Effects of row spacing on dryland forage grass quality
by Christopher Lee Murphy

A thesis submitted in partial fullfillment of the requirements for the degree of Master of Science in Agronomy
Montana State University

Abstract:
An economic gain can be obtained by Montana livestock producers if the quality of dryland forage grasses can be improved. Forage grass quality is the measure of a forage grass to produce a desired livestock response. The objective of this study was to determine the effects of row spacing on forage quality of five important Montana dryland forage grasses. The grasses were seeded during the spring of 1994 in density wheels at three Montana locations. The grasses were harvested during the boot stage in 1995 and 1996. Crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and in vitro digestible dry matter (IVDDM) were predicted using the near infrared reflectance spectroscopy (NIRS) method. The concentrations of CP and ADF for (both years), and NDF and IVDDM (in 1995) were influenced by row spacing, location and species. Significant interactions made it difficult to make based conclusions. Data was not combined and analyzed for the two years because of the significant interactions that occured. It is difficult to make broad recommendations from this two year study and it has been determined that the trials will be maintained and results from independent years and years combined will be analyzed.

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Christopher L. Murphy

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

An economic gain can be obtained by Montana livestock producers if the quality of dryland forage grasses can be improved. Forage grass quality is the measure of a forage grass to produce a desired livestock response. The objective of this study was to determine the effects of row spacing on forage quality of five important Montana dryland forage grasses. The grasses were seeded during the spring of 1994 in density wheels at three Montana locations. The grasses were harvested during the boot stage in 1995 and 1996. Crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and *in vitro* digestible dry matter (IVDDM) were predicted using the near infrared reflectance spectroscopy (NIRS) method. The concentrations of CP and ADF for (both years), and NDF and IVDDM (in 1995) were influenced by row spacing, location and species. Significant interactions made it difficult to make based conclusions. Data was not combined and analyzed for the two years because of the significant interactions that occured. It is difficult to make broad recommendations from this two year study and it has been determined that the trials will be maintained and results from independent years and years combined will be analyzed.

CHAPTER 1

INTRODUCTION

Livestock production is a major contributor to the agricultural industry in Montana, averaging $880 million in cash receipts between 1991 and 1995. Livestock production in Montana depends on forages produced on approximately 40 million acres of range and pasture. An economic gain can be obtained by livestock producers if the quality and quantity of the forages produced on these can be improved.

Forage grass quality is the measure of a forage grass to produce a desired livestock response. Livestock performance is the ultimate analysis of forage grass quality. Crude protein, acid detergent fiber, neutral detergent fiber, and digestible dry matter are standards used to measure forage quality. Methods to analyze forage quality should be accurate, economical, precise, simple, quick, accepted for use by the scientific community, and related to livestock performance.

Near infrared reflectance spectroscopy is a relatively new instrumental method of analyzing forage quality. This technique consists of reflecting high intensity light on a ground forage sample. Based on the reflectance of different chemical bonds, the major chemical components of a forage sample can be differentiated.

Forage grass production on dryland range and pastures is affected by available moisture and nutrients, time of harvest, age of stand and row spacing. Grass production is positively correlated with precipitation recieved during the early-growing season. In Montana, high forage grass yields are highly correlated with preciptation received during the months of April, May, and June. The yields of forage grasses are also influenced by the amount of nutrients available to the plants. The higher the level of available nutrients, the higher the forage yields will be.

Forage grass dry matter production is highly dependent upon the stage of maturity at the time of harvest. The production level steadily rises until achieving peak production, which is usually between the boot and anthesis stage. Then, forage production rapidly declines due to seed ripening and dissemination, translocation, and respiration.

Forage grass yields are also influenced by the age of the stands. Peak forge production usually occurs two to three years after the forage has been planted.

Row spacing is critical for optimal forage production in dryland conditions. Generally, narrow row spacing provides the highest yields when grass stands are one to four years old. As the stands get older, yields of some species are higher at wide row spacings, while other species are not affected by row spacing.

Factors that affect forage grass quality are growth stage at time of harvest, species, available nutrients, and row spacing. Forage grass quality is highest in the vegetative stage and declines as the grasses approach maturity. Generally, forage quality declines as forage yields increase. This is due to the reduced mineral uptake while photsynthesis continues through the flowering and seed stage.

Forage grasses are more easily digested by livestock earlier in the growing season due to the lower leaf:stem ratio of the plants. As the season progresses, the leaf:stem ratio of the forage grasses increase, and digestibility decreases.

Potential quality of forage grass varies among species. Generally, Russian wildrye tends to have higher quality than the wheatgrass species on dryland conditions. However, wheatgrass species tend to produce more quality per hectare than Russian wildrye.

Research on row spacing effects in Montana has been limited to adaptation and yield evaluations. Forage stands with wide row spacings generally have higher water-use efficiencies, and nutrient recoveries, resulting in increased forage quality.

