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Annual Mineral Quality Curves for Graminoids in the Northern Great Plains

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Introduction

Beef cows require seventeen minerals to maintain proper body functions: seven macrominerals in large quantities and ten microminerals in trace amounts. The quantities of each mineral required vary with cow size, level of milk production, and production period (dry gestation, 3rd trimester, early lactation, lactation). Livestock mineral requirement curves show the amount of each mineral animals require during the production periods. Many essential minerals are provided to the animals by the forages they consume. The mineral content of perennial forage grasses and sedges changes as the plants develop and mature through phenological stages. Annual mineral quality curves for forage plants show these changes in mineral content during the year. Coordination of annual mineral quality curves of available perennial forage plants with livestock mineral requirement curves is necessary for the development of management strategies that efficiently provide the quantities of minerals animals require at each production stage.

The major perennial graminoid plants livestock use as forage are separated into four categories based on the period during which most of the plant growth occurs: domesticated cool-season grasses, native range upland sedges, native range cool-season grasses, and native range warm-season grasses. This report summarizes published information on the annual mineral quality curves of these four graminoid categories.

Methods

Two publications have reported the changes in mineral content of perennial grasses growing on the Northern Great Plains mixed grass prairie of western North Dakota and eastern Montana. In the historical literature for the Northern Great Plains, changes in mineral content and related phenological growth stages of perennial graminoids are reported only for phosphorus. Phosphorus is the mineral most commonly deficient in diets of cattle grazing forages. Calcium and salt (sodium and chlorine) are the other minerals most likely to be deficient in forage diets.

Whitman et al. (1951) published a bulletin on the nutrient content of grasses and sedges in western North Dakota. Graminoid species samples were collected weekly in 1946 and 1947 from the Dickinson Experiment Station at Dickinson, North Dakota. Only current year's growth was included in the sample; previous year's growth was separated and discarded. An attempt to collect ungrazed samples was made for available species except Kentucky bluegrass, which had been grazed, and smooth bromegrass, which was cut for hay in mid June. Data were reported as percent of oven-dry weight. Plant condition by stage of plant development and growth habit was reported for each species on sample dates. These data are presented as phenological growth stage in Manske (1999a, b, c, d). Weekly percent phosphorus of graminoid species reported by Whitman et al. (1951) was summarized by species and included in Manske (1999a, b, c, d). These data have been summarized and presented in four graminoid categories in this report.

Marsh et al. (1959) reported nutrient content of three grasses from the USDA Experiment Station at Miles City, Montana. Samples were collected by clipping every 28 days from August 1948 to June 1953 except when snow covered the vegetation. Data were reported as percent of oven-dry weight. Phenological growth stages of plants on sample dates were not reported. A summary of the phosphorus data by species was presented in Manske (1999c, d). These data have been summarized and presented in two graminoid categories in this report.

Results

The mineral quality of ungrazed domesticated cool-season grasses, native range upland sedges, native range cool-season grasses, and native range warm-season grasses changes with the phenological development of the plants. Early season vegetative growth of graminoids is generally high in phosphorus. As the plants mature, their phosphorus content decreases. Phenological development patterns are similar from year to year because they are regulated primarily by photoperiod (Manske 1998b, 2000), although annual differences in temperature, evaporation, and water stress may result in slight variation.

