Nutritional Characteristics of Blue Grama Herbage under the Influence of Added Water and Nitrogen

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Highlight: The effects of water and nitrogen treatments on nutritional characteristics of blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.] herbage were studied at a native shortgrass prairie site in northeastern Colorado. Results indicated greater total nonstructural carbohydrates (TNC) (g m^{-2}), protein (g m^{-2}), gross energy (GE) (kcal m^{-2}), and total carbon (g m^{-2}) in herbage from the water and water + nitrogen treatments than from the untreated control or nitrogen treatments. On the other hand, there were greater concentrations (% dry weight) of TNC and nitrogen in the nitrogen treatment than in the other three treatments. The greater yield of TNC, protein, and GE in the water and water + nitrogen treatments was mainly a result of greater aboveground-live biomass production than in the control or nitrogen treatments. TNC/N and C/N ratios of herbage from these treatments were calculated and are discussed in light of their importance in nutrition of grass forage for livestock production.

Production in the shortgrass prairie ecosystem in North America is usually limited by water and nutrient availability. Addition of water and nutrients (mainly nitrogen) has increased production of range grasses several-fold (Lauenroth and Sims 1973; Klages and Ryerson 1965; Wight and Black 1972). The effect of water stress and other environmental factors on carbohydrate reserves and regrowth potentials has been discussed in a number of reviews (May 1960; Jameson 1963; Cook 1966; White 1973). Carbohydrate contents of herbage undergo diurnal and seasonal changes due to changes in their environment, such as temperature, water potential of soil and leaves, and nutrient status of soil (McIlroy 1967; Waite and Boyd 1953; Green and Beard 1969; Holt and Hilst 1969; Dina and Klikoff 1973).

The effect of nitrogen fertilization on forage quality of range grasses depends upon the species, rate of application, time of application, and other environmental conditions. Kelsey et al. (1973) and Pettit and Fagan (1974b) reported that nitrogen fertilization increased crude protein concentration of blue grama and other grass species. Heavy application of nitrogen decreased carbohydrate contents of several grasses (Waite 1958; Adegbola and McKell 1966). Several investigators have reported that irrigation and fertilization decrease carbohydrate reserves in perennial plants (Pettit and Fagan 1974a; Brown and Blaser 1965; Nowakowski 1962).

Total nonstructural carbohydrates (TNC) are important sources of available energy which affect the quality of forage and its digestibility (Cooper 1973; Wilson and Ford 1973; Noble and Lowe 1974). The ratio of available energy-to-protein in pasture has been found to have a great effect on growth and performance of animals (Reid and Jung 1973).

This study was conducted to investigate the relationship between TNC and protein contents of blue grama plants at various phenological stages under the influence of additional increments of water and nitrogen.

Methods and Materials

The study site is situated about 40 km northeast of Fort Collins at 40°49′ N latitude, 104°46′ W longitude and at an elevation of 1,650 m (4,500 ft). Mean annual precipitation is 311 mm, with a range of 110 to 580 mm recorded over the past 31 years at the Central Plains Experimental Range. Approximately 70% of the mean annual precipitation occurs during the April to September growing season. Mean monthly temperature ranges from below 0°C in December and January to 22°C in July. Mean open pan evaporation was 1,230 mm, with a high of about 1,350 mm in 1974. Principal perennial species are blue grama (*Bouteloua gracilis*), fringed sagewort (*Artemisia frigida*), plains pricklypear (*Opuntia polyacantha*), needleleaf sedge (*Carex eleocharis*), and scarlet globemallow (*Sphaeralcea coccinea*).

Four treatments each of two replications on a 1-ha plot included control (no additional water or nitrogen), water, nitrogen, and water + nitrogen treatments. The nitrogen treatment was initiated in the spring of 1970 by applying 150 kg N/ha as ammonium nitrate to maintain a difference of at least 50 kg/ha of mineral nitrogen (NH_4 + NO_3) between the nitrogen and control treatments. The water treatment was initiated in 1971 by applying water by means of a sprinkler system to maintain matric potential between 0 and −0.8 bars at a depth of approximately 10 cm in the water and water + nitrogen treatments. The water + nitrogen treatment received additional amounts of nitrogen in the spring of 1972, 1973, and 1974 at the rate of 150, 100, and 100 kg/ha of equivalent nitrogen, respectively. An additional 100 kg/ha of nitrogen was also applied to the nitrogen treatment in 1973 and 1974.

