Relationships Among Quality Components in Cool-season Grasses Following Varied Rates of Nitrogen Fertilizer

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Abstract

Plant constituents that influence the nutritive value of forages are all formed from carbon chains produced in photosynthesis. This study investigates the relationship of certain of these constituents in four forage grasses (orchardgrass, tall fescue, annual ryegrass, and perennial ryegrass), that received varied rates of nitrogen (N) fertilization. Forage constituents studied included nitrogenous compounds, classed as crude protein (CP), and carbohydrate-based compounds including acid detergent fiber (ADF), neutral detergent fiber (NDF), and total nonstructural carbohydrates (TNC). With quantitative N fertilizer rates, regression and correlation statistical analyses were completed on yield, concentrations of the quality constituents, N efficiencies, and protein removed in hay. Tall fescue exhibited increased yields over the first three N fertilization rates and then yield declined slightly at the highest rate. Though not observed in all cases, increasing N fertilization rates caused concentration of CP in the forages to increase and concentrations of ADF, NDF, and TNC to decrease. When correlating the constituents, CP was inversely related to the carbohydrate-based compounds. Concentrations of ADF, NDF, and TNC were positively correlated with each other. Nitrogen efficiencies were highest at the lowest N fertilization rates and declined with increasing N fertilization rates.

Introduction

Photosynthesis in forages and all other plants is the source of skeletal carbon chains that are the backbones for biochemical compounds. In cool-season forage grasses, the initial compound in this reaction is the three-carbon species, 3-phosphoglyceric acid. This basic building block compound goes through a variety of chemical conversions to form all of the biochemical species found in cool-season grass forages, including carbohydrates, lipids, or nitrogenous compounds. The nitrogenous compounds can be proteins, nucleotides, or other compounds. The formation of the various biochemical products is dictated by dynamic equilibriums that are driven by concentrations of enzymes, concentrations of substrates, and environmental conditions (Goodwin and Mercer 1972).

Carbohydrates in grasses occur in structural and nonstructural forms. Cell walls are the major structural units and are the chief source of plant fiber. Carbohydrates associated with cell walls include cellulose, the most common biochemical compound in nature, hemicellulose, and pectic compounds. Non carbohydrate materials in cell walls include organic lignins, minerals, and silicates (Buxton and Mertens 1995). Cellulose is indigestible in simple-
stomached animals but can be broken down in ruminant animals by bacterial enzymes. Hemicellulose is moderately digestible while pectic compounds are almost totally digestible. Livestock can use minerals found in cell walls but no class of livestock can digest lignin or silicates (Paterson et al. 1994).

There are two main analytical methods used to determine the fiber content of forages. The first of these uses a neutral detergent solution to extract pectic compounds and cell contents. The remaining material left after this extraction is known as NDF and is comprised mainly of cellulose, hemicellulose, lignin, minerals, and silica. This particular fiber has been used as an indicator for the amount of feed that livestock can intake.

The other common forage analysis uses acidic detergent solution to extract non fiber components. The remaining fiber is known as ADF. The main difference between the two fibers is that NDF includes hemicellulose. ADF is used as an index for forage digestibility.

Non structural carbohydrates consist of simple and complex sugars that are totally digestible. These carbohydrates supply energy for plant metabolism. The complex forms of these sugars, fructosans for cool-season grasses and starches for warm-season grasses, provide energy for plants during dormant periods or for regrowth needs after grazing or hay harvests. The total of these simple and complex sugars is classified as TNC (Goodwin and Mercer 1972).

Most nitrogen in forages is found in organic compounds containing amino groups. These include amino acids, the building blocks of peptides and proteins, and nucleotides, compounds that store and allow genetic information to be expressed. These two nitrogenous classes of compounds make up most of the CP of forages. Concentrations of CP in forages vary with species and maturity of the forages (Goodwin and Mercer 1972).

With the addition of any agronomic input, questions arise as to the efficiency that a crop will exhibit in using that input. Excessive N use leads to two major concerns. The first is the movement of nitrate to ground or surface water. Nitrate is very soluble and is transported with water that leaves the treated site (Follett and Wilkinson 1995).

