clipped to 15 cm, less so on plants clipped to 30 cm and not reduced by the 45 cm clipping. Yields associated with three week intervals were significantly lower than the six or nine week intervals.

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A thesis submitted to the Graduate Faculty in partial
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of

DOCTOR OF PHILOSOPHY

in

Crop and Soil Science

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August 1972

ACKNOWLEDGMENT

My sincere appreciation to:

Dr. S. R. Chapman, my major professor, for his advice, and wisdom, in preparation of this manuscript, as well as his generosity of time throughout the past two years.

Drs. C. S. Cooper and J. H. Brown for their assistance in the research and reviewing this manuscript.

Drs. W. E. Booth, J. M. Capric, and W. J. Dorgan for reviewing this manuscript.

The concerned M.S.U. faculty and students for their suggestions and inspiration.

Mr. Dennis Roseleip and Mr. Dave Roseleip, Project Technicians, for their assistance and interest in this study.

Montana State University for the monetary contributions which financed my assistantship.

My wife, Kathleen not only for typing the manuscript, but also in taking an active part in assisting with the research.

My daughter, Mary Eileen for the greeting smiles every day during this program.

My son, Lawrence Joseph III, for unknowingly active participation in life during the past year and a half.

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ABSTRACT

After establishment, spaced basin wildrye plants were clipped to 10 or 30 cm at three developmental stages in 1971. Total nonstructural carbohydrates (TNC) were measured 1, 2, 3, and 10 weeks following the initial clipping and after a regrowth clipping which was three weeks after each initial clipping. Seasonal TNC trends of unclipped plants were also determined. In an additional experiment, the effect of clipping to 45, 30, or 15 cm at three, six, and nine week intervals at three starting dates on total seasonal dry matter production of spaced basin wildrye plants in 1970 was studied. The same treatments were imposed in 1971 with three additional starting dates, earlier than in 1970.

Seasonal TNC levels of unclipped plants declined rapidly during June when many developmental events were occurring. After this time, TNC levels increased through the summer, except for a decline in mid-August associated with the following year's tiller development. TNC of plants clipped once or twice to 10 cm was significantly lower than plants clipped to 30 cm for all developmental stages at all dates following clipping with a greater decline associated with plants clipped twice to 10 cm. A restoration of TNC occurred within three weeks with plants clipped to 30 cm, but only a slight restoration occurred with plants clipped to 10 cm. TNC levels of clipped plants ten weeks after the initial clipping were generally lower in plants clipped to 10 cm than in unclipped plants or plants clipped to 30 cm.

Total seasonal dry matter yields were greatly reduced due to clipping, particularly at the later starting dates, during one year's clipping. The amount of regrowth following clipping appeared directly related to growing point removal. The dry matter yields during the second year of clipping were markedly lower on plants clipped to 15 cm, less so on plants clipped to 30 cm and not reduced by the 45 cm clipping. Yields associated with three week intervals were significantly lower than the six or nine week intervals.

INTRODUCTION

Basin wildrye (Elymus cinereus Scribn. and Merr.) has attracted attention of pasture and range managers because of its prolific production and early spring growth. This species was in the past confused with giant wildrye (Elymus condensatus Presl.). The spikes are usually compound on giant wildrye and not on basin wildrye (33). The blades are somewhat narrower (5 to 15 mm wide) on basin wildrye than on giant wildrye (15 to 35 mm wide) (33). The lemmas are more or less pubescent on basin wildrye, but glabrous to sparsely strigose on giant wildrye (33). Basin wildrye is found on river banks, in ravines, on moist or dry slopes and on the plains from Minnesota to British Columbia and south to Colorado and California. Giant wildrye is found on sand dunes, sandy or rocky slopes, and moist ravines, mostly near the coast from Alameda County to San Diego County, California, and on the adjacent islands off the coast (3).

Basin wildrye is a coarse, robust, bunch type perennial plant with stems up to 12 feet high; however, rhizomes have been reported. It produces an enormous number of tillers and large amounts of forage. In Montana it can be found growing in clumps of from 2 to 4 feet in diameter and from 3 to 6 feet or more in height (51). It is grazed to some extent while young, but soon becomes coarse and increasingly unpalatable as the plant matures. Lack of resistance to spring grazing is one of the major problems associated with basin wildrye (3, 42).

Basin wildrye formerly was very important as a winter forage plant in parts of Nevada, Utah, and Idaho, but overgrazing, especially during the spring months when growth was starting, has greatly reduced or eliminated it. It is moderately palatable to cattle and horses in California and the Northwest, except during the fall when it becomes very hard and dry. Winter rains soften it, and it is again grazed (3). In addition to forage use, another proposed use for basin wildrye may be as a snow catcher (vegetative barrier) on cultivated land.

Ergot (Claviceps purpurea) is another major problem associated with basin wildrye besides its lack of resistance to spring grazing. Livestock consumption of grass infected with ergot (sclerotia) may cause death loss.

Chapman (12) reported that basin wildrye is a highly cross pollinated species, indicating genetic variability. Basin wildrye is slightly higher in ash, crude fiber, and crude protein than are 67 common western range grasses but is slightly lower in ether extract and nitrogen-free extract (40).

Basin wildrye, an early cool season grass, begins growth at Bozeman, Montana in the later part of March, with the first leaves emerging considerably earlier than most other cool season grasses. It remains in the vegetative stage for a long time. The developmental events of this species occur over an extended period. Basin wildrye appears as the rancher's dream because of the extended vegetative stage

and prolific production. But this dream is plagued with the major problem of maintaining the species as a pasture plant. It seems to lack resistance to spring grazing (3, 42).

The sensitivity of basin wildrye to spring grazing may be related to low carbohydrate reserves. Experience has shown that it is hard to maintain this species under spring grazing conditions. This may be due to lack of adequate carbohydrate reserves when plants are grazed at a critical developmental stage; thus, the level of carbohydrate reserves may indicate why basin wildrye is sensitive to spring grazing.

LITERATURE REVIEW

Food reserves are essential for plant survival and production of tissues during periods when the photosynthetic activity cannot keep pace with food utilization. The formation of food reserves is dependent upon photosynthesis and available plant nutrients and moisture, as well as other factors. The principal organic materials stored in plants are carbohydrates, proteins, fats and oils (58). Carbohydrates, such as sugars, starch, or fructosans, are most readily available to the plant as building material or as a source of energy and usually are utilized before proteins and fats.

Smith (60) prefers the term "total nonstructural carbohydrates" to "total available carbohydrates". Total nonstructural carbohydrate (TNC) content is an estimate of the carbohydrate energy readily available to plants. Smith contends that the term "total available carbohydrates" is often confusing to animal scientists since ruminant animals also obtain energy from at least part of the structural carbohydrates. Sullivan and Sprague (64) and Weinmann (73) stated that structural carbohydrates—hemicellulose and cellulose—are not a significant source of reserve energy to the plant.

The type as well as the relative proportions of individual carbohydrate reserve components varies among grass species. Perennial forage grasses fall in two groups based on the type of nonstructural polysaccharide accumulated (59, 75). Grasses of subtropical and

tropical origin accumulate starch; whereas, those of temperate origin accumulate fructosans. All species in the tribes Aveneae, Festuceae, and Hordeae, of which Elumys cinereus is a member, appear to store fructosans (59, 75).

The particular plant part where reserve carbohydrates are stored varies widely between species. Carbohydrate reserves are stored in the roots, stem, and seed. Smelov and Morozov (57) reported that the significant accumulation of carbohydrate reserves is not confined to the underground plant parts but is found in the lower regions of the stems in grasses. In perennial ryegrass (Lolium perenne L.), Baker (4) reported that the percentage of total water soluble carbohydrate was consistently higher in stubble than in roots. Other workers (5, 64) have reported similar findings. Bromegrass (Bromus inermis Leyss.) and reed canarygrass (Phalaris arundinacea L.) store the largest proportion of their reserve carbohydrates in the rhizomes, and orchardgrass (Dactylis glomerata L.) and timothy (Phleum pratense L.) in the stem bases (58).

Seasonal fluctuations in carbohydrate reserves are certain to occur because of the dynamic changes in the seasonal growth pattern of perennial plants. Hyder and Sneva (35) concluded that growth rate and plant developmental phase determine the level of carbohydrate reserves in the stem bases of grasses. McCarty (48) concluded that carbohydrate storage in stem bases of mountain bromegrass (Bromus carinatus Hook.

and Arn.) throughout three seasons was inversely related to herbage growth. Working with Colorado wildrye (Elymus ambiguus Vasey and Scribn.) and mountain muhly (Muhlenbergia gracilis Hitchc.), McCarty (47) found that carbohydrate reserves decreased during periods of fast herbage growth and increased during periods of slower growth.

In perennial plants, the onset of spring growth usually causes a decline in stored carbohydrates (69, 73, 74, 75). Although the spring decline in carbohydrates is general, the level of carbohydrate reserves through the rest of the season is quite variable. One pattern is recovery of carbohydrate storage after the initial spring loss, with continuing increases in carbohydrate storage to the end of the season. For example, Lindahl et al. (43) reported that carbohydrates in rhizomes of switch cane (Arundinaria tecta Walt.) declined until the third leaf stage, then began to increase. Other examples of this pattern have been reported (48, 56, 71).

In many grass species carbohydrate reserves recover early in the season, but in others the reserves continue to decline until midseason (2, 27, 68). The lowest level for the season then occurs with flowering. Another pattern is a rise following the spring decline, and then later a decrease during seed ripening (22, 35).

The level of carbohydrate reserves of grasses varies not only seasonally but also diurnally. Holt and Hilst (34) found that a significant portion of the total nonstructural carbohydrates in brome grass

herbage was utilized during the night, but the diurnal fluctuations for other grass species were less. For the grass species they studied, TNC content in the herbage was lowest at 6 AM and increased linearly to a high at 6 PM.

Various environmental factors such as temperature affect the seasonal change in reserves. Above-optimum temperatures decreased the percentage of carbohydrates in Canada bluegrass (Poa compressa L.), Kentucky bluegrass (Poa pratensis L.) and orchardgrass (9) and also in timothy (6). Water stress as well as low light intensity may very well influence the amount of reserves.

The effect of herbage removal on carbohydrate reserves has been discussed extensively. Such questions as: At what degree of herbage removal will the reserves be severely depleted? What are the effects of plant development upon TNC depletion? What are the management considerations? These questions have been discussed in the literature for some time.

Carbohydrate reserves (TNC) are assumed to be used for the growth of new leaves after defoliation. After a certain quantity of leaf tissue is developed, restoration of reserve carbohydrates occurs, most often to a value near the original level. The carbohydrate reserves appear to be translocated to the aerial parts of the plant where they are used to produce new leaves. When sufficient new leaf tissue is formed, the carbohydrate is replenished in the reserve plant part.

Sampson and McCarty (56) found that grazing or cutting purple needlegrass (Stipa pulchra Hitchc.) once or twice during early growth did not prevent maximum accumulation of reserves, but removal of herbage (by grazing or cutting) between the time of flower stalk formation and seed maturity did prevent maximum accumulation of carbohydrate reserves. McCarty (48) found that clipping mountain brome grass three times at 5 day intervals during the spring decreased the sugars and starch stored in stem bases by one third. In a further contribution McCarty and Price (49) reported that clipping as well as grazing lowered the percentages of reserve carbohydrates in stem bases of mountain brome grass and slender wheatgrass (Agropyron trachycaulum Hitchc.); the degree of reduction depended on the time, frequency and closeness of herbage removal. Clipping plants early and at or near the close of the season decreased carbohydrate reserves less than clipping during the middle of the season, during seed ripening. The level of reserves was lowest in those plants clipped closely and frequently. Eight clippings to a height of 1 inch at 15-day intervals during the growing season reduced the reserves of mountain brome grass by 57%, and reserves of slender wheatgrass by 30%. Hanson and Stoddart (28) reported that there was 7% sugars and starch in the roots and stem bases of beardless wheatgrass (Agropyron inerme Scribn. and Smith) on protected areas and only 4.7% in those plants on heavily grazed areas. Clipping little bluestem (Andropogon scoparius Michx.) to the crown level at 2-week

intervals during 8 weeks of the vegetative stage reduced the combined percentage of sugars and polysaccharides by 50% in the roots and 73% in the herbage (lower internodes) (2).

Donart and Cook (23) found that the carbohydrate reserves of beardless wheatgrass and letterman needlegrass (Stipa lettermani Vasey) were significantly reduced when 90% of the herbage was removed during the 3 to 5 leaf stage. Herbage removal on both grasses during early season, when carbohydrate reserves were low, was considerably more detrimental than during late season, when carbohydrate reserves were high. Intensive clipping reduced the level of carbohydrate reserves in stem bases of hardinggrass (Phalaris tuberosa var. Stenoptera Hack.) more than clipping only at maturity (50).

Paulsen and Smith (53) reported that clipping bromegrass decreased the carbohydrate reserves, but not to the extent as reported by other workers with other species. Carbohydrate reserves recovered within five weeks following clipping. In Colorado grazing did not significantly decrease the carbohydrates of sand reedgrass (Calamovilfa longifolia Scribn.) on most sampling dates (76).

The effect of clipping during spring is important on the level of reserves present during the autumn. Plants require energy for respiration throughout the winter and for initiation of spring growth when there is insufficient photosynthetic area to meet energy demands. Hyder and Sneva (36) found that clipping crested wheatgrass (Agropyron

cristatum Gaertn.) between heading and anthesis resulted in lower autumn-storage of carbohydrate reserves than in unclipped plants. This pattern of clipping effects appeared to be related to a seasonal decrease in carbohydrates of unclipped plants during this period (35).