The objective of this study was to detemine the effects of row spacing on forage quality of five important Montana dryland forage grasses. The grasses were seeded during the spring of 1994 in replicated plots at three Montana locations. The grasses were harvested during the boot stage in 1995 and 1996. The samples were dried and dry matter forage yield estimated. Crude protein, acid detergent fiber, neutral detergent fiber, and in vitro digestible dry matter were predicted using the near infrared reflectance spectroscopy method. The data was analyzed, and the effects of row spacing on forage quality were discussed.

CHAPTER 2

LITERATURE REVIEW

Importance of Forage Grasses

Agriculture is the major industry in Montana. Livestock production is a major contributor to the agricultural industry. Between 1991 and 1995, livestock production averaged $880 million in cash receipts (Montana Agricultural Statistics, 1996). Livestock production depends on forages produced on rangeland, pastureland, and hayland. Montana has approximately 40 million acres of private range and pasture (Montana Agricultural Statistics, 1996). If the quality and the quantity of the forage grasses produced on these lands can be improved, an economic gain will be realized by livestock producers.

The major dryland forage grasses grown in Montana for pasture and hay production are crested wheatgrass (*Agropyron desertorum* (Fisch.ex Link) Schult.), intermediate and pubescent wheatgrasses (*Thinopyrum intermedium* (Host) Barkw. & D.R. Dewey), and smooth bromegrass (*Bromus inermis* Leyss.). Major dryland grasses grown in Montana primarily for pasture production are slender wheatgrass (*Agropyron trachycaulum* (Link) Malte ex H.F. Lewis), green needlegrass (*Stipa viridula* Trin.), bluebunch wheatgrass (*Agropyron spicatum* Pursh), thickspike wheatgrass (*Agropyron dasystachyum* (Hook.)

Scribn.), western wheatgrass (*Agropyron smithii* Rydb.), altai wildrye (*Elymus angustus* Trin.), basin wildrye (*Elymus cinereus* Scribn. & Merr.), and Russian wildrye (*Elymus junceus* Fisch.) (Smoliak et al., 1990).

Analyzing Forage Quality

Forage grass quality is the measure of a forage grass to produce a desired livestock response. The ultimate analysis of forage grass quality is livestock performance. Methods of analyzing grass forage quality should be accurate, economical, precise, simple, quick, accepted for use by the scientific community, and related to livestock performance (Barnes, 1973). Standards used to measure forage grass quality include crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), *in vitro* digestible dry matter (IVDDM) and relative feed value (RFV). Crude protein is the total protein equivalent including nitrogen from both protein and non-protein sources. Crude protein indicates the ability of forages to meet livestock protein needs. Acid detergent fiber is the amount of highly indigestible plant material in forages. The lower the ADF level, the greater the amount of forage livestock can digest. Neutral detergent fiber is the amount of cell wall material in forages. The lower the NDF level, the more forage livestock can potentially consume. Digestible dry matter is an estimate of the level of forage that is digestible based on feeding trials with animals. Relative feed value is a composite forage quality value calculated for ADF and NDF, where an index of 100 is equal to full bloom alfalfa (Gray, 1988)(Church and Pond , 1988).

Near infrared reflectance spectroscopy (NIRS) is a relatively new method used to predict forage quality. The NIRS procedure estimates the chemical composition of forage samples. The NIRS technique consists of reflecting high intensity light on a ground forage sample. Based on the reflectance of different chemical bonds, the major chemical components of a forage sample can be differentiated (Marten et al., 1985; Shenk and Westerhaus, 1994). Several research programs have independently utilized NIRS to accurately predict forage quality. Norris et al., (1976) accurately predicted CP, ADF, NDF, and lignin content in alfalfa (*Medicago sativa* L.), bromegrass, and tall fescue (*Festuca arundinacea* Schreb.) using NIRS. Crude protein and ADF levels of range forage were successfully predicted using NIRS (Ward et al., 1982). Albrecht et al., (1987) analyzed cell-wall carbohydrates and starch in alfalfa by NIRS. Trace elements of crested wheatgrass, tall fescue, and alfalfa were analyzed using NIRS. It was concluded that NIRS is an acceptable method for first approximations of trace minerals, and it is generally more accurate than values from feed tables (Clark et al., 1989). Windham and Barton, (1991) used NIRS to accurately measure moisture in alfalfa hay, grass-legume mixed hay, barley straw (*Hordeum vulgare* L), sorghum silage (*Sorghum bicolor* (L.) Moench), orchardgrass (*Dactylis glomerata* L), and tall fescue. Mayland et al., (1992) compared the seasonal trends in quality of Agropyron and chose the NIRS method for analysis. The following criteria needs to be met for the NIRS method to be effective: calibration samples that adequately represent the unknown samples to be analyzed; accurate laboratory analyses conducted on the calibration samples; proper data processing techniques; and proper wavelengths selected (Marten, et al., 1985; Hruschka, 1987).