The second concern is the accumulation of forage nitrate that can be toxic to livestock. Uptake of N in excess of amounts synthesized into nitrogenous organic compounds results in nitrate accumulation. This accumulation can be amplified under conditions of environmental stress that retards conversion of inorganic N to organic N. These stresses include cold, hot, or dry conditions that limit plant metabolism. Concentrations of nitrate in forages under 0.5 percent is considered safe. Concentrations from 0.5 to 2.0 percent can be toxic and it is recommended that forages containing this level should not be used as the only source of feed. Forages with concentrations of nitrates above 2.0 percent should not be fed to livestock (Follett and Wilkinson 1995).

Forage growth is highly correlated with the availability of nitrogen. A trial was established to increase the understanding of the relationships among nitrogen fertilization and forage growth and plant constituents. This trial involved four cool-season grass forages that received varied rates of nitrogen fertilizer. It is
hoped that producers can use relationships between CP, ADF, NDF, TNC, and forage persistence to make management decisions.

**Procedures**

A late-summer seeded trial was established on a field with Poe fine sandy loam soil that had grown oats for hay earlier in the season. This field was ripped to 12- to 18-in depth in July, followed by moldboard plowing, disking, and harrowing. A Brillion packer was pulled behind the harrow on the last pass to form a smooth, firm seedbed. Prior to seeding, plots received broadcast fertilizer treatments of 50 lb N, 62.5 lb P₂O₅, and 41 lb S/acre (16-20-0-13 at 310 lb/acre).

The trial was established on August 17, 2000 in a four by four randomized block factorial design with four replications. Tested forages were Potomac orchardgrass, Fawn tall fescue, Hercules annual ryegrass, and Baristra perennial ryegrass. The grasses were seeded at 0.25- to 0.5-in depth using a Kincaid (Kincaid Equipment Manufacturing) experimental plot planter with 6-in drill spacings. A seeding rate of 20 lb/acre was used for each grass. Plots were 4.5 ft wide and 20 ft long.

Nitrogen fertilizer treatment applications were applied early in the 2001 growing season and immediately following the first two harvests. The fertilizer treatments were 25, 50, 100, or 200 lb N/acre using URAN (32 percent N) solution for each application. Including the preplant N applications, total N rates of 125, 200, 350, and 650 lb N/acre were applied.

Prior to each of three harvests completed in the 2001 growing season, 5.5-ft strips were cut between the plots to prevent sample mixing. Harvests were made with a Carter (Carter Manufacturing Co., Inc.) self-propelled flail harvester with a 3-ft-wide header on May 30, July 5, and September 7. Random samples of about 1 lb from each plot were oven dried to determine dry matter yield. Dried samples were ground to pass a 2-mm sieve in a Wiley Mill (Arthur H. Thomas Co.) and then to pass a 1-mm sieve in a Udy Mill (UDY Corporation). These ground samples were then analyzed in a near infrared spectrophotometer (NIRS, NIRSystems) to determine CP, ADF, and NDF. Analyses of TNC were completed on the samples following an acid extraction using an anthrone solution as the indicator.

Data analyses were completed using SAS software. With the quantitative fertilizer treatments, standard ANOVA and means separation procedures were not applicable for this trial. Using orthogonal polynomials, it is valid to consider regression equations up to the cubic level with the four fertilizer rates. Regression analysis relates causative independent variables and resulting dependent variables. In this trial, these regressions compared the affect of the varying N fertilization rates on yields and concentrations of quality constituents. Linear correlations were also determined between plant constituents to define relationships. Correlation analysis compares dependent factors but does not attempt to establish cause and effect relationships.

**Results and Discussion**

Irrigation water from the Klamath Irrigation District was available from July 25 until August 23. Additional irrigation from a sump that collects water from tile drains was applied prior
to and after the surface irrigation water. The AgriMet station located at KES recorded total precipitation of 2.1 in from April 1 through the third cutting. Total irrigation applied was about 18.5 in. These two inputs totaled 20.6 in compared with the calculated evapotranspiration (ET) for cool-season grasses of 31.8 in. Thus about 65 percent of calculated ET was supplied during the trials in 2001. For the first cutting, 1.6 in of rain and 3.6 in of irrigation provided about 60 percent of the ET for cool-season grasses. For the second cutting, 0.4 in of rain and 3.2 in of irrigation supplied about 25 percent of calculated ET. For the third cutting, 0.1 in of rain and 11.8 in of irrigation represented about 120 percent of calculated ET for this period.