Samples for biomass estimation and chemical analyses were taken by clipping at least six quadrats (0.50 m^2) in each replicate of each treatment on six sampling dates.

Samples were dried at 60°C to a constant weight and weighed, and an aliquot from each sample was taken for chemical analyses. Total nonstructural carbohydrates (TNC) were extracted and determined according to the procedure of Smith (1969). Total nitrogen was determined by the microKjeldahl method. Gross energy (GE) was

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determined by the adiabatic bomb calorimetry method (Phillipson 1964). Total carbon was determined volumetrically by combusting an aliquot of the dried sample in a leco induction furnace. Total TNC ($g\ m^{-2}$) and total N ($g\ m^{-2}$) values were calculated by multiplying the concentration (per gram dry weight basis) of the above constituents at different sampling dates with the respective aboveground live biomass of blue grama on those dates from the four treatments. Gross energy (GE) values were calculated by multiplying the 1970–1972 average content of GE (kcal g^{-2} dry weight) of aboveground live herbage with the biomass of blue grama during the 1973 and 1974 growing season. Data were analyzed statistically using a model of repeated analysis of variance, testing for treatment differences while repeating each determination across a replicate of each treatment.

Results and Discussion

Data presented here in the form of tables and figures are mostly from the 1973 growing season because the data from the 1974 growing season are not complete and include only three sampling dates. Only salient features of the 1974 data will be presented and discussed at appropriate places.

Total Nonstructural Carbohydrates (TNC $g\ m^{-2}$)

During 1973 the maximum TNC in herbage of blue grama was found in the water + nitrogen treatment (30.5 $g\ m^{-2}$), followed by the water treatment (9.9 $g\ m^{-2}$) and the nitrogen (5.2 $g\ m^{-2}$) and control treatments (2.9 $g\ m^{-2}$) (Fig. 1).

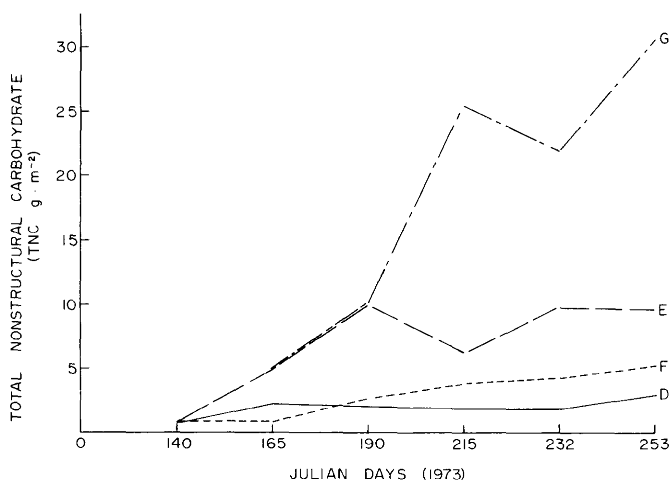

Fig. 1. *Total nonstructural carbohydrates (TNC, g m^{-2}) in the aboveground live compartment of the control (D), water (E), nitrogen (F), and water + nitrogen (G) treatments during the 1973 growing season.*

The TNC contents of herbage in all the treatments exhibited two peaks during the 1973 growing season except for the nitrogen treatment, which peaked at the end of the growing season. One of the two peaks in the three treatments occurred during the middle of the growing season, but not at the same time and the second at the end of the growing season. Mean annual TNC ($g\ m^{-2}$) content in herbage from the control, water, nitrogen and water + nitrogen treatments were 1.92, 6.86, 2.97, and 18.64 $g\ m^{-2}$, respectively.

During the 1974 growing season the maximum amounts of TNC in the herbage were from the water + nitrogen treatment (12.66 $g\ m^{-2}$). There was no significant difference between the peak TNC content of the control, water, and nitrogen treatments (about 3.00 $g\ m^{-2}$) in each case). The three dates in the 1974 growing season are at a comparable time of sampling with the 1973 growing season, and the data up to that point in time during both years does not reveal any significant year-to-year variation in the TNC content of the four treatments.