Davidson and Milthorpe (17, 18, 19) concluded that regrowth of orchardgrass following clipping was dependent upon carbohydrate reserves for only the first 2 to 4 days. During this period, stored carbohydrates were used for regrowth and respiration. Afterwards, regrowth was dependent upon other factors, such as photosynthetic rate and nutrient uptake. Ehara et al. (24) found that carbohydrate reserves, assimilated as labeled CO₂ by bahiagrass (Paspalum notatum Flugge.), were used to form leaves for six days after herbage removal. Smith and Marten (62) found that labeled nonstructural carbohydrates initially stored in the root and crown of alfalfa (Medicago sativa L.) were utilized as substrate for respiration of both roots and tops and as structural components of top growth. Ward and Blaser (69), working with orchardgrass, stated that carbohydrate reserves stimulated regrowth production for 25 days after partial or complete herbage removal. Davidson and Milthorpe reexamined Ward and Blaser's data and concluded that the rate of regrowth was only dependent upon carbohydrate reserves for the first 2-5 days and afterwards the rate of regrowth was dependent upon leaf area.

The effect of clipping on the accumulation of carbohydrates has been well reviewed by many other workers with other species. Carbohydrates generally decline for several days following herbage removal, then begin to recover after one to three weeks. However, the depletion of reserves as well as recovery varies among species, time of sampling, and intensity of clipping. Reviewing the literature concerning carbohydrate reserves is confusing, as many factors have to be considered in addition to the above such as: (1) Amount of photosynthetic material remaining following clipping, (2) Time lapse between clipping and actual sampling, (3) Plant part sampled, and (4) Method of carbohydrate analysis (77). Many factors other than the level of carbohydrate reserves need to be considered in order to make valid conclusions from the literature.

Excessive herbage removal will reduce carbohydrate reserves which will thus reduce vigor. Severe herbage removal by cutting or grazing not only decreases current herbage growth, but the reduction of reserves will reduce productivity during following years. For example, Odgen and Loomis (52) reported that, when carbohydrate reserves of intermediate wheatgrass (Agropyron intermedium (Host) Beauv.) were depleted to 1% dry weight, vigor of the grass was too low for recovery from a clipping treatment. Depletion of reserves below a certain critical level may lead to the death of the plant, and on a large scale manifests

itself in the reduction of basal cover in range land subjected to excessive defoliation by cutting or overgrazing.

Plants with low reserves may be more susceptible to adverse conditions, such as drought, heat, frost, and disease. According to Julander (39), a high level of carbohydrate reserves is essential to heat and drought resistance. If clipping and overgrazing decrease the reserve level, then plants are more susceptible to exposure to high temperatures than plants with a high content of reserves.

Many errors may be made by assuming that the effects of clipping are similar to those of grazing. Grazing removes herbage at varying heights from plant to plant; whereas, clipping removes all herbage to a certain height. Watson and Ward (70) found that carbohydrate reserves of dallisgrass (Paspalum dilatatum Poir.) increased as the percentage of unclipped tillers increased from 0 to 10%. Therefore it appears that if grazing leaves intact tillers while removing others, grazing may be less detrimental than clipping. However, grazing may be more detrimental than clipping if grazing removes herbage from some plants and not others. The ungrazed plants may compete for light, nutrients, and water with grazed plants.

The effects of clipping on dry matter yield have been investigated many times. In most cases where only a single species rather than a mixture of species has been treated, clipping has reduced dry matter yield. Previous reviews of the literature (14, 29, 30, 67) have all

pointed out that the more frequent and severe the clipping, the more dry matter yield is depressed. In addition to literature considered by these reviews, reduction of dry matter yield by increased frequency and intensity of harvesting has been shown also by other investigators (13, 20, 54). For example, clipping switchgrass (Panicum virgatum L.) sods at 14 day intervals reduced the total dry weight of tops by 13.1% and sideoats grama (Bouteloua curtipendula (Michx) Torr.) by 47.5% (7). Carter and Law (11) found a similar relationship for many native species of the northwestern United States. Everson (25) working with western wheatgrass (Agropyron smithii Rybd.) found that clipping plants to 2.5, 5.0, 7.5, and 10.0 cm four times at 3-week intervals reduced the total yields of tops, roots, and rhizomes.

Studies that have considered the effect of clipping on dry matter yield have usually included one to three heights of cutting combined with several frequencies of cutting. Frequency has been variously defined by a fixed interval between treatments, or cutting was repeated when regrowth reached a predetermined height or growth stage. Cutting when regrowth reaches a certain height or growth stage seems to have considerable merit when the objective is to determine desirable practices of harvesting hay. Cutting at specified intervals may be more useful for designing grazing systems.

Generally clipping reduces yields, but it may increase yields the first year or effects of clipping may increase with repeated treatments

over successive seasons. Delayed effects of clipping seem to be most common for low-growing grasses, such as blue grama (Bouteloua gracilis (H.B.K.) Lag.), buffalograss (Buchloe dactyloides (Nutt.) Engelm.) and Kentucky bluegrass. In a study by Albertson et al. (1), production of blue grama and buffalograss was not affected or increased after one year of clipping, but continued mid-season clipping reduced yields compared to plots clipped only at the end of the season. Graber (26) found that three close clippings of Kentucky bluegrass increased the first year's production but decreased the second year's production. Canfield (10) obtained essentially the same results with black grama (Bouteloua eripoda (Torr.) Torr.).

Height of cutting may be more important than frequency of cutting in grasses. Jacques and Edmond (37) found this to be true for orchard-grass and perennial ryegrass. Frequent clipping may prevent recovery of carbohydrate storage, and height of clipping becomes confounded with removal of various plant parts. Matches (45) studied the effect of clipping tall fescue (Festuca arundinacea Schrab.) to 1, 2.5 or 4 inches in a factorial combination of leaving 0, 10%, 20% or 30% intact (uncut) tillers. Increasing the height of stubble or leaving intact tillers increased tillering, yields, and carbohydrate reserves.

Generalizations about the effects of clipping at various times during the season are difficult because results have not been clear. Hedrick (29) concluded from his review of the literature that early

removal of herbage was more harmful than later removal. Smith (61) found that clipping of native tropical tallgrass range of Northern Territory, Australia, early in the season reduced yields more than clipping later in the season. Sampson and McCarty (56), however, reported that two early clippings had little effect on total yield of purple needlegrass. Stoddart (63), working with bluebunch wheatgrass (Agropyron spicatum Scribn. and Smith) concluded that enough time should be left after the last defoliation or before the first defoliation for the plants to store carbohydrates before the end of the growing season. Over a four year period Knoblauch et al. (41) found that clipping timothy during anthesis was less detrimental than clipping during early heading.

Clipping generally reduces yield, but not in all cases. Fall mowing increased yield of crested wheatgrass from 1,374 pounds per acre to 1,755 pounds per acre (44). Cooper (16) recorded no effect of clipping at two, four, and six inches for four years in a native meadow in Oregon. Heinrichs and Clark (31) in southern Saskatchewan, Canada, found that Russian wildrye (Elymus junceus Fisch.), crested wheatgrass, and streambank wheatgrass (Agropyron riparium Scribn. and Smith.) produced more forage when cut at six-week intervals for five years than when cut at three- or eight-week intervals.

The relationship of dry matter yield to physiological processes has been studied. Leaf area index (LAI), which is the ratio of leaf

area to ground area, has been studied in reference to pasture growth (21). If optimum LAI's are not present, production will be reduced by defoliation, since productivity depends on leaves to intercept light. Tall-growing grasses, such as orchardgrass, bromegrass, and basin wild-rye, that have most of their leaf area high on the plant are almost totally dependent on stored reserves to produce recovery growth after close clipping since all or most of the photosynthetic area is removed. The initial regrowth of short-growing grasses, such as Kentucky bluegrass and creeping red fescue (Festuca rubra L.) are less dependent upon stored reserves because clipping does not remove all photosynthetic material.

The location of the meristematic tissue and the manner in which the stems elongate may influence the response of grasses to clipping or grazing. Branson (8) and Rechenthin (55) have shown that grass species vary in the number of short basal internodes on the stems and also in the ratio of fruiting to vegetative stems. Branson (8) concluded that grasses producing mostly fruiting stems were less tolerant to grazing than those producing mostly vegetative stems.

The amount of regrowth produced by certain grasses following cutting in the spring may depend on the stage of bud development as well as the level of carbohydrate reserves. In bromegrass, Teel (65, 66) found the critical stage occurred when the young stems were beginning to elongate. Close spring clipping or grazing at this "early-jointing"

stage removes the majority of the growing tips. Regrowth then had to come from basal buds. Regrowth was slow, however, because the basal buds were not yet well enough developed to initiate growth, or they initiated growth slowly. This critical stage or date when clipping removes the growing point is reached by different grasses on different dates. After bromegrass had reached the early heading stage, there was good regrowth, because the basal buds were well developed and readily initiated new growth (66).

Cook and Stoddart (15) found that if harvesting crested wheatgrass while the terminal bud was still relatively close to the crown removed any part of the developing culm below the uppermost culm node, regrowth came only from stimulated axillary buds at the base of the culm. If clipped above the last node, the shoot continued to elongate and develop.

It is apparent that in making reliable management decisions, knowledge of morphological and physiological development of grasses is needed. One needs to know when the shoots begin to elongate, the length of period of elongation, crown bud and tiller development, and the status of carbohydrate reserves at various stages of development.

Carbohydrate reserve and dry matter data have been used to formulate management concepts. Management practices and the effect of clipping often can be evaluated by observing the level of carbohydrate reserves. The effects of clipping on seasonal trends of carbohydrate

reserves of species sensitive to spring grazing such as basin wildrye will help pasture and range managers to formulate better management systems (42).

Concerning this problem with basin wildrye, Krall et al. (42) reported the effects of differential herbage removal from growth initiation to full bloom, followed by removal of all growth to a 5 cm height in the fall. They found that yields were reduced in the year of clipping and the year following, particularly when plants were clipped at the boot stage. This period coincided with the rapid elevation of growing points above the soil surface and a decrease in total available carbohydrates (Figure 1).

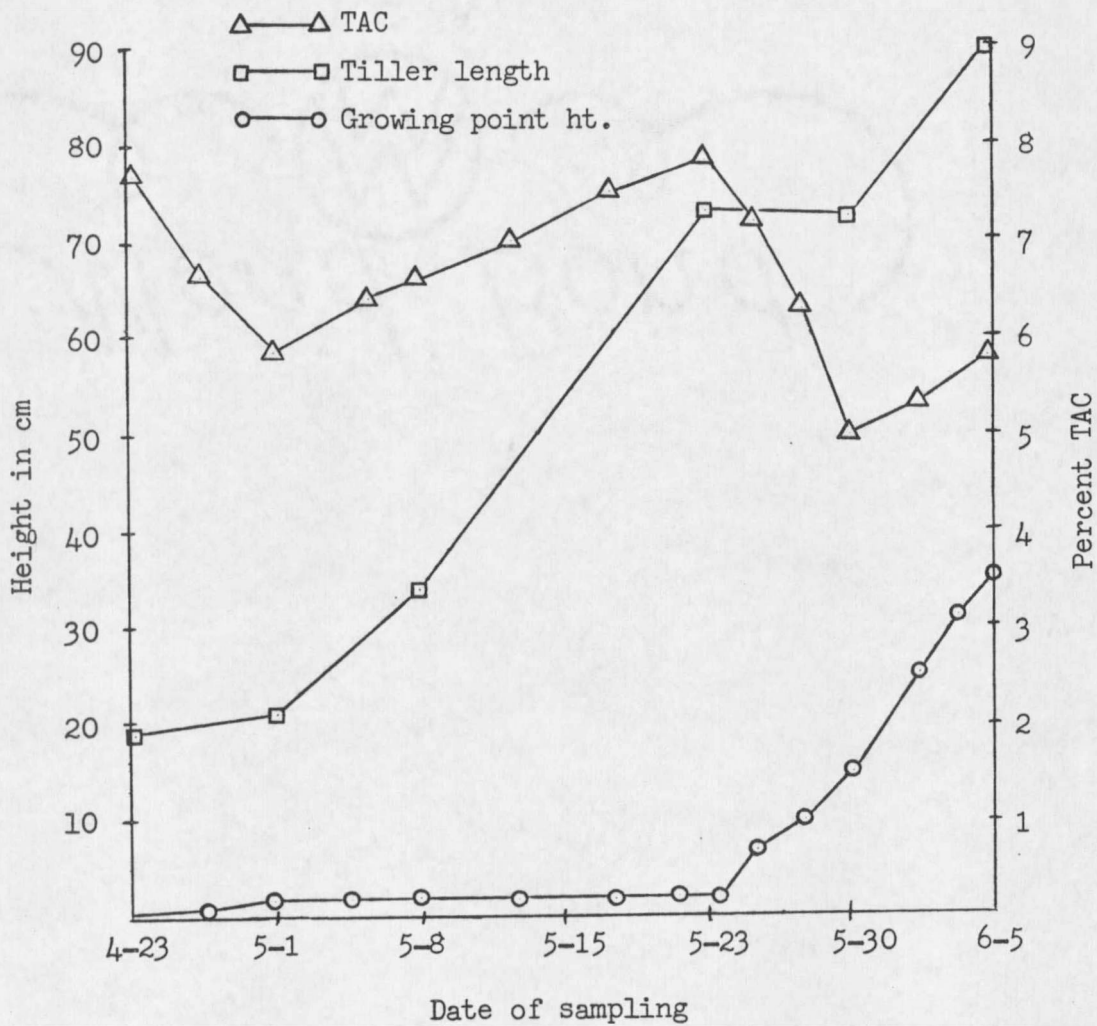


Figure 1. Tiller length, height of growing point and total available carbohydrates (TAC) in crowns of basin wildrye during the early spring growing season at Bozeman, Montana (42).