Results--Daily Mineral Requirements

Understanding both the mineral quality curves for perennial forage plants and the mineral requirement curves for beef cows is necessary for efficient nutritional management of livestock. Beef cow daily nutritional requirements (NRC 1996), including phosphorus and calcium requirements, change with cow size, level of milk production, and production period. During the dry gestation period, beef cows with average milk production and live weights of 1000 lbs, 1200 lbs, and 1400 lbs require 0.11%, 0.12%, and 0.12% phosphorus in diet dry matter, respectively; during the 3rd trimester period, they require 0.15%, 0.16%, and 0.17% phosphorus in diet dry matter, respectively; during the early lactation period, they require 0.20%, 0.19%, and 0.19% phosphorus in diet dry matter, respectively; and during the lactation period, they require 0.18%, 0.18%, and 0.18% phosphorus in diet dry matter, respectively (table 1). During the dry gestation period, beef cows with average milk production and live weights of 1000 lbs, 1200 lbs, and 1400 lbs require 0.15%, 0.15%, and 0.16% calcium in diet dry matter, respectively; during the 3rd trimester period, they require 0.24%, 0.25%, and 0.26% calcium in diet dry matter, respectively; during the early lactation period, they require 0.30%, 0.29%, and 0.28% calcium in diet dry matter, respectively; and during the lactation period, they require 0.27%, 0.26%, and 0.26% calcium in diet dry matter, respectively (table 1). Beef cattle require greater amounts of calcium than of phosphorus. However, because perennial grasses contain considerably more calcium than phosphorus, diets of cattle grazing forages are more likely to be deficient in phosphorus.

Results--Domesticated Cool-Season Grass

The domesticated grass species included in the study by Whitman et al. (1951) were crested wheatgrass and smooth bromegrass. Ungrazed or uncut domesticated cool-season grasses (table 2, figs. 1 and 2) contain their highest levels of phosphorus in early May, during the early stages of development. As the plants continue to develop, the percentage of phosphorus decreases. Phosphorus levels drop below 0.18% (the percentage required by lactating cows) in late July, when plants reach the mature seed stage.

One replication of smooth bromegrass in Whitman's study was cut for hay in mid June. Phosphorus levels of the immature tillers that grew after the cutting remained above 0.18% until early September (table 2, fig. 3). These data from hayed smooth bromegrass show that secondary tillers have phosphorus levels above 0.18% for at least one month longer than undefoliated plants. Additional research data need to be collected on the effects haying and grazing have on the mineral levels of domesticated cool-season grasses.

Results--Native Range Upland Sedge

The native range upland sedge species included in the study by Whitman et al. (1951) was threadleaf sedge. Ungrazed upland sedges (table 2, fig. 4) contain their highest levels of phosphorus during the early stages of development, in late April. As the plants continue to develop, the percentage of phosphorus decreases. Upland sedges grow very early and produce seed heads in late April to early May. Phosphorus levels drop below 0.18% (the percentage required by lactating cows) in mid May, when plants reach the mature seed stage.

Defoliation by grazing or haying affects the mineral content of graminoids. The reviewed literature contains no examples of defoliation's effects on the mineral curves of native range upland sedges. Additional research data need to be collected on the effects haying and grazing have on the mineral levels of native range upland sedges.

Results--Native Range Cool-Season Grass

The ungrazed native range cool-season grasses included in the study by Whitman et al. (1951) were western wheatgrass, plains reedgrass, prairie Junegrass, needle and thread, and green needlegrass. The grazed cool-season grass for which Whitman et al. (1951) reported data was Kentucky bluegrass. The native range cool-season grasses for which Marsh et al. (1959) reported data were western wheatgrass and needle and thread. Ungrazed native range cool-season grasses (table 2, fig. 5) contain their highest levels of phosphorus during the early stages of development, in April, May, and early June. As the plants continue to develop, the percentage of phosphorus decreases. In western North Dakota, phosphorus levels of ungrazed native range cool-season grasses drop below 0.18% (the percentage required by lactating cows) in late July, when plants reach the mature seed stage (table 2). In eastern Montana, phosphorus levels drop below 0.18% in late June (table 3). This difference between phosphorus levels of plants in two geographic areas suggests that the rate of leaf senescence may have an effect on mineral levels of grasses.