The above conditions were not normal for the Klamath Basin. Perennial forage recommendations require results over time to ensure crop performance over the varying climatic conditions encountered by producers. This report provides information for only 1 year; a year with atypical irrigation management. These data will be compiled with data in future years to comprise more complete recommendations.

**Forage Yield**

Forage yields for the four grasses at the varied N fertilization rates for each of the three cuttings and the total are included in Table 1. Trends indicated were for the third cutting to yield more than the other two cuttings. The lowest yields were noted for the second cutting. This relates to the percent of irrigation water applied compared with calculated potential water use.

Interactions between yield and N fertilizer rates varied among the tested species. Varying interactions were also noted between the cuttings. Significant regressions comparing yield and species within cutting events occurred for tall fescue for the first and third cutting and for the total of all three cuttings (Fig. 1). The best-fit prediction lines were produced using quadratic equations. The relationship between N fertilizer rates and tall fescue yield tended to increase from the lowest rate to a point less than the highest N fertilizer rate. For the first cutting, it is predicted that yield would peak at about 3,850 lb/acre with the use of about 160 lb N/acre. For the third cutting, it is predicted that yield would peak at about 5,330 lb/acre with the use of about 150 lb N/acre. For the total of the three cuttings, it is predicted that yield would peak at about 11,870 lb/acre with the use of about 155 lb N/acre.

**Fertilizer Rate Relationships with Plant Constituents**

The response noted with increasing N fertilizer rates changed among species and also among cuttings. The significant regressions for orchardgrass are presented in Figure 2. For this species increases in concentrations of CP were noted in all three cuttings with increasing N fertilization rates. The rate of this increase was also similar for the three cuttings. This increase was between 0.24 and 0.29 percent CP for every additional 10 lb of N applied.

When considering changes in the concentration of ADF with changing N fertilization rates, an inverse relationship was indicated with orchardgrass for the first and third cutting. The decline in the concentration of ADF was about 60 percent greater in the first cutting compared with the third cutting. A similar relationship was noted with
concentrations of TNC and N fertilizer rates. However, the decline in concentrations of TNC was about 15 times greater for the third cutting compared with the second cutting. In contrast to these inverse relationships between N rates and ADF and TNC, concentrations of NDF increased with increasing N rates with orchardgrass in the third cutting.

Significant regressions for tall fescue with N fertilization rates and CP and ADF are presented in Figure 3. As with orchardgrass, concentrations of CP increased and concentrations of ADF decreased with increasing N fertilizer rates. These relationships were noted for both the first and third cuttings. The rate of the CP increase and ADF decrease was greater, 67 and 50 percent, respectively, for the third cutting compared with the first cutting.

For annual ryegrass the comparisons made with N fertilizer rates and CP, ADF, NDF, and TNC over the three cuttings indicated that only the concentration of CP was significantly affected by N fertilizer rate (Fig. 4). The rate of increase for the concentration of CP with increasing N rates was similar to that of other species, an increase of 0.22 percent CP for every 10 lb of N applied.

Significant regressions for perennial ryegrass with N fertilization rates and CP, ADF, and TNC are presented in Figure 5. These relationships were positive for the concentrations of CP and negative for concentrations of ADF and TNC. For the concentrations of ADF, the rate of decline with increasing N rates was similar for the second and third cuttings, as were the rates of decline for concentrations of TNC for the first and second cuttings. The concentrations of CP increased more than 66 percent for the second and third cuttings compared with the first cutting.

Relationships among Plant Constituents
Correlation analyses were completed on the forage species for each of the three cuttings to define relationships among CP, ADF, NDF, and TNC. For all four tested species, concentrations of CP and any of the carbohydrate-based constituents, ADF, NDF, and TNC, were inversely related while concentrations of ADF, NDF, and TNC were positively related. For orchardgrass, significant correlations were noted for CP and ADF (all cuttings), CP and TNC (first and third cuttings), ADF and NDF (second cutting), and ADF and TNC (first and third cuttings; Fig. 6).