MATERIALS AND METHODS

Carbohydrate Studies

One thousand individual basin wildrye seedlings from a Soil Conservation Service accession, No. P-15609 (M-48)^{1/}, were grown in peat-moss pots in the greenhouse to the 4-5 leaf stage. On August 5, 1970, 840 seedlings were transplanted to the field in a 3-foot grid and hand watered each day for one month to assure establishment. Replacements of the same age were transplanted for those seedlings which died. Nothing more was done with the nursery until Spring 1971. Individual plants were scored as to degree of vigor in the Fall, 1970, and Spring, 1971, on a visual scale of one (excellent) to five (poor). The nursery consisted of 28 rows and 30 columns with one row on the outside as a border.

To determine the seasonal trends in total nonstructural carbohydrates (TNC), four plants per date were analyzed for TNC beginning on April 20, 1971, and at seven day intervals thereafter until October 26. Plant height in cm was measured. For each sampling interval, location of the growing point and new tillers at the basal stem area were noted for each plant.

To determine the effect of one clipping on TNC, plants were clipped to 10 or 30 cm starting at three developmental stages. The developmental

^{1/} Seed stocks were provided by the Soil Conservation Service, Plant Materials Center, Bridger, Mont. I gratefully acknowledge their cooperation.

stages were late vegetative (clipped on June 1), early boot (clipped on June 14), and inflorescences completely emerged (clipped on June 23). The immediate effect of clipping was measured by TNC samples taken 1, 2, and 3 weeks following the initial clippings for each developmental stage. TNC was also estimated 10 weeks after the initial clipping for the first two developmental stages and 11 weeks after the last stage. This interval represented recovery from clipping or the level of TNC going into the fall.

To determine the effect of two clippings on TNC, additional plants were re-clipped three weeks after each initial clipping to 10 or 30 cm. TNC was estimated 1, 2, and 3 weeks following the second clipping as well as in the fall (i.e. the same time as those plants clipped once).

To determine the effect of clipping to 10 or 30 cm on dry matter accumulation, the herbage was removed to these heights from the plants which were sampled for TNC, and dried in an oven to a uniform moisture level of about 12%. Height of plant regrowth in cm was measured at each TNC sampling. The type of regrowth was scored in terms of vegetative and/or fertile tillers.

The experiment was conducted as a randomized complete block design with two replications. The basic experimental unit consisted of four plants. The net result is that each treatment mean is of eight plants treated alike. A separate analysis of variance was conducted for plants clipped once or twice within each developmental stage.

Therefore a total of six analyses of variance were conducted. The same procedure was used for dry matter accumulation and plant height.

During 1971 no supplemental irrigation or fertilizers were applied. Weeds were hand removed.

That portion of the plant which was analyzed for TNC was the basal 10 cm of all tillers except for those plants sampled for seasonal TNC during April and May. The basal 5 cm was analyzed during April and May as stem height was less than 10 cm. Leaf sheaths were not included in the sample. After removing the sampled portion from the plant, the material was washed and placed in an oven at 100 C for 60 minutes followed by 24 hours in an oven at about 70 C. The dried samples were passed through a 40-mesh Wiley Mill screen and stored for TNC analysis.

The method of TNC analysis was a modification by Smith (60) that was first described by Weinmann (72) and later changed slightly by Lindahl et al. (43). The TNC was extracted with takadiastase enzyme solution (Clarase 900, Miles Laboratories, Inc., Elkhart, Ind.). The fructosans extracted in the solution were hydrolyzed to monomers with sulfuric acid. Reducing power was measured by the Shaeffer-Somogyi copper-iodometric titration method as described by Heinze and Murneek (32). Results were reported on a percentage dry weight basis using a glucose standard.

In September 1971, two new tillers on each of 12 plants were tagged with fish line to determine if these were the following year's tillers.

Seasonal trends in TNC were also determined for 1970 and the spring of 1971 from plants grown in the dry matter management study nursery described below. Four plants per date were analyzed for TNC beginning on June 7, 1970, and at seven day intervals thereafter until September 14, 1970. During the spring, 1971 plants were sampled for TNC from April 6 to June 15 at seven day intervals. Plant height, height of growing point, and length of inflorescence in cm were also determined at each TNC sampling date in 1970. The basal 10 cm of a representative sample of tillers from each plant was analyzed. The basal 10 cm of the attached previous year's tillers were included for plants sampled during 1971 and June 1970 as it was felt the previous year's plant material was furnishing energy to the new tillers. For each TNC sampling period, except in 1971, the number of new tillers and individual tiller lengths were measured from 12 representative stems of a single plant.

Dry Matter Management Study

Individual basin wildrye seedlings from the S.C.S. collection, Wyo. 107, were grown in peat-moss pots in the greenhouse to the 2-3 leaf stage. Seedlings were then transplanted to the field in early August, 1968, in a 3-foot grid and hand watered each day for one month to assure establishment. Replacements of the same age were transplanted

for those seedlings which died. In May, 1969, timothy was interseeded in 30 inch bands for weed control. Other than a single irrigation in mid-July, 1969, nothing more was done with the nursery until the spring of 1970. The nursery consisted of 28 rows and 34 columns with one row on the outside as a border.

No supplemental irrigation, except as noted above, or fertilizers were applied from 1969 to completion of the study. Weeds were hand cultivated during 1968 and the spring of 1969. Thereafter, weeds were hand removed. The growth of timothy throughout the study was controlled by mowing with a lawn mower to about two inches.

To determine the effect of clipping on dry matter production, individual basin wildrye plants were clipped to 45, 30, or 15 cm starting on June 6, 15, and 22, 1970. Dry matter accumulation was then measured at 3, 6, and 9 week intervals thereafter until the current year's production ceased. The material was dried in an oven to a uniform moisture content of about 12%. Height of growth in cm from soil surface to the top of the plant was also measured for each harvest. These treatments were also imposed during 1971 with three additional starting dates (May 17 and 25, and June 2), all earlier than in 1970. The same clipping treatments are being continued during 1972 and 1973 as part of a continuation of the present study. Plants were observed as to characteristics of regrowth, location of growing point, and relative size in growth at each harvest.

The average number of tillers per mature plant (late boot stage to fully headed) was estimated on 52 plants on June 29, 1970, by measuring the circumference of the plants in cm and counting the tillers in a 15 cm circumference of a representative portion of each plant.

Soil temperature was recorded 7 cm below the soil surface at two-day intervals for two weeks in April, 1972, within plants that had been clipped to 45, 30, 15, or 0 cm the previous fall. Soil temperatures might account for differences in plant growth in the spring that had been clipped at different heights the previous fall.

The experiment was conducted in a randomized complete block design with two replications. The basic experimental unit consisted of six plants. The net result is that each treatment mean is of a maximum of 12 plants treated alike. Starting dates, clipping heights, and intervals were jointly analyzed with their interactions as a factorial arrangement for 1970 and separately for the first three and last three starting dates for 1971. Two analyses of variance were conducted in 1971 as the potential existed that the clippings in 1970 had an effect on plants in 1971. Therefore a total of three analyses of variance were conducted for dry matter production.

Both studies were located at the Montana Agricultural Experiment Station 6 miles west of Bozeman, Montana. The soil in the nurseries is Amsterdam silt loam.

The climatological data for the station during the study as well as a long term average is given in Table 1. The average freeze free season between 1958 and 1970 was 102 days, with May 31 and September 10 as the average date for the last and first freeze, respectively.

Table 1. The average temperature and total precipitation for each month during 1970 and 1971 and the long term average from 1958 to 1970 at the Montana Agricultural Experiment Station, Bozeman, Montana.^{1/}

Month	1970		1971		1958-1970	
	Ave. temp. °F	Total precip. in.	Ave. temp. °F	Total precip. in.	Ave. temp. °F	Total precip. in.
Jan.	23.9	.57	23.5	.40	21.1	.52
Feb.	34.8	.31	29.0	.51	26.6	.36
March	28.9	1.57	32.5	.41	29.9	.96
April	35.8	1.43	40.1	3.09	40.6	1.32
May	52.2	3.62	51.0	3.07	51.1	2.35
June	61.5	1.57	57.6	2.85	57.9	2.80
July	66.2	3.38	63.0	.25	65.0	1.42
Aug.	67.6	.49	68.3	.97	63.7	1.25
Sept.	50.9	2.21	51.6	2.10	53.7	1.20
Oct.	41.1	1.92	42.3	.71	45.1	1.31
Nov.	33.1	1.26	33.3	.67	32.1	1.07
Dec.	22.8	.50	19.7	.21	23.8	.46
Total		18.83		15.24		15.02

^{1/} Official U. S. Weather Bureau data provided by Dr. J. M. Caprio.

RESULTS AND DISCUSSION

Carbohydrate Studies

Establishment and growth of plants were good with no winter kill following transplanting. The vigor of the plants in the carbohydrate study in the spring, 1971, averaged 2.8.

The seasonal trend of TNC of unclipped plants sampled at seven day intervals in 1970 and Spring, 1971, from basin wildrye plants grown in the dry matter management nursery is shown in Figure 2. The reserves in 1970 were low during June when plant height and growing point height were rapidly increasing. The averaged length of the inflorescence increased from 7.0 to 16.3 cm between June 7 and July 5, 1970. An average of two new tillers per stem was initiated during June with an average length of 0.65 mm at the end of June. These grew to an average length of 1.10 mm and 2.10 mm by August 16 and October 16, 1970, respectively.

During 1970 TNC increased markedly during July and August. The data in Figure 2 indicate a significant decrease in TNC from August, 1970, to April, 1971. TNC was apparently utilized for respiration and initiation of the first photosynthetic tissue in the Spring.

The TNC levels reported for April, May and June in Figure 2 may have been influenced by sampling technique. The attached previous year's tillers were included in the analysis for TNC. Separating the previous year's tillers from the current year's tillers indicated a

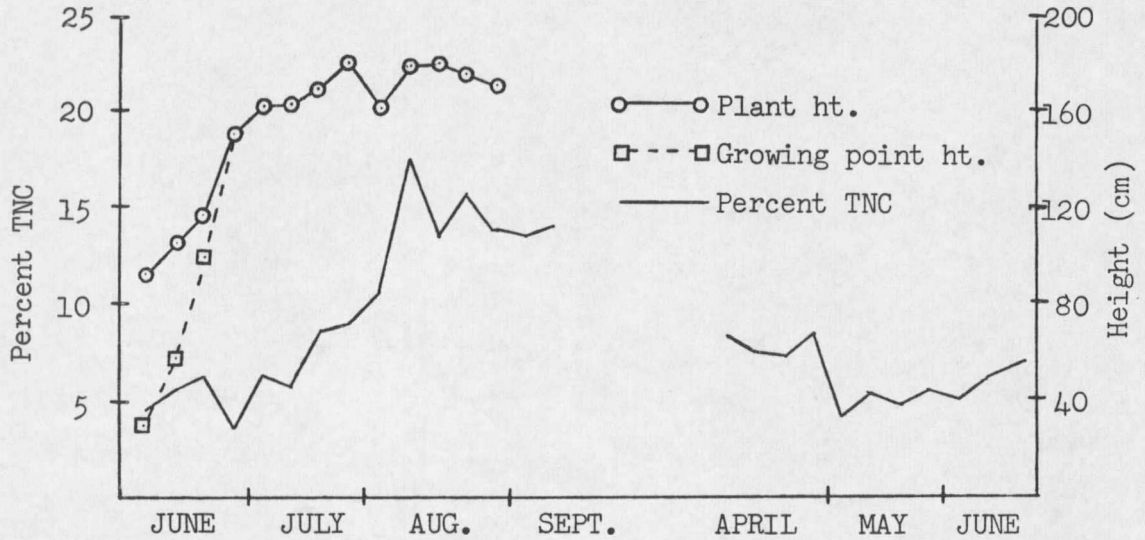


Figure 2. Seasonal trends in TNC, plant and growing point heights of unclipped basin wildrye plants at 7 day intervals during 1970 and 1971.

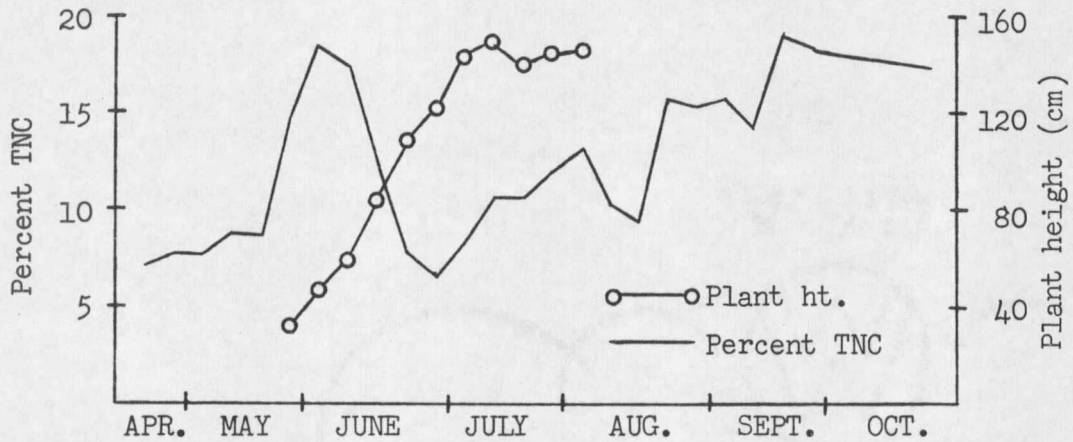


Figure 3. Seasonal trends in TNC and plant height of unclipped basin wildrye plants at 7 day intervals during 1971.

dilution effect due to the former. TNC of old and new tillers was 2.3 and 10.2%, respectively, averaged over the May 25, June 1 and 8, 1971, sampling periods.