Forage Grass Production

Forage grass production in the Northern Great Plains is affected by available moisture, available nutrients, time and frequency of harvest, age of stand, and row spacing.

Grass production is positively correlated with early-growing season precipitation. Stitt (1958) reported that 8-year forage yields of crested wheatgrass, smooth bromegrass, Russian wildrye, and big bluegrass (*Poa ampla* L) in central Montana had highly significant correlations (0.86 to 0.93, P<0.01) with April-May precipitation. In a study near Sidney, MT precipitation levels received between April and June were compared to the yields of Russian wildrye and crested wheatgrass. Yields decreased approximately 50% when the precipitation decreased 25% (White, 1986).

Available nutrients affect the yield of forage grasses. In a 10-year study conducted near Sidney, MT yields of fertilized cool season grasses were compared with the yields of unfertilized grasses. The average yield from the fertilized grasses increased 114% over the unfertilized grasses (Wight and Black, 1979). In Saskatchewan, old stands of crested wheatgrass were fertilized with various nitrogen(N) rates . Production increased as the N level increased (Read and Winkleman, 1982). In a long-term study at Havre, MT, yields of introduced and native grasses that were fertilized with 50 or 100 pounds of N per acre were significantly higher than the same grasses that were not fertilized (Lorbeer et al, 1994).

Forage grass dry matter production is highly dependent upon the stage of maturity at the time of harvest. During spring growth, biomass growth increases steadily until achieving peak production. Then, biomass growth begins to decline rapidly (Fairbourn, 1983). Highest total dry matter production for most forage grasses occurs between the boot stage and anthesis (White and Wight, 1981; Fairbourn,1983). Dissemination of seeds, translocation, and respiration are the causes for the quick loss of dry matter production 1 to 2 months after peak production (White and Wight,1981).

The age of stand influences the yield of forage grasses. Lawrence (1973) reported the second-year yields of intermediate wheatgrass were significantly higher than the third-year yields. A nine-year study in southern Saskatchewan showed dry matter yields of Russian wildrye were highest in the first three years of production (Kilcher et al., 1976). Wichman and Dubbs (1986) reported that yields of intermediate and crested wheatgrasses were significantly greater the first year after planting than the third year after planting. There were no significant yield differences between the second- and third-year harvests. Leyshon et al. (1990) conducted a four-year study at Swift Current, Saskatchewan involving Russian wildrye production. Yields peaked during the second year and then declined thereafter. Introduced forage grasses will reach peak production usually in the second, or third year after planting (Lobeer et al., 1994).

Row spacing is critical for optimal forage production in dryland conditions. In Southern Idaho, crested wheatgrass was seeded in row spacings of 15, 30, 45, and 60 cm. The 15 and 30 cm spacings provided the higher yields during the first four years, but by the fifth year, yields from all the row spacings were similar (Hull, 1948). Lavin and Springfield (1955) planted crested wheatgrass in Northern Arizona in rows spaced 15, 30, and 46 cm. Forage yields were highest in the second year in the 15-cm spacing, whereas in the fifth year, the highest yield was at the 46 cm spacing. McGinnies (1960) evaluated crested wheatgrass in Colorado, at spacings of 18, 36, 53 cm and found no significant yield difference between row spacings during the third and seventh year. During the eighth year, he did find higher yields for the 53-cm row spacings. In southeastern Oregon, crested wheatgrass was planted in 15, 30, 60, and 120 cm row spacings. Narrow row spacings had higher yields during the first 2 years, but the yields of all the row spacings were equal over the 10-year production period (Sneva and Rittenhouse, 1976). In a five-year study, Russian wildrye, crested wheatgrass, and alfalfa were evaluated in 30, 60, and 90-cm row spacings. Initially, the 30-cm spacing of all species produced the highest yields. By the fifth year, highest yields for all species were obtained at the 90-cm spacing (Leyshon et al, 1981).

Effects of row spacing on hay yields of crested wheatgrass, intermediate wheatgrass, smooth bromegrass, Russian wildrye, reed cannarygrass (*Phalaris arundinacea* L), and timothy (*Phleum pratense* L) were evaluated by Darwent et al. (1987). During the first year, yields of all species were the highest at the 27 cm-row spacing while decreasing as the row spacings increased to 93 cm. After the first year, yields at all row spacings were not significantly different. Thus, the effect of row spacings was most significant during the first year of production.