The greater amounts of TNC ($g\ m^{-2}$) in the herbage of the water and water + nitrogen treatments were mainly due to greater biomass production in the two treatments and not necessarily due to greater TNC concentrations (percent dry weight). For example, mean annual aboveground live biomass of water and water + nitrogen treatments during 1973 were 91.5 and 230.8 $g\ m^{-2}$, respectively, as compared to 21.1 $g\ m^{-2}$ from the control and 33.4 $g\ m^{-2}$ from the nitrogen treatments. Aboveground peak standing live biomass was 150.0 $g\ m^{-2}$ from the water and 348.9 $g\ m^{-2}$ from the water + ntrogen treatments. On the other hand, the TNC concentrations of herbage from the water and water + nitrogen treatments were slightly lower (7.3% and 7.8%, respectively) than the control (9.5%) and nitrogen (8.5%) treatments. The decrease in TNC concentrations of these treatments was due to its rapid utilization by the vigorous growth that results from the addition of water + nitrogen, which confirms early findings of Waite (1958) and Nowakowski (1962). Additional supply of nitrogen in the presence of adequate water increased biomass of blue grama more than that of water alone (Lauenroth and Sims 1973). This increase in aboveground live biomass places extra demands on photosynthates to support the growth and maintenance of these structures. Consequently, there is faster turnover of TNC pool in the shoots of these two treatments and also a greater dilution of TNC due to build up of more fibrous components in the shoots at maturity. For the utilization of additional amounts of nitrogen in the case of the water + nitrogen treatment there are additional demands on the carbohydrates to provide additional carbon skeleton for the incorporation of nitrogen into amino acids and proteins.

Comparing the peak TNC yield ($g\ m^{-2}$) of the four treatments, the herbage from the water + nitrogen treatment had 900%, 200%, and 400% greater TNC than that of the control, water, and nitrogen treatments, respectively. The increase in TNC of the nitrogen treatment over that of the control treatment was about 80%. The water treatment recorded an 89% increase in TNC over that of the nitrogen treatment. Repeated measures of analysis of variance indicated no significant difference between the TNC at different sampling dates (Tukey's Q = 10.07) except for the water + nitrogen treatment. There were significant dates × treatment interactions ($P < 0.001$), mainly due to the water + nitrogen treatment following the second sampling date. Addition of water alone had no significant effect on TNC content (Tukey's Q = 13.36); however, water in conjunction with nitrogen significantly increased TNC content during the middle and final vegetative growth period.

Gross Energy Content (kcal m^{-2})

The GE content of blue grama herbage from the four treatments is given in Figure 2. During the 1973 growing season the maximum GE in the herbage was in the water + nitrogen treatment (1,296 kcal m^{-2}). The maximum GE content from the control treatment was 110 kcal m^{-2}, and it was 636 kcal m^{-2} from the water and 192 kcal m^{-2} from the nitrogen treatments.

The mean annual GE content of herbage from the control, water, nitrogen, and water + nitrogen treatments was 62.4, 342.4, 194.6, and 863.7 kcal m^{-2}, respectively. During the 1974 growing season, the maximum GE content in the herbage from the water + nitrogen treatment was at the middle of the growing season (788 kcal m^{-2}). During the same period, the control, water, and nitrogen treatments recorded maximum values of 114, 144, and 146 kcal m^{-2}, respectively. The average

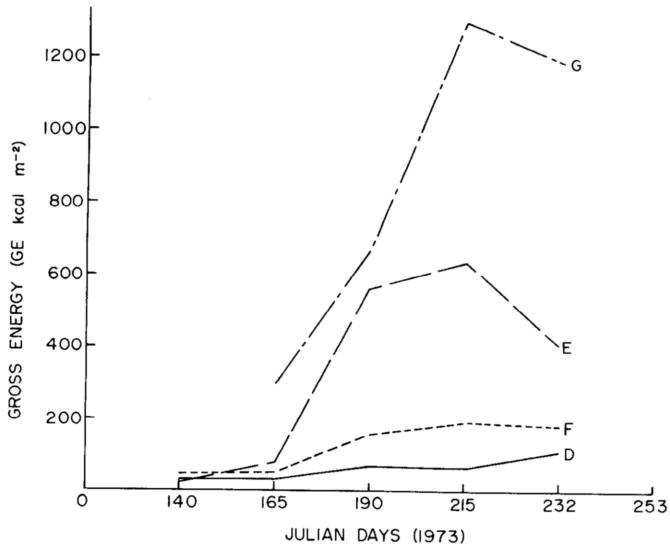

Fig. 2. *Gross energy (GE, kcal m^{-2}) in the aboveground live compartment of the control (D), water (E), nitrogen (F), and water + nitrogen (G) treatments during the 1973 growing season.*