The seasonal trend of TNC of unclipped plants sampled at seven day intervals was also determined for 1971 from the basin wildrye plants grown in the carbohydrate nursery (Figure 3). TNC was between 7 and 8.5%, a moderately low level, during April and the first half of May. During this time the growing point was observed to be at or below the soil surface. Ranchers would like to graze basin wildrye during this period because of the amount of vegetative material, but, as TNC is low, grazing may deplete TNC to untenable levels.

The rapid TNC increase during the second half of May occurred during the late vegetative stage with the growing point at or below the soil surface. TNC declined rapidly during June, from 18.5 to 6.7%. Many developmental events were associated with the rapid decline. During this period: (1) Plants increased from 45 to 125 cm in height (Figure 3), (2) Growing points were elevated from near the soil surface to nearly maximum height, (3) Inflorescences became fully expanded, and (4) New tillers for the following year (based on visual observations) were initiated. These minute new tillers were noted at the root-stem junction area. All of these developmental events apparently required large amounts of energy. The rapid decline in TNC in June indicated that the plants were not manufacturing the required photosynthate for

growth and development and must have been utilizing reserves. Thus, June (in Bozeman) is a critical period in both the seasonal growth cycle and in the management of basin wildrye.

TNC was rapidly restored in July, and seed maturation occurred during the latter part of July. A depression in TNC did not occur (Figure 2) at this stage as reported by other workers with other species (22, 35).

TNC declined in August when tillers initiated in June began to grow. Visual observations indicate that, once initiated, these tillers did not develop further until August. These tillers grew an average of 2.5 cm between August 1 and 20, 1971, and then stopped growth until the following spring when they became the source of 1972's vegetative material. The effect of the current year's management of this species on tiller initiation may greatly affect the following year's growth. Severe grazing of this species not only lowers TNC but may also affect tillers for the following year.

TNC levels of unclipped plants in September were about 17%, which was similar to the peak TNC level on June 1.

The level of TNC during September, 1971, was higher than that reported for 1970 (Figure 3 vs 2). This may reflect differences in the age of the plants. Also, the plants in the carbohydrate nursery remained green longer than the older plants in the dry matter management nursery. Because of a longer photosynthetic period, younger

basin wildrye plants may be able to store more TNC during the summer than older plants.

The two years' data (Figures 2 and 3) indicate TNC levels are critical during June (in Bozeman) which must be considered in management decisions. The lowest level of reserves in 1970 (Figure 2) occurred at the same time as in 1971 (Figure 3), although the identity of dates would not be expected.

The seasonal trends of TNC of basin wildrye reflect two years' data at one location. Similar trends at other locations at similar stages of development would be expected.

The effect of clipping to 10 or 30 cm on TNC at the late vegetative stage of basin wildrye (June 1) is shown in Figure 4. For plants clipped once or twice, significant differences in TNC following clipping occurred among sampling dates and between clipping heights. The pattern of TNC depletion was about the same following each clipping.

When plants were clipped once to 10 or 30 cm, TNC declined rapidly within one week. TNC of plants declined from 18.5 to 10.5% and from 18.5 to 6.25% when clipped to 30 or 10 cm, respectively. TNC continued to decrease at the second and third sampling dates (Figure 4). The greater decline associated with the 10 cm clipping occurred because very little plant tissue remained since basin wildrye plants have few leaves near the soil surface to supply photosynthate. Proportionally, the 30 cm

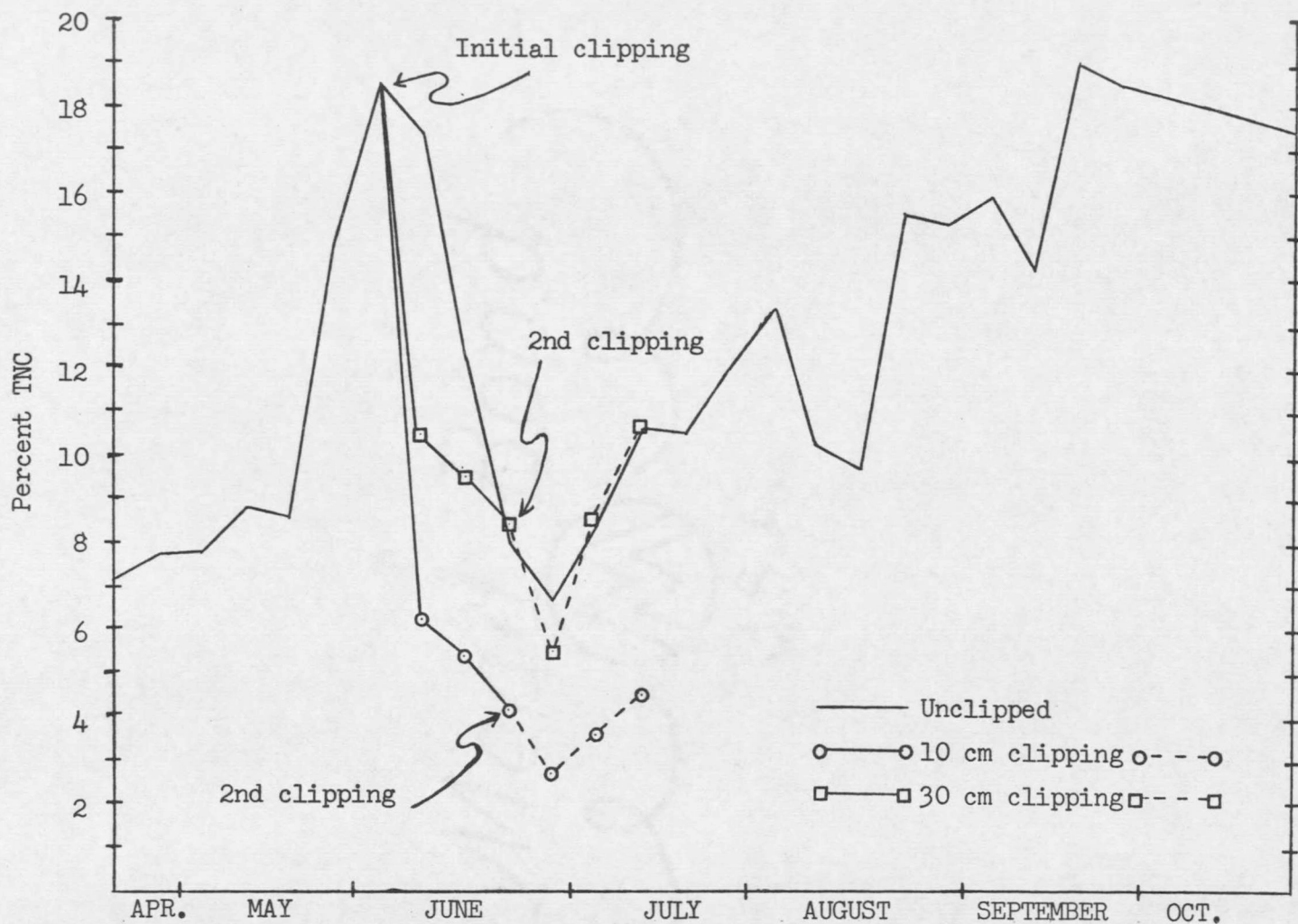


Figure 4. Effect of one or two clippings initiated on June 1 (late vegetative stage) to 10 or 30 cm on TNC of basin wildrye.

clipping had much more photosynthetic tissue remaining. A portion of TNC depletion can be attributed to energy demands to elevate growing points.

Plants were clipped to 10 or 30 cm three weeks after the initial clipping. Both clippings removed all growing points. There was no regrowth following the second clipping except for some new vegetative tillers. The TNC of plants clipped twice to 10 cm declined to 2.7% following clipping. If a third clipping to 10 cm had been imposed, the plants could have been in a dangerously weakened condition due to extremely low reserves.

TNC was restored following the second clipping, particularly with the 30 cm clipping. Inflorescence removal eliminated one photosynthetic sink. Removing the growing point would appear to remove a significant photosynthetic sink, allowing some TNC restoration.

Plant material sampled for TNC analysis ten weeks after clipping spoiled due to inadequate drying. The level of reserves of these samples averaged only 5%.

Clipping to 10 or 30 cm on June 1 not only affected TNC but dry matter accumulation and plant height as well (Tables 2 and 3). Significant differences occurred among sampling dates following clipping and between heights for plants clipped once or twice. For each sampling period, plants clipped to 30 cm accumulated more dry matter, grew taller, and maintained higher TNC levels (Figure 4) than plants clipped

Table 2. Effect of clipping height and time interval on dry matter accumulation in grams following an initial cut on June 1.

Clipping ht. cm	Initial yld. on June 1	Regrowth period			
		1 wk.	2 wk.	3 wk.	10 wk.
<u>After one cut on June 1</u>					
10	11.3	3.8	10.0	16.4	112.5
30	3.5	6.2	17.2	32.7	102.5
<u>After two cuts (June 1 and June 22)</u>					
10	12.1	0.5	0.5	3.8	22.3
30	3.2	1.8	2.8	3.9	32.9

Table 3. Effect of clipping to 10 or 30 cm and time interval on plant height in cm following an initial cut on June 1.

Clipping ht. cm	Initial ht. on June 1	Regrowth period			
		1 wk.	2 wk.	3 wk.	10 wk.
<u>After one cut on June 1</u>					
10	46.1	30.0	51.2	74.3	125.7
30	47.7	57.8	78.2	98.9	147.8
<u>After two cuts (June 1 and June 22)</u>					
10	44.0	23.1	31.5	53.8	63.8
30	48.5	50.0	72.1	77.3	111.1

to 10 cm. Thus, clipping height is important for management of this species in reference to forage yields and maintenance of sufficient stored energy for plant survival.

More dry matter was accumulated at the later sampling periods, but clipping a second time to 10 or 30 cm severely reduced yields in late season. This yield reduction was expected since basin wildrye has a high ratio of fertile to vegetative tillers and fertile tillers showed little growth following removal of the growing point. Species with a high fertile to vegetative tiller ratio appear more sensitive to grazing (8) which may explain the observed sensitivity of basin wildrye to spring grazing.

The effect on TNC of clipping to 10 or 30 cm on June 14, during early boot stage, is shown in Figure 5. For plants clipped once or twice, highly significant differences in TNC occurred among sampling dates following clipping and between clipping heights. The sampling date X clipping height interaction was significant for plants clipped once.

Plants clipped once declined rapidly in TNC the first week, particularly when clipped to 10 cm. Three weeks after clipping, depleted reserves began to be restored in the plants, particularly in plants clipped to 30 cm. Clipping to 10 cm removed all growing points, but clipping to 30 cm removed only a few growing points. The slight recovery in reserves of plants clipped to 10 cm may be due to the