Other researchers have demonstrated that narrow row spacings provided higher yields. In a five-year study in North Dakota, Russian wildrye and crested wheatgrass were planted in row spacings of 15, 30, 60, 90, and 120 cm. The highest yields were obtained at the 15-cm spacing with the yields decreasing as the row spacings increased (Nyren and

Patton, 1990). Bishnoi (1980) evaluated wheat (*Triticum aestivum* L. emend. Thell.), and rye (*Secale cereale* L), and triticale (*xTriticosecale* Wittmack) at 12.5 and 25 cm row spacings for forage production. He found the higher yields to be at the 12.5-cm row spacing. Wider row spacings provided greater forage yields in other studies. In southern Saskatchewan, Russian wildrye produced the highest yields at the 60 cm spacing (Kilcher et al., 1976). Lawrence and Heinrichs (1968) in a study conducted in Swift Current, Saskatchewan, found that Russian wildrye yields were highest at 60-cm spacings, and the lowest at 30-cm spacings.

In research trials near Swift Current, Saskatchewan, there were no significant differences in yields of Russian wildrye seeded in row spacings of 15 or 60 cm (Leyshon et al., 1990) Springfield (1965) seeded crested wheatgrass in 15, 30, and 46 cm row spacings in New Mexico. He reported no significant yield differences between row spacings. McGinnies (1970) found in an established crested wheatgrass stand, that 30 and 46 cm spacings provided the highest yields followed by 61 cm, 15 cm, and 76 cm spacings.

Forage Grass Quality

Quality of forage grasses vary due to growth stage at time of harvest or grazing, species, available nutrients, and row spacing (Dubbs, 1970; White, 1986; Stannard and Kelley, 1993).

Forage grass quality is highest in the vegetative stage and declines as the grasses approach reproductive stage and maturity (Murray et al., 1978; Newell and Moline, 1978; Stannard and Kelley, 1993). Generally, there is a high negative correlation between biomass accumulation and forage quality (White and Wight, 1984). The reduction in forage quality during maturation is due to reduced mineral uptake while photosynthesis continues through the flowering and seed stage. Carbon is partitioned into structural elements that are less digestible and other mineral element concentrations are diluted as digestibility decreases (Mayland et al, 1992). Seven varieties of crested wheatgrass were harvested at five different growth stages by Mayland et al. (1992). Mineral concentration and IVDDM decreased linearly as the grasses matured.

The season of use affects the digestibility of forages. Forages are more easily digested by livestock earlier in the growing season. This is primarily due to the increase of the leaf:stem ratio in August and September (Abdalla et al., 1988). White and Wight, (1981) found *in vivo* digestibility of dryland forage grasses declined 22% between April and December. The greatest decline occurred between April and August, thereafter, the digestibility decreased slightly.

Forage grass quality potential varies among species. White (1986) reported that the CP concentration of Russian wildrye at anthesis was adequate for yearling steers to gain one kg per day. In contrast, crested wheatgrass at anthesis was only adequate for cow maintenance. A long-term study at Moccasin, MT compared the forage quality of intermediate wheatgrass, pubescent wheatgrass, smooth bromegrass, crested wheatgrass, and Russian wildrye. Intermediate wheatgrass, pubescent wheatgrass, and smooth bromegrass produced significantly more pounds of CP per acre than crested wheatgrass or Russian wildrye (Wichman and Dubbs, 1986).

Forage grass quality is dependent on available nutrients, primarily N. Plant uptake of N increases as the rate of applied N increases (Black and Reitz, 1969). Fertilization of intermediate wheatgrass, crested wheatgrass, orchardgrass, smooth bromegrass, and Russian wildrye influenced CP concentration in the grasses. As the rate of nitrogen fertilizer increased, the CP concentration of the grasses increased (Smika et al, 1960; Reid et al, 1966; Lawrence et al, 1970). Similar results were found when fertilized warm-season grasses were compared to unfertilized warm-season grasses (Monson and Burton, 1982; Puoli et al., 1991).

Effects of row spacing on forage grass quality has varied. Dubbs (1966) found in Central Montana, that Russian wildrye and crested wheatgrass had higher CP concentration in 90 cm-row spacing versus solid stands. In Sidney, MT, intermediate wheatgrass, Russian wildrye, and green needlegrass were seeded with row spacings of 0, 76, 107, and 152 cm. The stands with row spacings displayed higher water-use efficiencies, and recovered more applied N than solid stands resulting in higher forage quality (Black and Reitz, 1969).

Other studies have shown no significant differences in forage quality due to row spacing. Nyren and Patton (1990) hypothesized that dryland forage grasses would have higher ADF and NDF levels at the wider rows due to coarser, stemmier, and larger plants. Instead, they found no significant difference in forage quality. In Southern Saskatchewan, a study was conducted to determine the ideal row spacing for Russian wildrye fall pastures. The grasses were spaced 20, 40, and 60 cm. No significant differences were found in CP, organic matter digestibility, and crude fiber due to row spacings (Kilcher et al., 1976). A study of crested wheatgrass over a 10-year period in southeastern Oregon concluded that differences of quality due to row spacing were nonsignificant (Sneva and Rittenhouse, 1976).