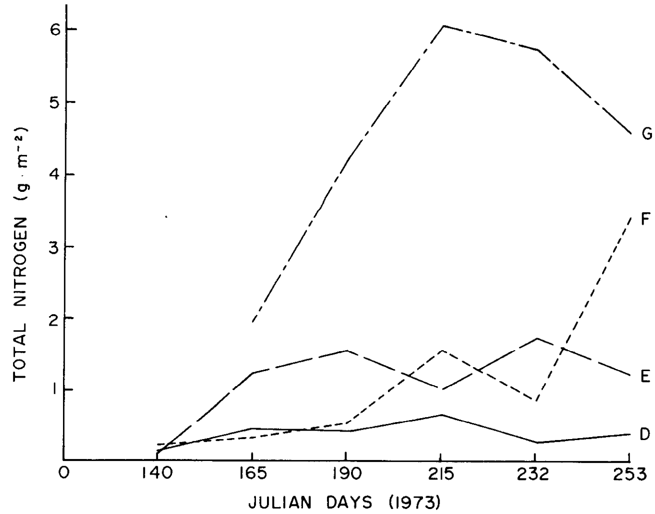

Fig. 3. *Total nitrogen (g m^{-2}) in the aboveground live compartment of the control (D), water (E), nitrogen (F), and water + nitrogen (G) treatments during the 1973 growing season.*

annual GE content from the control, water, nitrogen, and water + nitrogen treatments was 4.11, 4.15, 4.12, and 4.21 kcal/g dry wt, respectively.

The greater amounts of GE in the water (194.6 kcal m^{-2}) and water + nitrogen (863.7 kcal m^{-2}) treatments than that of the control (62.4 kcal m^{-2}) or nitrogen (194.6 kcal m^{-2}) treatments are due to greater amounts of aboveground live biomass, and not due to greater GE concentrations (kcal g dry wt^{-1}). GE is composed of two components, the nonlabile energy (structural components), which is not available for redistribution once it is fixed, and the labile energy (nonstructural carbohydrates), which is available for distribution between all the plant parts. Of the two components of GE the nonlabile energy is the predominant form. Both nonlabile and labile energy content (kcal m^{-2}) of blue grama shoots from the water and water + nitrogen treatments are higher than the control or the nitrogen treatments. Similar results were reported earlier by Bokhari et al. (1974) when blue grama plants were grown in environment controlled growth chambers under identical treatment conditions as described for this study. The magnitude of GE of the shoots from the growth chamber experiment was, of course, different than that of the field experiments.

Total Nitrogen Content (g m^{-2})

The total nitrogen content of blue grama herbage during the 1973 growing season varied from a maximum of 6.0 g m^{-2} in water + nitrogen treatment to a maximum of 0.67 g m^{-2} in the control, 1.74 g m^{-2} in the water, and 3.41 g m^{-2} in the nitrogen treatments (Fig. 3). The control, water, and nitrogen treatments exhibited two peaks while the water + nitrogen treatment showed one peak during the 1973 growing season. The mean annual total nitrogen content in herbage of the control, water, nitrogen, and water + nitrogen treatments was 0.40, 1.15, 1.16, and 4.11 g m^{-2}, respectively.

The amounts of total nitrogen in the biomass of the nitrogen treatment indicated greater content than that of the control and water treatments mainly because of greater concentration of nitrogen (percent dry weight). For example, the maximum concentration of nitrogen in herbage of the control treatment during the 1973 growing season was 2.50%, and it was 2.00% in the water treatment, 3.20% in the nitrogen treatment, and 2.64% in the water + nitrogen treatment. Mean annual concentration of nitrogen in herbage of the control, water, nitrogen, and water + nitrogen treatments was 1.97, 1.41, 2.19, and 2.15%, respectively.