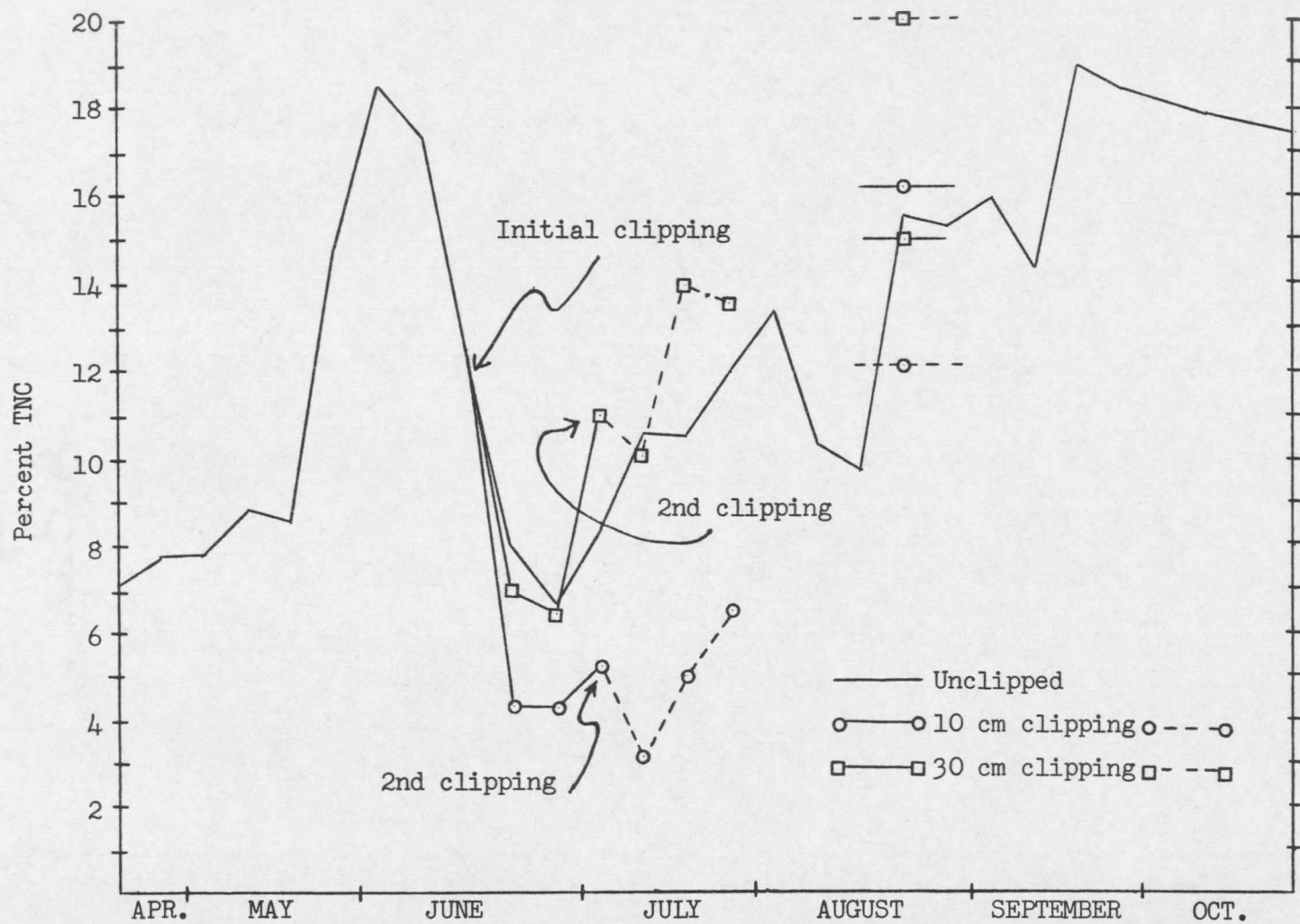


Figure 5. Effect of one or two clippings initiated on June 14 (early boot stage) to 10 or 30 cm on TNC of basin wildrye.

removal of the photosynthetic sink discussed above. TNC trends of plants clipped to 30 cm were similar to those of unclipped plants. Following clipping, vegetative tillers developed and elongated on plants clipped to 10 cm but not on plants clipped to 30 cm. Fertile tillers clipped to 30 cm elongated, but those clipped to 10 cm did not, which may account for the difference in restoration of TNC. Perhaps greater TNC levels are needed for vegetative tiller development associated with the 10 cm clipping than for continuation of fertile tiller development associated with the 30 cm clipping.

Ten weeks after the initial clipping, TNC of clipped and unclipped plants was similar (Figure 5). Plants clipped to 10 cm restored a higher level of TNC than plants clipped to 30 cm. Plants clipped once to 10 or 30 cm at the early boot stage apparently went into the fall with sufficient stored energy.

The second clipping to 10 or 30 cm of plants initially clipped on June 14 removed the growing point on all plants. TNC of plants clipped twice to 10 cm declined to 3.0% within one week. If a third clipping to 10 cm had been imposed, the vigor of the plants might have been very poor due to extremely low reserves. Little decline in TNC occurred in plants clipped twice to 30 cm. Apparently, remaining leaf material was sufficient to not only maintain TNC but also to restore TNC to a higher level than for unclipped plants.

TNC of plants clipped twice to 10 or 30 cm differed markedly going into the fall (Figure 5). TNC of plants clipped twice to 30 cm was 20% or 4.5 percentage units greater than unclipped plants. The higher level may be partly attributed to removal of the inflorescence which eliminated a drain on the photosynthate and allowed storage of TNC. TNC of plants clipped twice to 10 cm was 11.75% which is 5 percentage units less than unclipped plants.

The effect of clipping to 10 or 30 cm on June 14 (early boot stage) on subsequent growth is shown in Tables 4 and 5. Significant differences occurred among sampling dates following clipping and between heights for plants clipped once or twice. The sampling date X clipping height interaction was significant for dry matter accumulation and plant height. This interaction is reflected by the reversal in patterns between the two clipping heights at the 10 week interval (Tables 4 and 5).

More vegetative tillers were observed going into the fall on plants clipped to 10 cm than on those clipped to 30 cm, which may account for differences in dry matter accumulation (Table 4). Although basin wildrye has a high fertile to vegetative stem ratio, management practices may encourage development of vegetative tillers. Dry matter accumulation differences of plants clipped twice at the 10-week

Table 4. Effect of clipping height and time interval on dry matter accumulation in grams following an initial cut on June 14.

Clipping ht. cm	Initial yld. on June 14	Regrowth period			
		1 wk.	2 wk.	3 wk.	10 wk.
<u>After one cut on June 14</u>					
10	31.0	3.2	5.8	9.5	90.8
30	19.1	7.0	11.5	20.1	69.7
<u>After two cuts (June 14 and July 5)</u>					
10	27.9	1.4	5.0	6.2	54.4
30	20.1	0.5	2.6	8.2	20.5

Table 5. Effect of clipping to 10 or 30 cm and time interval on plant height in cm following an initial cut on June 14.

Clipping ht. cm	Initial ht. on June 14	Regrowth period			
		1 wk.	2 wk.	3 wk.	10 wk.
<u>After one cut on June 14</u>					
10	80.7	38.2	55.9	72.3	103.5
30	81.4	70.2	87.3	94.9	140.3
<u>After two cuts (June 14 and July 5)</u>					
10	81.2	32.2	46.5	51.6	96.9
30	83.5	50.0	74.2	83.3	87.9

interval may in part account for the difference in TNC levels going into the fall (Figure 5).

The effect of clipping to 10 or 30 cm on TNC after the inflorescences have completely emerged on June 23 is shown in Figure 6. For plants clipped once or twice, highly significant differences in TNC occurred among sampling dates following clipping and between clipping heights. The sampling date X clipping height interaction was significant for plants clipped once.

TNC trends of plants clipped to 30 cm were similar to those of unclipped plants with a greater percent TNC restoration associated with plants clipped twice. The inflorescence had been removed, eliminating a photosynthetic sink. TNC levels of plants clipped once or twice to 30 cm were 4.25 and 2.25 percentage units, respectively, greater than unclipped plants going into the fall. The benefit of clipping to 30 cm on TNC may be due to: (1) Removal of a photosynthetic sink, (2) Little regrowth immediately following clipping (Table 6), and (3) Presence of leaf material to carry on photosynthesis.

TNC declined rapidly with no significant recovery within three weeks following one or two clippings to 10 cm. It is apparent these plants were at critical TNC levels. If a third clipping had been imposed, TNC levels could have been depleted to such critically low levels that the plants might not have recovered, as reported with intermediate wheatgrass (52). Plants clipped twice to 10 cm were going

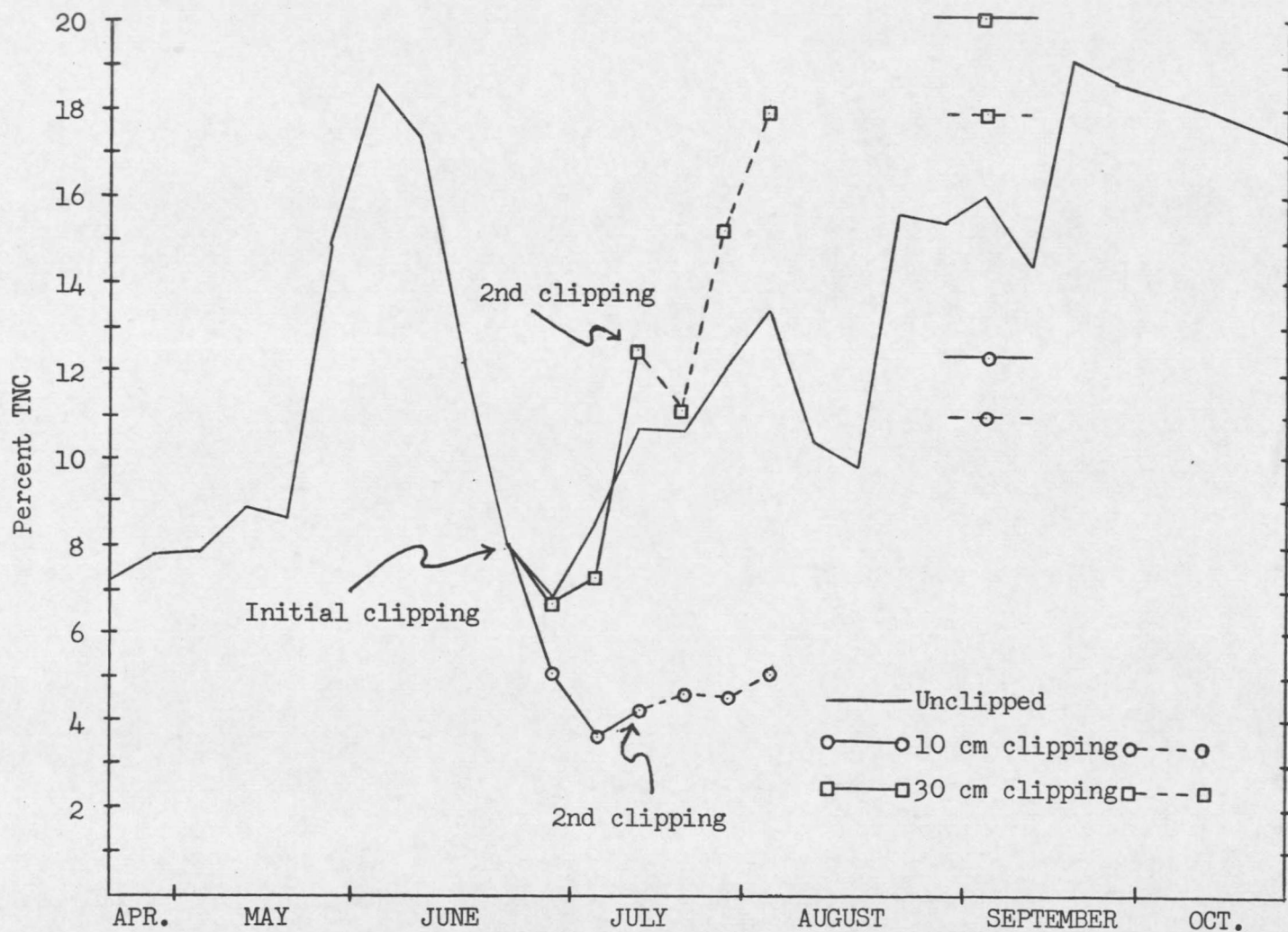


Figure 6. Effect of one or two clippings initiated on June 23 (heads completely emerged) to 10 or 30 cm on TNC of basin wildrye.

Table 6. Effect of clipping height and time interval on dry matter accumulation in grams following an initial cut on June 23.

Clipping ht. cm	Initial yld. on June 23	Regrowth period			
		1 wk.	2 wk.	3 wk.	11 wk.
<u>After one cut on June 23</u>					
10	67.5	0.5	1.7	2.5	60.0
30	47.8	0.5	4.3	5.1	60.6
<u>After two cuts (June 23 and July 14)</u>					
10	53.9	0.5	6.5	13.9	49.1
30	43.4	2.4	5.4	6.2	57.7

Table 7. Effect of clipping to 10 or 30 cm and time interval on plant height in cm following an initial cut on June 23.

Clipping ht.	Initial ht. on June 23	Regrowth period			
		1 wk.	2 wk.	3 wk.	11 wk.
<u>After one cut on June 23</u>					
10	108.2	22.6	37.4	41.8	85.0
30	108.1	46.9	66.8	80.9	107.0
<u>After two cuts (June 23 and July 14)</u>					
10	103.3	30.3	49.2	64.2	85.0
30	105.7	54.9	70.2	76.2	110.1

into the fall with less than 11% TNC or 4.75 percentage units below the level of unclipped plants. The data in Figure 2 indicate a decline of ten percentage units in TNC from September, 1970, to May, 1971. If such a decline were to occur with plants going into the fall with only 11% TNC (Figure 6), survival of the plants might be questionable, particularly if a third or fourth clipping to 10 cm were imposed, lowering TNC still further.

TNC recovery was more affected by clipping to 10 cm at this developmental stage (inflorescences completely emerged) than the previous two stages (Figures 4, 5 and 6). However, TNC levels at time of initial clipping were much lower than the previous two stages.

The effect of clipping to 10 or 30 cm on June 23 on subsequent growth is shown in Tables 6 and 7. Plants responded similarly in dry matter accumulation to the two clipping height treatments. No significant differences occurred between heights. Plant material at all harvests following the initial clipping consisted of vegetative tillers. The individual vegetative tillers were small in diameter, with short internode distances, compared to fertile tillers.

The data over two years show that seasonal TNC levels of unclipped plants are related to developmental stages in basin wildrye. The frequency and intensity of herbage removal influences TNC. Frequent and severe herbage removal may weaken plants. Proper field management practices may depend on management of TNC in basin wildrye.

Dry Matter Management Study

Plants in the dry matter management nursery were two years older and therefore much larger in basal plant diameter and height than plants in the carbohydrate nursery. Mature untreated plants were between 180 and 220 cm tall and yielded 823.2, 598.4, and 540.6 grams of dry matter per plant when clipped to 15, 30, or 45 cm, respectively. Yield differences (224.8 grams) show a significant amount of plant material present between 30 and 15 cm. With such high yields per plant, basin wildrye has great yield potential if the plant can be managed. The estimated average number of tillers per mature plant was 105, of which most were fertile. Data were based on spaced plants; it is unknown if these relationships would occur in solid seedings.