There has been limited research to determine the effects of row spacing on dryland forage grass quality in Montana, and the results have varied. The objective of this study was to determine the effects of row spacing on CP, ADF, and NDF concentrations of Russian wildrye, basin wildrye, crested wheatgrass, intermediate wheatgrass, and pubescent wheatgrass.

CHAPTER 3

MATERIALS AND METHODS

Forage Grasses

'Hycrest' crested wheatgrass, 'Oahe' intermediate wheatgrass, 'Manska' pubescent wheatgrass, 'Trailhead' basin wildrye, 'Bozoisky-Select'(hereafter referred as Bozoisky) Russian wildrye were the five grasses selected for this study. These species were selected because of their widespread use for dryland pastures and haylands (Smoliak et al., 1990).

Hycrest crested wheatgrass was released in 1984 by the USDA-Agricultural Research Service in cooperation with the Utah Agricultural Experiment Station and the USDA-Natural Resource Conservation Service (Asay et al., 1985). Hycrest was developed by crossing an induced tetraploid form of 'Fairway' crested wheatgrass with a natural tetraploid 'Standard' crested wheatgrass. Hycrest is usually larger, more robust, and more productive than either parental species. Hycrest is long-lived, winterhardy, drought-resistant, perennial bunchgrass that performs well on a wide variety of soil types. Hycrest is best suited for spring pasture (Asay, et al., 1985; Smoliak, et al., 1990).

Oahe intermediate wheatgrass was released in 1945 by the South Dakota Agricultural Experiment Station (Ross, 1963). Oahe is a perennial, introduced bunchgrass that displays sod-forming tendencies under irrigation. Oahe grows best on well-drained soils and is best adapted to areas receiving 35 cm or more of annual precipitation. Oahe is well-suited for hayland production and from mid-spring to mid-summer, provides good pasture which is palatable to all classes of livestock (Ross, 1963; Smoliak et al, 1990).

Manska pubescent wheatgrass was released in 1992 by the USDA-Agricultural Research Service in cooperation with the USDA-Natural Resource Conservation Service, the North Dakota State Agricultural Experiment Station, and Agricultural Research Division, Institute of Agriculture and Natural Resources, University of Nebraska (Berdahl, et al., 1993). Manska is a perennial, introduced, sod-forming grass that is similar to intermediate wheatgrass, but is distinguishable by the pubescence on the heads and seeds. Manska performs well in areas with at least 30 cm of annual precipitation and is suited for all soil types. It can be used for hay production or a mid-spring to mid-summer pasture (Smoliak et al, 1990; Berdahl et al, 1993).

Trailhead basin wildrye was released in 1991 by the USDA-Natural Resources Conservation Service Plant Materials Center - Montana (USDA-SCS, 1991). Trailhead is an early-season, long-lived, native, perennial bunchgrass. Trailhead is winter hardy, drought tolerant, moderately alkaline tolerant, but will not stand long periods of flooding. It is adapted to all soil textures, but does not perform well on shallow soil sites. Trailhead is one of the first grasses to green up, providing spring pasture. Trailhead maintains high quality and palatability into fall and winter, therefore, it makes excellent fall and winter pasture when it is used in a grazing system. Trailhead is not recommended for hay production due to the size of the plant and the difficulty of harvesting by mechanical means. Trailhead provides excellent habitat and food source to wildlife (USDA-SCS, 1991; Smoliak et al, 1990).

Bozoisky Russian wildrye is a long-lived perennial introduced bunchgrass. It was released by the USDA-Agricultural Research Service in cooperation with the Utah Agricultural Experiment Station and the USDA-Natural Resource Conservation Service in 1984 (Asay et al., 1985). Bozoisky is an improved cultivar of Russian wildrye with a recommended minimum row spacing of 45 to 90 cm for optimum production. Bozoisky does not perform well on soils with low fertility and is better adapted to loam and clay soils. It is drought and cold tolerant and is highly saline tolerant. Bozoisky is not recommended for hay production because most of the leaf growth is basal and difficult to harvest mechanically. Bozoisky is tolerant to close grazing, regrows quickly, and has the ability to cure on the stem. These characteristics allow for a long grazing season (Asay et al., 1985; Smoliak et al., 1990).

Experimental Design

Plots were seeded in density wheels in May, 1994 at Bozeman, Bridger, and Moccasin, MT. Each grass species was seeded in four-row plots that served as the radii of a circle. Each plot was replicated three times and randomized. The completed planting looks like the spokes of a wheel with the rim of the wheel removed. Every row was seeded at twenty-five pure live seeds per linear 30 cm. Each row was 12.5 m long, with the row spacings being zero at the center and 130 cm at the circumference (Gross,1972).