During the 1974 growing season, the maximum total nitrogen content (g m^{-2}) from the control, water, nitrogen, and water + nitrogen treatments was 0.55, 0.85, 1.12, and 3.07 g m^{-2}, respectively. Nitrogen concentration varied from a minimum of 1.67% to a maximum of 2.31% in the control, from 1.20% to 1.60% in the water, from 2.34% to 3.00% in the nitrogen, and from 1.14% to 3.10% in the water + nitrogen treatments. During 1974 maximum nitrogen concentration in herbage was identical with the water + nitrogen and nitrogen treatments. Repeated statistical comparisons by analysis of variance indicated significant dates × treatment interactions ($P < 0.001$), which is attributable mainly to the water + nitrogen treatment. There were no significant differences in terms of nitrogen content (g m^{-2}) of herbage at different sampling dates (Tukey's $Q = 1.66$) from the control, water, and nitrogen treatments. Water + nitrogen significantly (Tukey's $Q = 2.20$) increased nitrogen content.

In the control and nitrogen treatments there seems to be a buildup of nitrogen in the shoots (probably as nitrate, as postulated by Sullivan, 1962) due to lack of capability of the shoots (photosynthates) to provide sufficient carbon skeleton for the incorporation of additional nitrogen. On the average there are greater protein concentrations in the shoots of the nitrogen treatment. (15%) than those of the water (9%) or water + nitrogen (13%) treatments. Uresk and Sims (1975) reported an average of 10% crude protein in live blue grama herbage from different grazing treatments during 1970 with a minimum of 7.8% at maturity and a maximum of 18% during early vegetative growth.

Total Carbon Content (g m^{-2})

The total carbon content of blue grama herbage from the four treatments during the 1973 growing season is given in Figure 4. The water treatment produced greater content of carbon in herbage than control or nitrogen treatments. The mean annual content of total carbon in herbage of the control, water,

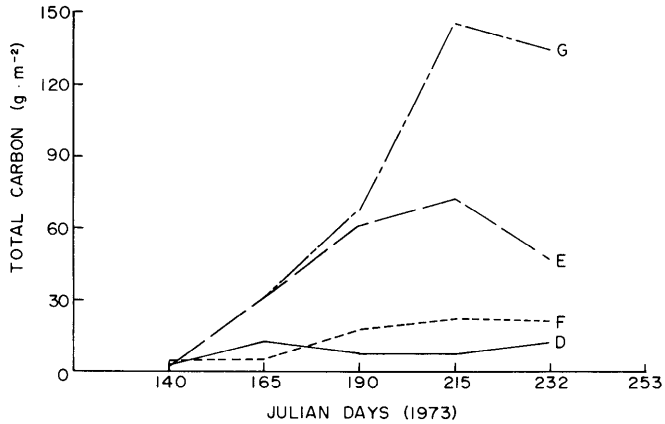

Fig. 4. *Total carbon (g m^{-2}) in the aboveground live compartment of the control (D), water (E), nitrogen (F), and water + nitrogen (G) treatments during the 1973 growing season.*

nitrogen, and water + nitrogen treatments was 8.6, 42.6, 14.0, and 44.2 g m^{-2}, respectively.

During the 1974 growing season, the maximum content of carbon in herbage of plants growing in control, water, nitrogen, and water + nitrogen plots was 12.66 g m^{-2}, 15.61 g m^{-2}, 14.78 g m^{-2}, and 80.03 g m^{-2}, respectively, up to the middle of the growing season.

There were no significant differences in carbon concentration (percent dry weight) of herbage among the four treatments (averaging 41% to 45%) at any given time during the growing season. The carbon concentration in herbage of plants growing in all treatments increased as the plants approached maturity. On the average, the 38% carbon in the herbage at the beginning of the growing season increased to 48% by the end of the growing season.

C/N Ratio

The C/N ratio in herbage of all four treatments fluctuated throughout the growing season (Table 1). Maximum C/N ratio in blue grama herbage during the 1973 growing season was from the water treatment (69.9) and minimum from the nitrogen treatment (6.0). The seasonal average C/N ratio in herbage of plants growing in the control, water, nitrogen, and water + nirogen plots was 18.2, 38.2, 17.2, and 21.1, respectively. During the 1974 growing season, the maximum C/N ratio in herbage was found during the middle of the growing season.

The control treatment, which represents the normal conditions of the native shortgrass prairie site with a lower C/N ratio than the water and water + nitrogen treatment, indicates that there is proportionately greater accumulation of carbon-containing substances in the water and water + nitrogen treatments than in the control treatment. The lowest C/N ratio in the nitrogen treatment (17.2) indicates comparatively greater content of nitrogenous compounds, which again may be due to the presence of nonproteinaceous substances as well as nitrogen in the form of nitrate.