The effects of the three clipping heights at three frequencies and three starting dates during early summer on total seasonal dry matter yields of basin wildrye in 1970 are shown in Table 8. Only clipping height significantly influenced yields. Starting date, frequency of clipping, and interactions, except starting date X clipping height, were non-significant. The growing point was below the 15 cm clipping for the majority of plants initially clipped on June 6, between 25 and 40 cm on plants initially clipped on June 15, and above 45 cm on plants initially clipped on June 22.

Little regrowth occurred following removal of the growing point except for plants clipped to 15 cm. Small vegetative tillers were

Table 8. Effect of three clipping heights at three frequencies and starting dates on total seasonal dry matter of basin wildrye during 1970 (g/plant).

Starting date	Frequency of harvest (wk.)	Clipping height			Means
		15 cm	30 cm	45 cm	
June 6	3	189.6	171.2	224.7	227.3a
	6	177.5	225.9	295.5	
	9	196.4	269.2	296.4	
June 15	3	294.2	236.5	191.3	233.8a
	6	224.2	229.4	209.8	
	9	343.2	186.3	188.6	
June 22	3	275.7	268.4	200.6	260.2a
	6	382.7	269.0	214.5	
	9	324.2	237.8	169.1	
Height means		267.6a ^{1/}	232.5b	221.1b	

^{1/} Means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

present at most succeeding harvests of plants clipped to 15 cm, but these produced little dry matter.

The significant variation in yield of plants clipped at different heights was expected, as a greater amount of plant material was removed at 15 cm than at 30 or 45 cm (Table 8). In terms of total yield, regrowth did not compensate for yield differences due to initial clipping heights. Unclipped plants produced twice as much as clipped plants (Table 8). Reductions in dry matter from clipping have been previously reported for basin wildrye (42) and for other species (14, 29, 30, 67).

The significant starting date X height interaction (Figure 7) appears to be related to growing point removal followed by amount of regrowth. A nearly opposite response occurred among clipping heights between the June 6 starting date and the other two starting dates (Figure 7). Since the growing point was not removed on plants clipped on the June 6 starting date, considerable regrowth occurred following each clipping which did not occur on the June 15 and 22 starting dates. This regrowth consisted of stem extensions with inflorescences (continued growth, not new growth). Regrowth following the 15 cm clipping on the June 6 starting date was much less than the 30 or 45 cm clippings, possibly due to less remaining photosynthetic tissue and a greater TNC depletion associated with low clippings (Figures 2, 3, and 4). However, much more photosynthetic tissue remained on plants clipped to 45 cm, aiding in additional dry matter production (Figure 7).

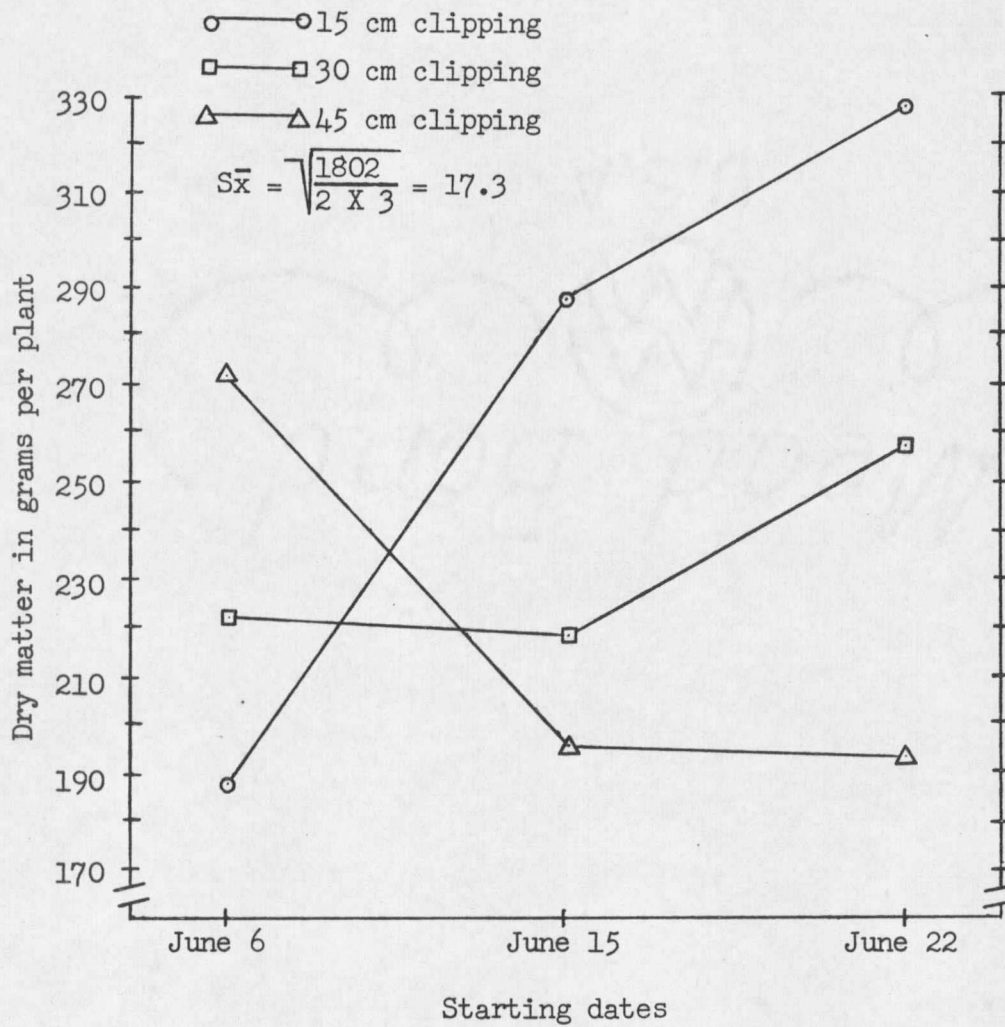


Figure 7. Effect of three clipping heights averaged over three frequencies at three starting dates on total seasonal dry matter of basin wildrye in 1970.

The effect of three clipping heights at three frequencies and three starting dates on total seasonal dry matter production of basin wildrye in late spring, 1971, is shown in Table 9. Both starting dates and frequency of clipping significantly influenced yields. Only the starting date X frequency of clipping interaction was significant (Figure 8). The growing point was not removed until the second harvest, except for the May 17 starting date when it was removed at the third harvest for plants clipped at three week intervals. No regrowth of plants occurred following growing point removal except for small vegetative tillers of plants clipped to 15 cm. The same phenomenon was noted in 1970.

Plants clipped at the May 25 starting date accumulated significantly more dry matter than plants of the other two starting dates (Table 9). Because of differences between years, direct comparisons cannot be justified (Tables 8 and 9); however, patterns of response of plants to various clipping treatments can be examined. Plants clipped at the early starting dates in 1971 accumulated 100 to 190 grams more seasonal dry matter per plant than plants clipped at later stages in 1970 (Tables 8 and 9). It is not likely that the tremendous difference in yields is due entirely to climatic differences between the two years. In fact, more rainfall occurred in 1970 (Table 1) when less total growth was produced. With regrowth following clippings in 1971, the plants had the potential of producing greater seasonal yields than

Table 9. Effect of three clipping heights at three frequencies and starting dates on total seasonal dry matter of basin wildrye during late spring, 1971 (g/plant).

Starting date	Clipping ht. (cm)	Frequency of harvest			Means
		3 wk.	6 wk.	9 wk.	
May 17	15	215.8	371.6	528.7	354.3a
	30	225.4	351.6	477.8	
	45	232.5	314.1	461.4	
May 25	15	219.2	429.5	588.2	417.8b
	30	218.8	463.6	658.4	
	45	225.2	459.5	497.5	
June 2	15	281.7	365.9	281.2	351.1a
	30	260.3	470.2	424.6	
	45	214.7	370.0	490.7	
Frequency means		232.6a ^{1/}	399.6b	491.0c	

^{1/} Means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

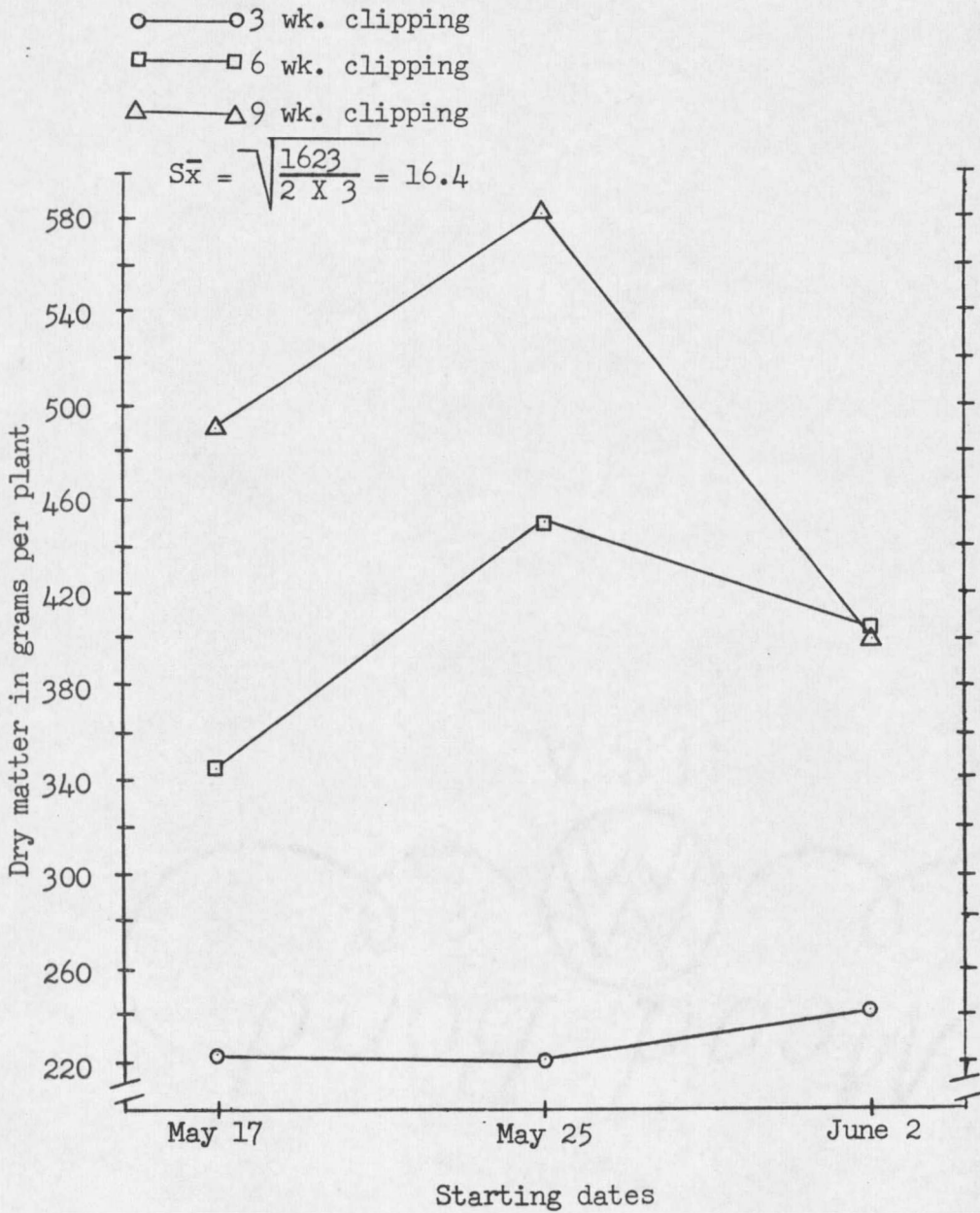


Figure 8. Effect of clipping at three frequencies at three starting dates averaged over heights on total seasonal dry matter of basin wildrye in late spring, 1971.

plants clipped at the later stages in 1970 when the growing point was removed at the initial harvest. For one year grazing purposes, it would appear that grazing basin wildrye in late spring rather than early summer (in Bozeman) would maximize dry matter yields. However, this represents only one year's response and should not be interpreted as a continuing practice.

In every instance plants clipped at three-week intervals clearly yielded less than plants clipped at six or particularly at nine week intervals (Table 9). Thus clipping basin wildrye at three week intervals is too frequent for maximum dry matter production unless the growing point is removed with the first harvest. Plants clipped at a nine-week interval had much more time for dry matter production following the initial harvest than plants clipped at six or three week intervals. The carbohydrate study indicated that two clippings to 10 cm at three-week intervals drastically reduced TNC. Plants clipped to 15 cm at three-week intervals in this nursery may have had low TNC which limited potential regrowth.

When clipping occurred to a height immediately above the growing point, culm elongation following clipping consisted of stem material with an inflorescence and little leafy tissue above the clipping height. Regrowth looked like a barren culm, particularly at the nine week interval. TNC must have been utilized for this stem material because of reduction in photosynthetic material. Clipping of leafy

tissue at several stages resulted in no leaf blade extension. Regrowth of some harvests had very short leaf blades on the upper plant portions. Apparently the leaf blade meristematic area was no longer active after such clippings. Similar relationships were found in crested wheatgrass (15).

Generally, height of regrowth (culm elongation) was less on plants clipped to 15 cm than plants clipped to 45 cm for each harvest frequency. This may be because: (1) TNC levels may not have permitted replacing clipped foliage in addition to maximum stem elongation, and (2) There was less remaining photosynthetic tissue of plants clipped to 15 cm than to 30 or 45 cm.