The density wheel design was chosen for this study because it was an efficient use of plot space and the design allowed for greater visual demonstration of grass performance due to row spacing.

Procedures

Following the year of establishment in 1994, the two inside rows of each grass replication were harvested by hand clipping at 30, 61, 91, and 122 cm row spacings for a total of 24 samples per grass species. Thirty linear cm were harvested in 1995 and 1996 when each grass species was in the boot stage of growth. The system of describing growth stages of perennial forage grasses developed by Moore et al. (1991) was used to identify when the plants reached the boot stage. Harvest height was the recommended plant height at the end of the grazing season (crested wheatgrass and Russian wildrye - 10 cm, pubescent and intermediate wheatgrasses - 15 cm, basin wildrye - 20 cm). After harvest, the grass samples were dried and weighed to estimate dry matter yield. Yield was determined by converting g 0.3 linear m^{-1} to kg ha^{-1}. The dried grass samples were sequentially ground through a Wiley mill and Cyclone mill to pass through a 1 mm stainless steel screen. Samples were then stored in plastic whirl-pak sterile bags.

Forage Grass Quality Analyses

The ground grass samples from the density wheels were scanned by a NIRSystems Inc. Model 4500 Spectrophotometer (NIRSystems, Inc. Silver Spring, MD 301-680-9600). The scans along with scans from a forage grass maturity study were entered into the database of the ISI Infra-red software named "Infratec 2" (NIRSystems, Inc. Silver Spring, MD 301-680-9600). A calibration equation was developed by using the "Center" and "Select" programs in the software, which isolated 124 scans. The samples from the 124 scans were submitted for laboratory analysis of CP, ADF, and NDF. The micro-Kjeldahl procedure (Bremner and Mulvaney, 1982) was used to estimate CP, while ADF and NDF were determined using the Ankom Fiber procedure (Komarek et al., 1994). Digestible dry matter was estimated by the *in vitro* method (Tilley and Terry, 1963). These analyses were conducted in duplicate at the Western Experiment Station, Corvallis, MT and at the M.S.U. Animal Nutrition Laboratory. Results from the laboratory were entered into the software database. The laboratory data were entered into the 'Calibration' program of the software, and a calibration equation for forage grasses was developed. The standard error of calibration(SEC) for each constituent was used in the NIRS quality control calculations to establish error limits (Undersander et al., 1993).

All the density wheel forage grass scans were analyzed using the 'Predict' program. The 'Predict' program used the calibration equation to predict CP, ADF, NDF, and IVDDM. Results were stored on disk and hard copies were produced.

Validation of the calibration equation was accomplished by selecting 20 forage grass samples for a validation set. The validation set represented forage grass samples of various species and stages of maturity at different locations in Montana. Ground samples of the validation set were sent to the laboratory for CP, ADF, NDF, and IVDDM analysis. The results from the laboratory were entered into the software database. The validation set samples were scanned by the spectrophotometer and entered into the software database. The scans were analyzed using the "Predict" program in the software providing predicted results. The predicted results were compared to the laboratory results using the "Statistical" program in the software. A standard error of prediction corrected for bias (SEPC) was produced for each constituent. The SEPC for each constituent was compared to the quality control limits. In 1996, scans of 30 samples were added to the Prediction equation using the before mentioned process.

Data Analyses

The experiment was analyzed as a split-plot design with species and location as main effects and row spacings as split-plot effect. Yield and quality data were entered into MSUSTAT, version 5.25 (M.S.U. Bozeman, MT , Richard E. Lund). Analyses of variance were produced to detect significant differences at the 5% level for location, species, row spacing, location x species interaction, location x row spacing interaction, species x row spacing interaction, and location x species x row spacing interaction. Fitted treatment means with multiple comparisons based on least significant differences (LSD) were produced for location, species, and row spacing. Two-way tables were also produced to evaluate interaction effects. Data for 1995 and 1996 were analyzed separately.

Soils

The wheel trials were successfully established in 1994. In Bozeman, the trial was established on a silt loam that is 152 cm deep. The soil permeability is moderate and the available water capacity is high. The trial was established on a 152 cm-deep silty clay loam soil in Bridger. The soil permeability is slow, and the available water holding capacity is high. The soil in Moccasin has a 76-cm layer of clay loam over a gravelly loam. The soil permeability throughout the profile is moderately fast and the available water capacity is low.