Table 1. Carbon and nitrogen ratios (C/N) in aboveground live herbage of blue grama during the 1973 and 1974 growing seasons.

Year	Sampling dates (Julian days)	Treatments Control	Water	Nitrogen	Water + nitrogen
1973	138–140	19.0	19.0	19.0	—
	159–166	13.2	25.1	15.4	15.8
	179–191	18.0	39.2	32.0	16.0
	207–235	11.0	69.9	13.8	23.8
	235–253	29.8	38.1	6.0	29.1
	Average	18.2	38.2	17.2	21.1
1974	144–151	17.3	25.1	13.8	13.0
	163–168	24.1	28.8	13.1	16.4
	203–206	23.1	31.7	14.4	26.0
	Average	21.5	28.5	13.7	18.4

TNC/N Ratio

The proportion of total available carbohydrate and total nitrogen content (TNC/N) is considered a reliable index of quality and potential utilization of herbage by livestock (Reid and Jung 1973). The TNC/N ratio in all treatments during 1973 increased toward the end of the growing season, except for the nitrogen treatment, which began to decline at this time (Table 2). The maximum TNC/N ratio recorded was about 7.0 in the herbage of the control and water treatments. Average TNC/N ratios during the 1973 growing season were 5.0 from the control, 6.0 from the water, 3.3 from the nitrogen, and 3.8 from the water + nitrogen treatments. Average TNC/N ratios up to the middle of the 1974 growing season were 6.2, 5.4, 3.8, and 3.4 from the control, water, nitrogen, and water + nitrogen treatments, respectively (Table 2).

Table 2. Total nonstructural carbohydrates (TNC) and total N ratios (TNC/N) in aboveground live herbage of blue grama during the 1973 and 1974 growing seasons.

Year	Sampling dates (Julian days)	Treatments Control	Water	Nitrogen	Water + nitrogen
1973	138–140	4.4	7.0	3.7	—
	159–166	4.7	4.0	2.5	2.5
	179–191	4.7	6.3	4.8	2.4
	207–215	2.7	6.0	2.4	4.1
	229–235	6.1	5.5	4.8	3.8
	235–253	7.1	7.7	1.5	6.6
	Average	5.0	6.0	3.3	3.8
1974	144–151	6.1	5.0	5.3	3.0
	163–168	6.5	6.1	2.7	3.2
	203–206	6.2	5.2	3.4	4.1
	Average	6.2	5.4	3.8	3.4

TNC is a source of readily available energy which, according to Cooper (1973), enhances rumen microbial activity and forage utilization and also aids in utilization of protein and nonprotein nitrogen (Macrae et al. 1972; Noller and Rhykerd 1973). Rumen microorganisms require a source of readily available energy for conversion of nonprotein nitrogen to microbial protein (Nowakowski 1962). Low available energy-to-protein ratios have been associated with poor feeding quality of silage, depressed growth and performance of animals on pasture, and a higher susceptibility to metabolic disease (Butler and Jones 1972; Reid and Jung 1973).

Crude Protein (N × 6.25 g m^{-2})

Herbage from the water + nitrogen treatment had a higher content of crude protein throughout the 1973 growing season than did that from the other three treatments (Fig. 5). Maximum amounts of crude protein in the herbage were from the water + nitrogen treatment (37.93 g m^{-2}).

Compared to the other three treatments, the control treatment had the lowest amounts of crude protein throughout the growing season with a maximum amount of 4.18 g m^{-2} during the middle of the growing season and a minimum amount of 1.03 g m^{-2} at the beginning of the growing season. During the 1974 growing season, the maximum content of protein was in the herbage