Plants clipped at three week intervals accumulated similar seasonal dry matter yields for each starting date (Figure 8). Why were seasonal dry matter yields of plants, clipped at six and nine week intervals, significantly greater at the May 25 starting date than the May 17 starting date, contributing to the significant interaction (Figure 8)? Both the initial and regrowth harvests of the May 17 starting date were significantly less than those of the May 25 starting date. The plants were evidently more capable of regrowth following the May 25 starting date than the May 17 starting date. It is not known why total dry matter production of the nine week interval was significantly less for the June 2 starting date than the May 17 or May 25 starting dates which contributed to the interaction.

The effects of the three clipping heights at three frequencies and three starting dates during early summer 1971 on total seasonal dry matter production of basin wildrye are shown in Table 10. Both clipping height and frequency of clipping significantly influenced yields. Only the starting date X frequency of clipping interaction was significant (Figure 9). The plants of this study were treated identically during 1970 and 1971; thus, the plant yields for 1971 (Table 10) were probably influenced by the previous year's clippings. Average yields in 1971 were 84 grams less per plant than in 1970 with the greatest decline associated with plants clipped to 15 cm. Yield differences between the two years were 147, 53, and 0 grams for the 15, 30, and 45 cm clippings, respectively (Tables 8 and 10). The impact of low clippings on the following year's herbage production is apparent. With little photosynthetic tissue remaining below the 15 cm clipping height in 1970, plants were evidently utilizing TNC for respiration after the initial harvests in 1970 and until growth initiation in 1971. This represents a long period of TNC utilization particularly during the warm summer months when respiration rates are high. Evidently, plants clipped to 15 cm were going into the fall with low TNC levels followed by even lower levels in Spring, 1971, accounting for the poorer response in 1971 than for plants clipped higher. This suggests that grazing of basin wildrye to low heights must be prevented so that

Table 10. Effect of three clipping heights at three frequencies and starting dates on total seasonal dry matter in basin wildrye during early summer 1971 (g/plant).

Starting date	Frequency of harvest (wk.)	Clipping height			Means
		15 cm	30 cm	45 cm	
June 9	3	76.7	121.2	179.7	187.4a
	6	151.7	123.4	305.3	
	9	183.3	267.2	283.3	
June 17	3	84.4	189.0	180.8	155.2a
	6	102.4	193.2	198.5	
	9	130.6	146.0	172.2	
June 25	3	93.3	196.3	244.4	176.4a
	6	120.5	228.1	248.9	
	9	137.4	148.1	171.0	
Height means		119.9a ^{1/}	178.6b	220.5c	

^{1/} Means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

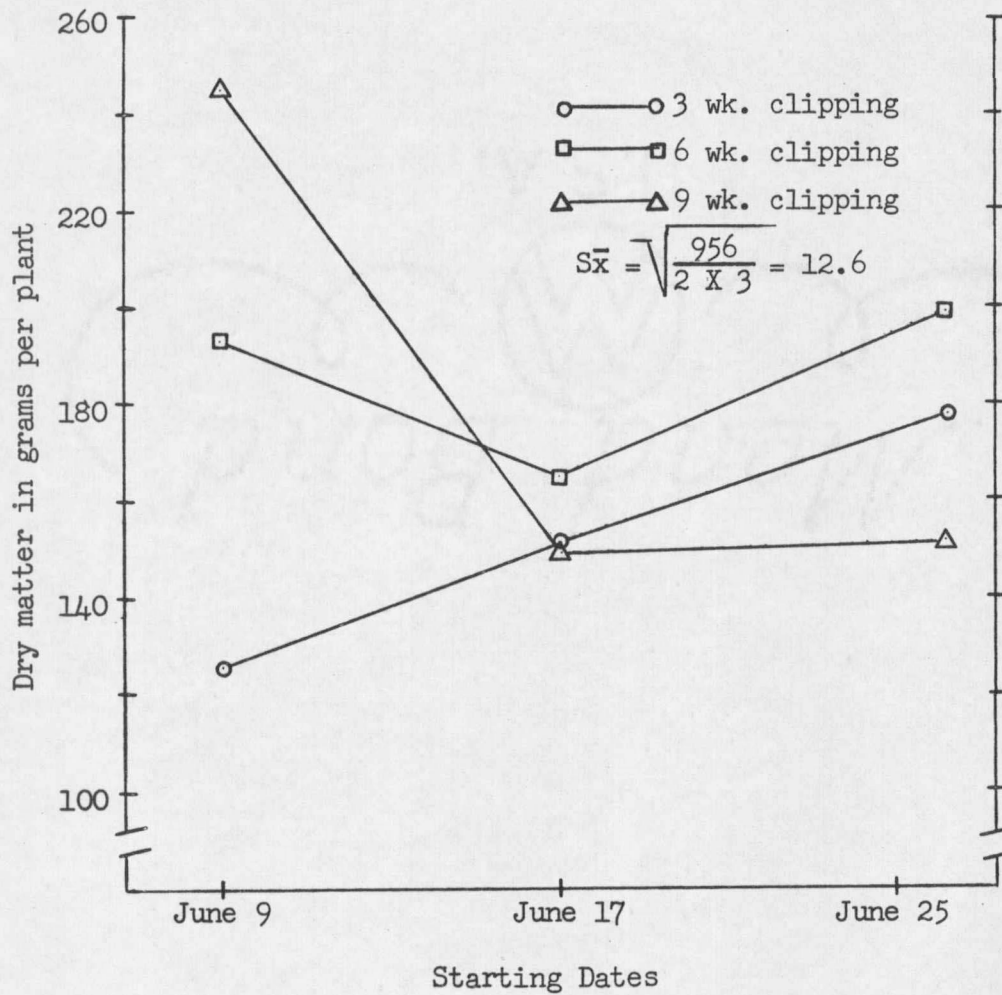


Figure 9. Effect of clipping at three frequencies at three starting dates averaged over heights on total seasonal dry matter of basin wildrye in early summer, 1971.

photosynthetic tissue remains throughout the summer period to maintain TNC levels.

The previous year's clipping to 15 cm markedly reduced plant circumference, height, and vigor in 1971. If plants were continually treated in such a fashion, survival of the plant would be questionable. The declining yields in 1971 associated with the 15 cm clipping occurred to about the same degree with all three starting dates. A greater decline was associated with plants clipped at three week intervals than at six or nine week intervals.

In 1971 plants clipped in 1970 appeared to be later in development than unclipped plants, particularly with plants clipped to 15 cm in 1970. Stem diameters, plant height, and overall size of the plant were less than unclipped plants, particularly with plants clipped to 15 cm in 1970. Thus the previous year's clipping affected the following year's plant developmental response in addition to seasonal yields. Such responses if continued over successive years of grazing would be disadvantageous for potential grazing of basin wildrye. Herbage production of basin wildrye in early spring has attracted attention but if developmental responses are delayed due to previous grazing, this may lessen the potential of this plant for spring grazing. Grazing of basin wildrye appears limited to the 30 or 45 cm height if TNC and yields are to be maintained. If grazing in the spring must be delayed until foliage is above the 30-45 cm height, the potential for early

spring grazing is diminished. Many other cool season grasses have significant foliage present for grazing at or before the time basin wildrye reaches these heights.

The significant variation among frequency of clippings (Table 10) was expected because of the impact of the previous year's clipping on yields in 1971. The three week interval mean yield was significantly lower than for the six and nine week intervals. This is mainly associated with the June 9 starting date (Figure 9). In addition to the impact of the previous year's clipping, this relationship occurred because of little regrowth following the initial harvests of the June 17 and 25 starting dates. However, regrowth occurred following the initial harvest of the June 9 starting date. Plants clipped at six and nine week intervals after the June 9 starting date had more time for herbage production before the second harvest than plants clipped at three week intervals. This also may account for the significant starting date X frequency of clipping interaction.

Based on the data presented for 1970 and 1971, no specific starting date was more detrimental than another in terms of total seasonal dry matter yields. Since this study is being continued, the impact of two to three years' clipping on seasonal yields and survival of basin wildrye may be found, and a suitable starting date at a specific height might be identified.

Since grazing of basin wildrye appears limited to the 30 or 45 cm height, the problem of allowing grazing to such a height is apparent. Because of stem characteristics, this may be possible. When the plant is clipped after elongation of the growing point, the remaining stems are coarse and very sharp to the touch when attempting to go below the clipping level. Thus green foliage below that height would remain unaccessible to livestock. The carbohydrate study indicated that clipping to 30 cm is a must to maintain TNC. Therefore preventing grazing below 30 or 45 cm would help maintain TNC and dry matter yields. However, in early spring 1971 and 1972 plants clipped to the soil surface the previous fall tended to initiate growth slightly faster with more foliage than plants clipped to greater heights. This appears to be disadvantageous to the proposal discussed above. It was hypothesized that soil temperatures 7 cm below the soil surface within plants might be accounting for these observed differences in growth. Twice during the soil temperature recording period, two inches of snow were present for two days. The mean temperatures were 3.70, 4.09, 4.15, and 5.23 C for the 45, 30, 15, and 0 cm clippings, respectively, indicating little difference, although mean soil temperature below plants clipped to 0 cm was 1.5 C higher than below plants clipped to 45 cm. Many other factors such as lag time of soil temperatures due to buffering of plant foliage must be considered in interpreting temperature data.

Because of the lack of research on basin wildrye, many management principles are yet to be described. More research is needed for range managers to make sound management decisions concerning basin wildrye. For example, would fertilization result in more regrowth following growing point removal? How might the palatability of basin wildrye be affected with nitrogen and/or phosphorus applications? What would be the effect of irrigation on basin wildrye yields? Studies of solid seeding establishment would certainly seem beneficial. Can the plant be maintained under such conditions?

Since the species is an early, cool season grass, the prolific herbage production is desirable to ranchers, but basin wildrye is sensitive to spring grazing. Studies involving continuous grazing for varying short periods of time in the spring may reveal that basin wildrye can tolerate an intensive short period of grazing. For example, intensive grazing or clipping might be imposed for two to three weeks at various times in the spring followed by complete rest for the remainder of the growing season. If such a practice would allow survival of basin wildrye, the total grazing season on Montana ranges could be extended. Additional grazing might also be possible in the fall or winter to remove matured plant material.

Since basin wildrye is an early cool season grass with poor regrowth following growing point removal, it might be possible that a mixture of basin wildrye and a warm season grass (switchgrass or

sideoats grama) would be a good mixture. A grazing program could be scheduled to remove accessible growing points of basin wildrye as well as foliage, in which case no regrowth would take place, then the warm season grass would be relatively free for growth in the summer at which time grazing would be allowed on the warm season species.

It is concluded that the two year seasonal clipping to 15 cm was the most detrimental of the three clipping heights. Clipping at three week intervals resulted in lower total dry matter than at six or nine week intervals. Plants that were clipped in 1970 were much reduced in plant size in 1971 and developmental processes appeared delayed in 1971 because of the previous year's clippings. The amount of regrowth following clipping appears to be directly related to whether or not the growing point is removed.

SUMMARY AND GENERAL CONCLUSIONS

Total nonstructural carbohydrates (TNC) of unclipped basin wildrye plants increased rapidly four weeks after the onset of spring growth. TNC peaked during the late vegetative stage of development, followed by a rapid decline during growing point elevation with restoration after this period. A continual recovery of TNC occurred going into late summer.

TNC of basin wildrye plants clipped to 10 cm was significantly lower than plants clipped to 30 cm for all developmental stages (late vegetative, early boot, and inflorescences emerged) and at all dates following clipping. The TNC levels declined greatly within one week for both clipping heights with a greater decline associated with the 10 cm clipping. Additional decline occurred by the second week for both clipping heights followed by an increase by the third week, except at the late vegetative stage. Plants which were clipped twice generally followed the same pattern, except for an overall lower TNC level following the second clip. Plants clipped twice to 10 cm did not fully restore depleted reserves to match unclipped plants within ten weeks; whereas, all other treatment combinations matched TNC levels of unclipped plants going into the fall. Clipping during a period of low TNC was more detrimental than during a period of high TNC.

It is concluded that knowledge of morphological and physiological characteristics of basin wildrye is necessary to properly interpret seasonal trends and effects of clipping on TNC.

Total seasonal dry matter production was greatly reduced when plants were clipped during the growing season, particularly when clipped to 15 cm. During the first year of clipping, less dry matter was produced when plants were clipped at the boot or later stages than at the vegetative stages. Following growing point removal, little regrowth occurred except for some vegetative tillers on plants clipped to 15 cm. A greater regrowth potential existed for the early clippings.

One year's clipping drastically reduced dry matter yields the following year for plants clipped to 15 cm, less so for plants clipped to 30 cm and no reduction occurred with the 45 cm clipping. The previous year's clipping not only affected dry matter production but also the overall size of the plant, and delayed developmental responses. Dry matter yields of plants clipped at three week frequencies were significantly lower than plants clipped at six or nine week frequencies.

The above study is being continued for two more years, and the survival of plants clipped to 15 cm will be measured.

Since TNC's are severely depleted in plants clipped to low heights, particularly with frequent clippings, grazing of basin wildrye must not be allowed too frequently or at too low heights. To maintain dry matter production and TNC, clipping to 45 or 30 cm appears desirable.