CHAPTER 4

RESULTS AND DISCUSSION

Climate

The 1995 spring growing season provided different climatic conditions at the three locations (Nexrad Weather Service). Bridger and Moccasin experienced similar wet and cool conditions during the spring growing season. The climatic conditions in Bozeman were dryer and warmer. Bozeman received near-normal precipitation in April, but May and June were 16% and 40% below long-term averages, respectively (Table 1). The mean annual temperatures were near the long-term averages. The Bridger site was cool and wet during the spring growing season (Table 2). Above-normal precipitation was received in April (+31%), May (+10%), and June (+10%). The mean temperatures were below the long-term averages in April, May, and June. At Moccasin, precipitation during April, May, and June were 98%, 47%, and 17%, above long-term averages, respectively (Table 3). Mean temperatures were cooler than long-term averages in April (37% below average), and May (17% below average). The mean temperature for June was near the long term average.

The 1996 spring growing season climate also provided location variation. At

Table 1. Summary of the climatic data for 1994 and 1995 crop years at Bozeman, MT.

	Sept 1994	Oct 1994	Nov 1994	Dec 1994	Jan 1995	Feb 1995	Mar 1995	Apr 1995	May 1995	June 1995	July 1995	Aug 1995	Total
Precipitation (cm)													
Current Year	3.81	5.89	2.43	0.79	3.23	0.56	3.68	4.14	6.78	4.32	6.17	6.68	48.5
Long Term Mean	4.95	4.06	3.02	1.88	2.21	1.71	3.61	4.75	8.07	7.26	3.43	3.81	48.8
Mean Temp (Celsius)													
Current Year	16.2	6.9	3.3	2.8	-3.6	1.8	1.7	6.4	10.1	16.1	21.1	19.6	
Long Term Mean	13.2	7.9	0.4	-4.3	-5.1	-2.2	0.8	5.9	10.8	15.6	19.6	20.6	

Last Killing Frost in Spring:

Current Year	June 10
Long Term Mean	May 30

Table 2. Summary of the climatic data for 1994 and 1995 crop years at Bridger, MT.

	Sept 1994	Oct 1994	Nov 1994	Dec 1994	Jan 1995	Feb 1995	Mar 1995	Apr 1995	May 1995	June 1995	July 1995	Aug 1995	Total
Precipitation (cm)													
Current Year	3.28	6.83	1.09	0.25	2.97	0.18	4.83	4.32	5.36	5.08	1.85	1.07	37.1
Long Term Mean	3.31	2.72	1.31	0.96	1.04	0.81	1.75	3.28	4.88	4.61	1.95	1.88	28.5
Mean Temp. (Celsius)													
Current Year	16.5	8.1	0.3	-2.2	-4.4	-0.5	1.1	3.9	8.4	14.6	19.2	19.8	
Long Term Mean	14.7	9.4	1.6	-3.8	-9.7	-1.7	2.4	7.6	12.7	17.6	21.5	20.5	

Last Killing Frost in Spring:

Current Year	May 30
Long Term Mean	May 20

Table 3. Summary of the climatic data for 1994 and 1995 crop year at Moccasin, MT.

	Sept 1994	Oct 1994	Nov 1994	Dec 1994	Jan 1995	Feb 1995	Mar 1995	Apr 1995	May 1995	June 1995	July 1995	Aug 1995	Total
Precipitation (cm)													
Current Year	1.04	6.31	1.73	1.27	0.56	0.71	2.18	5.77	9.65	9.42	9.17	4.75	52.6
Long Term Mean	3.56	2.26	1.47	1.45	1.47	1.22	1.88	2.92	6.58	8.08	4.32	4.09	39.3
Mean Temp. (Celsius)													
Current Year	15.2	6.6	-0.8	-1.1	-1.4	-1.4	-2.3	3.2	8.5	14.2	17.1	17.7	
Long Term Mean	12.4	7.1	0.3	-4.1	-6.1	-4.4	-1.1	5.1	10.2	14.5	18.6	18.1	

Last Killing Frost in Spring

Current Year:	May 27
Long Term Mean	May 28

Table 4. Summary of the climatic data for 1995 and 1996 crop years at Bozeman, MT.

	Sept 1994	Oct 1994	Nov 1994	Dec 1994	Jan 1995	Feb 1995	Mar 1995	Apr 1995	May 1995	June 1995
Precipitation (cm)										
Current Year	2.74	3.94	2.18	1.91	1.35	2.54	1.24	2.82	11.5	2.57
Long Term Mean	4.95	4.06	3.02	1.88	2.21	1.71	3.61	4.75	8.07	7.26
Mean Temp (Celsius)										
Current Year	14.5	6.4	2.9	-3.1	-7.3	-3.5	-1.6	8.3	9.2	18.9
Long Term Mean	13.2	7.9	0.4	-4.3	-5.1	-2.2	0.8	5.9	10.8	15.6

Last Killing Frost in Spring:

Current Year	May 21
Long Term Mean	May 30

Table 5. Summary of the climatic data for 1995 and 1996 crop years at Bridger, MT.