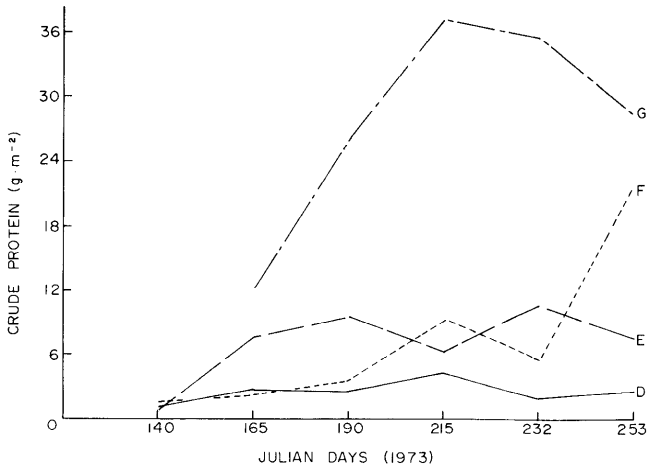

Fig. 5. *Total crude protein (N × 6.25 g m^{-2}) in the aboveground live compartment in the control (D), water (E), nitrogen (F), and water + nitrogen (G) treatments during the 1973 growing season.*

from the water + nitrogen treatment (19.22 g m^{-2}) and minimum from the control treatment. Up to the middle of the 1974 growing season, average protein contents in the control, water, nitrogen, and water + nitrogen treatments were 2.77, 3.85, 5.47, and 14.70 g m^{-2}, respectively, during the 1973 growing season.

Mean annual protein content (g m^{-2}) was greater in the herbage from the water + nitrogen treatment (28.2 g m^{-2}) than in that from the water or nitrogen (7.2 g m^{-2}), or the control (2.5 g m^{-2}) treatments. The greater concentration of protein (% dry weight) was found in the nitrogen treatment, which may not really represent protein nitrogen but most probably nonprotein or nitrate nitrogen. Usually the Kjeldahl procedure used for the determination of total nitrogen does not include nitrate unless a modified procedure is used. However, in most studies crude protein content of fertilized range grasses increased independently of yield (Rogler and Lorenz, 1957; Mason and Miltimore, 1964). Protein contents of blue grama herbage were higher during the middle of the growing season (June and July) in all treatments except the nitrogen treatment, which indicates the appropriate time of its nutritive values for livestock. Rodgers and Box (1967) reported similar trends in protein contents of several grasses including blue grama.

From a nutritional point of view these results indicate that nitrogen fertilization alone may reduce production and forage quality due to reduction in carbohydrate contents. Other quality factors such as increase in protein concentration may compensate for carbohydrate and yield losses. Irrigation alone or in combination with fertilization increases forage production and protein yield but may reduce forage quality due to low protein concentrations. Changes in the yield of protein may compensate for low protein concentration in otherwise highly productive range grasses.

Literature Cited

Adegbola, A. A., and C. M. McKell. 1966. Regrowth potential of coastal Bermudagrass as related to previous nitrogen fertilization. Agron. J. 58: 145-146.

Bokhari, U. B., M. I. Dyer, and J. S. Singh. 1974. Labile and nonlabile energy in blue grama (*Bouteloua gracilis*) as influenced by temperature, water stress, and fertilizer treatments. Can. J. Bot. 52:2289-2298.

Brown, R. H., and R. E. Blaser. 1965. Relationships between reserve carbohydrate accumulation and growth rate in orchardgrass and tall fescue. Crop Sci. 5:577-582.

Butler, G. W., and D. I. H. Jones. 1973. Mineral biochemistry of herbage. p. 146-150. *In:* G. W. Butler and R. W. Bailey (Eds.) Chemistry and Biochemistry of Herbage. Vol. 2. Academic Press, New York, N.Y.

Cook, C. W. 1966. Carbohydrate reserves in plants. Utah Res. Ser. 31, Logan, Utah. 47 p.

Cooper, J. P. 1973. Genetic variation in herbage constituents. p. 379-417. *In:* G. W. Butler and R. W. Bailey (Eds.) Chemistry and Biochemistry of Herbage. Vol. 2. Academic Press, New York, N.Y.

Dina, S. J., and L. G. Klikoff. 1973. Effect of plant moisture stress on carbohydrate and nitrogen content of big sagebrush. J. Range Manage. 26: 207-209.

Green, D. G., and J. B. Beard. 1969. Seasonal relationship between nitrogen nutrition and soluble carbohydrates in the leaves of *Agrostis palustris* Huds. and *Poa pratensis* L. Agron. J. 61:107-111.

Holt, D. A., and A. R. Hilst. 1969. Daily variation in carbohydrate content of selected forage crops. Agron. J. 61:239-242.

Jameson, D. A. 1963. Responses of individual plants to harvesting. Bot. Rev. 29:532-594.