Basin wildrye plants treated severely go into the fall period with significantly lower TNC levels than unclipped plants followed by drastically lower dry matter yields the following year. However, grazing to only 30 cm is difficult. A possible solution to this problem is discussed.

REFERENCES

1. Albertson, F. W., A. Riegel, and J. L. Launchbaugh. 1953. Effects of different intensities of clipping on short grasses in west-central Kansas. *Ecology* 34:1-20.
2. Aldous, A. E. 1930. Relation of organic food reserves to the growth of some Kansas pasture plants. *J. Amer. Soc. Agron.* 22:385-392.
3. Anonymous. 1937. Range plant handbook. Forest Serv., U. S. Dep. Agr., Washington, D. C.
4. Baker, H. K. 1957. Studies on the root development of herbage plants. 2. The effect of cutting on the root and stubble development, and herbage production, of spaced perennial ryegrass plants. *J. Brit. Grassland Soc.* 12:116-125.
5. Baker, H. K., and E. A. Garwood. 1961. Studies on the root development of herbage plants. V. Seasonal changes in fructosan and soluble-sugar contents of cocksfoot herbage, stubble and roots under two cutting treatments. *J. Brit. Grassland Soc.* 16:263-267.
6. Balasko, J. A., and D. Smith. 1971. Influence of temperature and nitrogen fertilization on the growth and composition of switchgrass (*Panicum virgatum* L.) and timothy (*Phleum pratense* L.) at anthesis. *Agron. J.* 63:853-857.
7. Biswell, H. H., and J. E. Weaver. 1933. Effects of frequent clipping on the development of roots and tops of grasses in prairie sod. *Ecology* 14:368-390.
8. Branson, F. A. 1953. Two new factors affecting resistance of grasses to grazing. *J. Range Manage.* 6:165-171.
9. Brown, E. M. 1939. Some effects of temperature on the growth and chemical composition of certain pasture grasses. *Missouri Agr. Exp. Sta. Res. Bull.* 299. 61 p.
10. Canfield, R. H. 1939. The effect of intensity and frequency of clipping on density and yield of black grama and tobosa grass. *U. S. Dep. Agr. Tech. Bull.* 681. 32 p.

11. Carter, J. F., and A. G. Law. 1948. The effect of clipping on the vegetative development of some perennial grasses. *J. Amer. Soc. Agron.* 40:1084-1091.
12. Chapman, S. R. 1969. Observations on the mating system of basin wildrye. *J. Range Manage.* 22:430.
13. Conard, E. C. 1954. Effect of time of cutting on yield and botanical composition of prairie hay in southeastern Nebraska. *J. Range Manage.* 7:181-182.
14. Cook, C. W., L. E. Harris, and F. Kinsinger. 1958. Responses of crested wheatgrasses to various clipping treatments. *Ecol. Monog.* 28:237-272.
15. Cook, C. W., and L. A. Stoddart. 1953. Some growth responses of crested wheatgrass following herbage removal. *J. Range Manage.* 6:267-271.
16. Cooper, C. S. 1956. The effect of time and height of cutting on yield, crude protein content and vegetative composition of a native flood meadow in eastern Oregon. *Agron. J.* 48:257-258.
17. Davidson, J. L., and F. L. Milthorpe. 1965. Carbohydrate reserves in the growth of cocksfoot (*Dactylis glomerata* L.). *J. Brit. Grassland Soc.* 20:15-18.
18. Davidson, J. L., and F. L. Milthorpe. 1966a. Leaf growth in *Dactylis glomerata* following defoliation. *Ann. Bot.* 30:173-184.
19. Davidson, J. L., and F. L. Milthorpe. 1966b. The effect of defoliation on the carbon balance in *Dactylis glomerata*. *Ann. Bot.* 30:185-198.
20. Davis, W. E. P. 1960. Effect of clipping at various heights on characteristics of regrowth in reed canarygrass (*Phalaris arundinacea* L.). *Can. J. Plant Sci.* 40:452-457.
21. Donald, C. M., and J. N. Black. 1958. The significance of leaf area in pasture growth. *Herb. Abstr.* 28:1-6.
22. Donart, G. B. 1969. Carbohydrate reserves of six mountain range plants as related to growth. *J. Range Manage.* 22:411-415.

23. Donart, G. B., and C. W. Cook. 1970. Carbohydrate reserve content of mountain range plants following defoliation and regrowth. *J. Range Manage.* 23:15-19.
24. Ehara, K., N. Maeno, and Y. Yamada. 1966. Physiological and ecological studies on the regrowth of herbage plants. 4. The evidence of utilization of food reserves during the early stage or regrowth in bahiagrass (Paspalum notatum F.) with $C^{14}O_2$. *J. Jap. Soc. Grassland Sci.* 12:1-3. (From *Herb. Abstr.* No. 37:348.)
25. Everson, A. C. 1966. Effects of frequent clipping at different stubble heights on western wheatgrass (Agropyron smithii, Rydb.). *Agron. J.* 58:33-35.
26. Graber, L. F. 1933. Competitive efficiency and productivity of bluegrass (Poa pratensis L.) with partial defoliation at two levels of cutting. *J. Amer. Soc. Agron.* 25:328-333.
27. Grandfield, C. O. 1930. The relation of organic food reserves to the effect of cutting pasture weeds at different stages of growth. *J. Amer. Soc. Agron.* 22:709-713.
28. Hanson, W. R., and L. A. Stoddart. 1940. Effects of grazing upon bunch wheat grass. *J. Amer. Soc. Agron.* 32:278-289.
29. Heady, H. F. 1961. Continuous vs. specialized grazing systems: A review and application to the California annual type. *J. Range Manage.* 14:183-193.
30. Hedrick, D. W. 1958. Proper utilization—a problem in evaluating the physiological response of plants to grazing use: A review. *J. Range Manage.* 11:34-43.
31. Heinrichs, D. H., and K. W. Clark. 1961. Clipping frequency and fertilizer effects on productivity and longevity of five grasses. *Can. J. Plant Sci.* 41:97-108.
32. Heinze, P. H., and A. E. Murneek. 1940. Comparative accuracy and efficiency in determination of carbohydrates in plant material. *Missouri Agri. Exp. Sta. Res. Bull.* 314. 23 p.
33. Hitchcock, A. S. 1950. Manual of the grasses of the United States. 2nd Edition. U. S. Dep. Agr. Misc. Publ. No. 200. 1051 p.

34. Holt, D. A., and A. R. Hilst. 1969. Daily variation in carbohydrate content of selected forage crops. *Agron. J.* 61:239-242.
35. Hyder, D. N., and F. A. Sneva. 1959. Growth and carbohydrate trends in crested wheatgrass. *J. Range Manage.* 12:271-276.
36. Hyder, D. N., and F. A. Sneva. 1963. Morphological and physiological factors affecting grazing management of crested wheatgrass. *Crop Sci.* 3:267-371.
37. Jacques, W. A., and D. B. Edmond. 1952. Root development in some common New Zealand pasture plants. V. The effect of defoliation and root pruning on cocksfoot (*Dactylis glomerata*) and perennial rye-grass (*Lolium perenne*). *New Zeal. J. Sci. Tech. Sect.* 34:231-248.
38. Jameson, D. A. 1963. Responses of individual plants to harvesting. *Bot. Rev.* 29:532-594.
39. Julander, O. 1945. Drought resistance in range and pasture grasses. *Plant Physiol.* 20:573-599.
40. Knight, H. G., F. E. Hepner, and A. Nelson. 1911. Wyoming forage plants and their chemical composition, studies No. 4. *Wyoming Agr. Exp. Sta. Bull.* 87. 152 p.
41. Knoblauch, H. C., G. H. Ahlgren, and H. W. Gausmann. 1955. Persistence of timothy as determined by physiological response to different management systems. *Agron. J.* 47:434-439.
42. Krall, J. L., J. R. Stroh, C. S. Cooper, and S. R. Chapman. 1971. The effect of time and extent of harvesting basin wildrye. *J. Range Manage.* 24:414-418.
43. Lindahl, I., R. E. Davis, and W. O. Shepherd. 1949. The application of the total available carbohydrate method to the study of carbohydrate reserves of switch cane (*Arundinaria tecta*). *Plant Physiol.* 24:285-294.
44. Lodge, R. W. 1960. Effects of burning, cultivating, and mowing on the yield and consumption of crested wheatgrass. *J. Range Manage.* 13:318-321.
45. Matches, A. G. 1966. Influence of intact tillers and height of stubble on growth responses of tall fescue. *Crop Sci.* 6:484-487.

46. May, L. H. 1960. The utilization of carbohydrate reserves in pasture plants after defoliation. *Herb. Abstr.* 30:239-245.
47. McCarty, E. C. 1935. Seasonal march of carbohydrates in Elymus ambiguus and Muhlenbergia gracilis and their reaction under moderate grazing use. *Plant Physiol.* 10:727-738.
48. McCarty, E. C. 1938. The relation of growth to the varying carbohydrate content in mountain brome. U. S. Dep. Agr. Tech. Bull. 598. 25 p.
49. McCarty, E. C., and R. Price. 1942. Growth and carbohydrate content of important mountain forage plants in central Utah as affected by clipping and grazing. U. S. Dep. Agr. Tech. Bull. 818. 51 p.
50. McKell, C. M., R. D. Whalley, and V. Brown. 1966. Yield, survival, and carbohydrate reserve of hardinggrass in relation to herbage removal. *J. Range Manage.* 19:86-89.
51. Morris, H. E., W. E. Booth, G. F. Payne, and R. E. Stitt. 1956. Important grasses on Montana ranges. *Montana Agr. Exp. Sta. Bull.* 500. 88 p.
52. Odgen, P. R., and W. E. Loomis. 1972. Carbohydrate reserves of intermediate wheatgrass after clipping and etiolation treatments. *J. Range Manage.* 25:29-32.
53. Paulsen, G. M., and D. Smith. 1968. Influences of several management practices on growth characteristics and available carbohydrate content of smooth brome. *Agron. J.* 60:375-379.
54. Pond, F. W. 1960. Vigor of Idaho fescue in relation to different grazing intensities. *J. Range Manage.* 13:28-30.
55. Rechenthin, C. A. 1956. Elementary morphology of grass growth and how it affects utilization. *J. Range Manage.* 9:167-170.
56. Sampson, A. W., and E. C. McCarty. 1930. The carbohydrate metabolism of Stipa pulchra. *Hildgardia* 5:61-100.
57. Smelov, S. P., and A. S. Morozov. 1939. Dynamics of reserve carbohydrates in the chief perennial grasses. *Sovetsk. Bot.* 5:18-30 (cited by May, 1960).

58. Smith, D. 1962. Forage management. WM. C. Brown Book Co. Dubuque, Iowa.
59. Smith, D. 1968. Classification of several native North American grasses as starch or fructosan accumulators in relation to taxonomy. J. Brit. Grassland Soc. 23:306-309.
60. Smith, D. 1969. Removing and analyzing total nonstructural carbohydrates from plant tissue. Wisconsin Agr. Exp. Sta. Res. Rep. 41. 11 p.
61. Smith, L. 1960. Effects of burning and clipping at various times during the wet season on tropical tall grass range in northern Australia. J. Range Manage. 13:197-203.
62. Smith, L. H., and G. C. Marten. 1970. Foliar regrowth of alfalfa utilizing ^{14}C -labeled carbohydrates stored in roots. Crop Sci. 10:146-150.
63. Stoddart, L. A. 1946. Some physical and chemical responses of Agropyron spicatum to herbage removal at various seasons. Utah Agr. Exp. Sta. Bull. 324. 24 p.
64. Sullivan, J. T., and V. G. Sprague. 1943. Composition of the roots and stubble of perennial ryegrass following partial defoliation. Plant Physiol. 18:656-670.
65. Teel, M. R. 1956. The physiological age of bromegrass as it affects recovery following defoliation. Doc. Diss. Purdue Univ.
66. Teel, M. R. 1957. Bromegrass can die out too. Hoards Dairyman p. 470, May 10.
67. Wagner, G. E. 1952. Yields and botanical composition of four grass-legume mixtures under differential cutting. U. S. Dep. Agr. Tech. Bull. 1063. 53 p.
68. Waite, R. 1957. The water-soluble carbohydrates of grasses. III. First and second year growth. J. Sci. Food Agr. 8:422-428.
69. Ward, C. Y. and R. E. Blaser. 1961. Carbohydrate food reserves and leaf area in regrowth of orchardgrass. Crop Sci. 1:366-370.

70. Watson, V. H., and C. Y. Ward. 1970. Influence of intact tillers and height of cut on regrowth and carbohydrate reserves of dallisgrass (Paspalum dilatatum Poir.). Crop Sci. 10:474-476.
71. Weinmann, H. 1940. Storage of root reserves in rhodes grass. Plant Physiol. 15:467-484.
72. Weinmann, H. 1947. Determination of total available carbohydrates in plants. Plant Physiol. 22:279-290.
73. Weinmann, H. 1948. Underground development and reserves of grasses: A review. J. Brit. Grassland Soc. 3:115-140.
74. Weinmann, H. 1961. Total available carbohydrates in grasses and legumes. Herb. Abstr. 31:255-261.
75. Weinmann, H., and L. Reinhold. 1946. Reserve carbohydrates in South African grasses. J. South African Bot. 12:57-73.
76. Welch, T. G. 1968. Carbohydrate reserves of sand reedgrass under different grazing intensities. J. Range Manage. 21: 216-220.
77. White, L. M. 1972. Carbohydrate reserves of grasses: A review. J. Range Manage. (in press)