	Sept 1995	Oct 1995	Nov 1995	Dec 1995	Jan 1996	Feb 1996	Mar 1996	Apr 1996	May 1996	June 1996
Precipitation (cm)										
Current Year	2.87	1.88	1.75	0.71	0.74	0.97	2.46	2.06	8.07	4.42
Long Term Mean	3.31	2.72	1.31	0.96	1.04	0.81	1.75	3.28	4.88	4.61
Mean Temp. (Celsius)										
Current Year	13.3	6.8	0.4	-5.5	-11	-4.4	-5.1	5.3	6.9	18.1
Long Term Mean	14.7	9.4	1.6	-3.8	-9.7	-1.7	2.4	7.6	12.7	17.6

Last Killing Frost in Spring:

Current Year	May 24
Long Term Mean	May 20

Table 6. Summary of the climatic data for 1995 and 1996 crop year at Moccasin, MT.

	Sept 1995	Oct 1995	Nov 1995	Dec 1995	Jan 1996	Feb 1996	Mar 1996	Apr 1996	May 1996	June 1996
Precipitation (cm)										
Current Year	4.75	4.34	2.57	1.32	0.41	0.66	2.36	2.59	7.77	3.21
Long Term Mean	3.56	2.26	1.47	1.45	1.47	1.22	1.88	2.92	6.58	8.08
Mean Temp. (Celsius)										
Current Year	13.1	15.1	17.1	-2.4	-10	-3.2	-4.7	6.4	8.1	14.4
Long Term Mean	12.4	7.1	0.3	-4.1	-6.1	-4.4	-1.1	5.1	10.2	14.5

Last Killing Frost in Spring

Current Year:	May 11
Long Term Mean	May 28

Bozeman, April and June were dry and warm, but May was wet and cool (Table 4). April was 41% below normal precipitation, and 41% above normal temperature. June was 70% below normal precipitation, and 21% above normal temperature. Precipitation was 43% above long-term average and the mean temperature was 15% below long term average in May. At Bridger, precipitation was 37% below the long-term average in April, and mean temperature was 30% below long-term average (Table 5). Precipitation in May was measured at 65% above long-term average, and mean temperature was 46% below long-term average. June precipitation and mean temperature was near the long-term average. The spring growing season in Moccasin also had monthly climatic variances. April had near average precipitation, while mean temperature was 25% above long-term average (Table 6). May was cooler and wetter than average. Precipitation was 18% above long-term average and mean temperature was 21% below long-term average. June had near long term average temperatures with 60% below long term average precipitation.

The climatic conditions during April vaired between locations. Bozeman and Bridger were drier than average while Moccasin received average precipitation. Bozeman and Moccasin experienced warmer than average temperatures than Bridger. All three locations had cooler and wetter than normal conditions during the month of May. Bozeman and Moccasin had temperatures near or above average while precipitation was lower than average. Bridger had average precipitation and temperature in June.

Harvest Dates

The forage yield and quality samples were harvested when each species reached boot stage. In 1995, Russian wildrye and crested wheatgrass samples were harvested May 24, May 19, and June 1 at Bozeman, Bridger, and Moccasin, respectively (Table 7). Pubescent wheatgrass, intermediate wheatgrass, and basin wildrye samples were harvested June 20, 1995, June 14, 1995, and June 15, 1995 at Bozeman, Bridger, and Moccasin respectively.

In 1996, Russian wildrye and crested wheatgrass samples were harvested June 6, May 29, and June 9, at Bozeman, Bridger, and Moccasin, respectively. Pubescent wheatgrass, intermediate wheatgrass, and basin wildrye were harvested June 16 (Bozeman), June 12 (Bridger), and June 20 (Moccasin).

The harvest date for Russian wildrye and crested wheatgrass at all locations occurred later in 1996 than in 1995. The basin wildrye, pubescent and intermediate wheatgrasses at all locations were harvested approximately the same time both years. In 1995, and 1996, Bridger had the earliest harvest dates of all locations.

Calibration and Validation Statistics

The standard errors for the 1995 CP, ADF, NDF, and IVDDM calibration equations were 6.04, 15.03, 23.44, and 45.91 g kg^{-1}, respectively (Table 8). The multiple correlation

Table 7. Harvest dates of five dryland grasses at three Montana locations

	Bozeman	Bridger	Moccasin
1995			
Russian wildrye	May 24	May 19	June 1
crested wheatgrass	May 24	May 19	June 1
pubescent wheatgrass	June 20	June 14	June 15
intermediate wheatgrass	June 20	June 14	June 15
basin wildrye	June 20	June 14	June 15
1996			
Russian wildrye	June 6	May 29	June 9
crested wheatgrass	June 6	May 29	June 9
pubescent wheatgrass	June 16	June 12	June 20
intermediate wheatgrass	June 16	June 12	June 20
basin wildrye	June 16	June 12	June 20