Kelsey, R. J., A. B. Nelson, G. S. Smith, and R. D. Pieper. 1973. Nutritive value of hay from nitrogen-fertilized blue grama rangeland. J. Range Manage. 26:292-294.

Klages, M. G., and D. F. Ryerson. 1965. Effects of nitrogen and irrigation on yield and botanical composition of western Montana range. Agron. J. 57:78-81.

Lauenroth, W. K., and P. L. Sims. 1973. Effects of water and nitrogen stresses on a shortgrass prairie ecosystem. US/IBP Grassland Biome Tech. Rep. No. 232. Colorado State Univ., Fort Collins. 117 p.

Macrae, J. C., M. J. Ulyatt, P. D. Pearce, and J. Handtlass. 1972. Quantitative intestinal digestion of nitrogen in sheep given formaldehyde treated and untreated cosim supplements. Brit. J. Nutr. 27:39-50.

Mason, J. L., and J. E. Miltimore. 1964. Effects of nitrogen content of beardless wheatgrass on yield response to nitrogen fertilization. J. Range Manage. 17:145-147.

May, L. H. 1960. The utilization of carbohydrate reserves in pasture plants after defoliation. Herb. Abstr. 30:239-245.

McIlroy, R. J. 1967. Carbohydrates of grassland herbage. Herb. Abstr. 37:79-87.

Noble, A., and K. F. Lowe. 1974. Alcohol-soluble carbohydrates in various tropical and temperate pasture species. Trop. Grassl. 8:179-187.

Noller, C. H., and C. L. Rhykerd. 1973. Relationship of nitrogen fertilization and chemical composition of forage to animal health and performance. p. 363-394. *In:* D. A. Mays (Ed.) Forage Utilization. Amer. Soc. Agron., Madison, Wisc.

Nowakowski, T. Z. 1962. Effects of nitrogen fertilizers on total nitrogen, soluble nitrogen, and soluble carbohydrate contents of grass. J. Agr. Sci. 59:387-392.

Pettit, R. D., and R. E. Fagan. 1974a. Influence of nitrogen and irrigation on carbohydrate reserves of buffalograss. J. Range Manage. 27:279-282.

Pettit, R. D., and R. E. Fagan. 1974b. Influence of nitrogen on irrigated buffalograss yield and protein content. J. Range Manage. 27:473-476.

Phillipson, J. 1964. A miniature bomb calorimeter for small biological samples. Oikos 15:130-139.

Reid, R. L., and G. A. Jung. 1973. Effects of elements other than nitrogen on the nutritive value of forage. p. 395-435. *In:* D. A. Mays (Ed.) Forage Fertilization. Amer. Soc. Agron., Madison, Wisc.

Rodgers, J. D., and T. W. Box. 1967. Seasonal protein content of four Southern mixed prairie grasses. J. Range Manage. 20:177-178.

Rogler, G. A., and R. J. Lorenz. 1957. Nitrogen fertilization of northern Great Plains rangelands. J. Range Manage. 10:156-160.

Smith, D. 1969. Removing and analyzing total nonstructural carbohydrates from plant tissue. Res. Rep. No. 41, Res. Div., Univ. Wisconsin, Madison.

Sullivan, J. T. 1962. Evaluation of forage crops by chemical analysis. A critique. Agron. J. 54:511-515.

Uresk, D. W., and P. L. Sims. 1975. Influence of grazing on crude protein content of blue grama. J. Range Manage. 28:370-371.

Waite, R. 1958. The water soluble carbohydrates of grasses. IV. The effect of different levels of fertilizer treatment. J. Sci. Food Agr. 9:39-43.

Waite, R., and J. Boyd. 1953. The water soluble carbohydrates of grasses. I. Changes occurring during the normal life-cycle. J. Sci. Food Agr. 4:197-203.

White, L. 1973. Carbohydrate reserves of grasses: A review. J. Range Manage. 26:13-18.

Wight, J. R., and A. L. Black. 1972. Energy fixation and precipitation use efficiency in a fertilized rangeland ecosystem of the northern Great Plains. J. Range Manage. 25:376-380.

Wilson, J. R., and C. W. Ford. 1973. Temperature influences on the in vitro digestibility and soluble carbohydrate accumulation of tropical and temperate grasses. Aust. J. Agr. Res. 24:187-198.