For tall fescue, concentrations of CP were correlated with ADF (all cuttings), NDF (second cutting), and TNC (first cutting). Concentrations of ADF were also correlated with concentrations of NDF (second and third cuttings; Fig. 7).

Concentrations of CP in annual ryegrass were inversely related to concentrations of ADF and NDF (all cuttings) and TNC (second cutting). Concentrations of ADF were positively correlated with NDF in all cuttings while concentrations of NDF and TNC were positively correlated in the first cutting (Fig. 8).

Concentrations of CP in perennial ryegrass were inversely related to concentrations of ADF (all cuttings), NDF (second cutting), and TNC (first and second cuttings). Concentrations of ADF were positively correlated with NDF (first and second cuttings) and TNC in the second cutting (Fig. 9).
Nitrogen Use Efficiencies

Nitrogen efficiencies were calculated by dividing N removed by N input. Input N included residual N assumed to equal 110 lb N/acre, fertilizer N applied preplant, early season, and after the first two cuttings. N removed was calculated as yield multiplied by CP to obtain harvested CP. This value was then converted to N removed by dividing by 0.16. The assumed residual N was the largest difference in N input and N removed for all of the plots.

Regression analyses were completed on N input compared with N efficiencies and CP removed in hay. These regressions did not indicate significance for any species or cutting. However, trends appeared evident and are included in Figure 10. For orchardgrass and tall fescue, the lowest two fertilizer rates produced similar N efficiencies; the efficiencies dropped off at the higher two rates. For both of the ryegrass species efficiencies were maximized at the lower N fertilizer rates and steadily declined with increasing fertilizer rates. Low N fertilizer rate efficiencies were 78, 79, 74, and 71 percent for orchardgrass, tall fescue, annual ryegrass, and perennial ryegrass, respectively. These efficiencies declined at the higher N rates to 39, 49, 42, and 27 percent, respectively.

Removal of protein in orchardgrass was lowest at the low N rates, increased for the next two rates, but then slightly declined at the highest N fertilizer rate. Annual ryegrass protein varied only slightly over the N fertilizer rates, while protein removal for tall fescue and perennial ryegrass tended to increase throughout the range of increasing N fertilizer rates.

Summary

While the results obtained in the first year of this study are preliminary and were influenced by limited irrigation, general observations are of interest for local forage producers. Forage yields were highest for tall fescue followed by perennial ryegrass, orchardgrass, and annual ryegrass. Yield response to N fertilizer rate declined in that order among species. Increasing N fertilizer rates generally resulted in higher crude protein content but lower ADF, NDF, and TNC.

References


Table 1. Yield of four grass species at four N fertilizer rates for each of three cuttings and the total for 2001 at Klamath Falls, OR.¹

<table>
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<th>Species (Variety)</th>
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<th>Cutting 2</th>
<th>Cutting 3</th>
<th>Total</th>
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¹Due to the quantative treatments, standard ANOVA and mean separation statistical methods are not applicable.
Figure 1. Effects on yield of Fawn tall fescue with increasing N fertilizer rates, Klamath Falls, OR, 2001.
Figure 2. Effects on forage quality of Potomac orchardgrass with increasing N fertilizer rates, Klamath Falls, OR, 2001.
Figure 3. Effects on forage quality of Fawn tall fescue with increasing N fertilizer rates, Klamath Falls, OR, 2001.
Figure 4. Effects on forage quality of Hercules annual ryegrass with increasing N fertilizer rates, Klamath Falls, OR, 2001.

\[ R^2 = 0.47 \]
\[ y = 14.497 + 0.022x \]
Figure 5. Effects on forage quality of Baristra perennial ryegrass with increasing N fertilizer rates, Klamath Falls, OR, 2001.
Figure 6. Correlations of forage quality constituents in Potomac orchardgrass, Klamath Falls, OR, 2001.
Figure 7. Correlations of forage quality constituents in Fawn tall fescue, Klamath Falls, OR, 2001.
Figure 8. Correlations of forage quality constituents in Hercules annual ryegrass, Klamath Falls, OR, 2001.
Figure 9. Correlations of forage quality constituents in Baristra perennial ryegrass, Klamath Falls, OR, 2001.
Figure 10. N efficiency and protein removed with three cuttings over varying N fertilizer rates for four forage species, Klamath Falls, OR, 2001.