One cool-season species in Whitman's study, Kentucky bluegrass, was not available in ungrazed condition, so grazed samples were collected. During the grazing season, the grazed plants of Kentucky bluegrass were generally higher in phosphorus content than were ungrazed plants of the other cool-season species (table 2, fig. 6). Phosphorus levels of grazed Kentucky bluegrass remained above 0.18% through late September. Kentucky bluegrass is not an ideal example to illustrate the effects of grazing on the mineral curves of cool-season native range grasses because the lead tiller of Kentucky bluegrass has weak hormonal control of axillary bud activity and does not inhibit secondary tillering to the same extent that the lead tillers of other native range grasses do (Manske 2000). However, these data show that the secondary tillers of Kentucky bluegrass have phosphorus levels above 0.18% for at least two months longer than the undefoliated cool-season plants. Additional research data need to be collected on the effects haying and grazing have on the mineral levels of native range cool-season grasses.

Results--Native Range Warm-Season Grass

The ungrazed native range warm-season grasses included in the study by Whitman et al. (1951) were big bluestem, little bluestem, blue grama, and prairie sandreed. The native range warm-season grass for which Marsh et al. (1959) reported data was blue grama. Ungrazed native range warm-season grasses (table 2, fig. 7) contain their highest levels of phosphorus in May, June, and July, during the early stages of development. As the plants continue to develop, the percentage of phosphorus decreases. In western North Dakota, phosphorus levels of ungrazed native range warm-season grasses drop below 0.18% (the percentage required by lactating cows) in late August, when plants reach the mature seed stage (table 2). In eastern Montana, the phosphorus levels drop below 0.18% in early July (table 3). This difference between phosphorus levels of plants in two geographic areas suggests that the rate of leaf senescence may have an effect on mineral levels of grasses.

Defoliation by grazing or haying affects the mineral content of graminoids. The reviewed literature contains no examples of defoliation's effects on the mineral curves of native range warm-season grasses. Additional research data need to be collected on the effects haying and grazing have on the mineral levels of native range warm-season grasses.

Discussion

Phosphorus content is high in domesticated cool-season grasses, native range upland sedges, native range cool-season grasses, and native range warm-season grasses during early phenological stages. At this time, these forages provide adequate levels of phosphorus (above 0.18%) for lactating beef cows. As the plants mature and continue to develop, the percentage of phosphorus decreases. Phosphorus levels drop below 0.18% during the mature seed phenological stage. In western North Dakota, ungrazed domesticated cool-season grasses develop mature seeds in late July; ungrazed native range upland sedges, in mid May; ungrazed native range cool-season grasses, in late July; and ungrazed native range warm-season grasses, in late August.

Defoliation of grasses manipulates the mechanisms that regulate vegetative reproduction (Manske 2000), causing changes in plant growth and mineral quality curves. Data to illustrate these changes in mineral quality curves are limited to one example of a domesticated cool-season grass cut for hay in mid June and one example of a grazed native range cool-season grass. The data from hayed smooth bromegrass show that secondary tillers have phosphorus levels above 0.18% until early September. The data from grazed Kentucky bluegrass show that secondary tillers have phosphorus levels above 0.18% through late September. Defoliation by haying extended the period that domesticated cool-season grasses contained phosphorus levels above 0.18% from late July to early September, and grazing extended the period that native range cool-season grasses contained phosphorus levels above 0.18% from late July through late September. Mineral quality curves of forage plants defoliated by haying or grazing are different from mineral quality curves of undefoliated plants.

Lactating beef cows grazing crested wheatgrass or smooth bromegrass spring pastures can obtain adequate phosphorus from the forage during May and June. After mid May, upland sedges do not contain adequate phosphorus levels to meet the requirements of a lactating beef cow. In western North Dakota, lactating beef cows grazing native range seasonlong can obtain adequate phosphorus from cool- and warm-season grasses during June and the early portion of July. In eastern Montana, phosphorus levels of cool- and warm-season grasses are below the requirements of a lactating cow in late June and early July. During late summer, phosphorus levels of ungrazed domesticated cool-season grasses, native range upland sedges, native range cool-season grasses, and native range warm-season grasses are below the levels required by lactating beef cows, and during fall and winter, phosphorus levels of these forages are below the levels required by dry gestating cows. Supplementation of phosphorus is needed after late June on native range pastures grazed seasonlong in eastern Montana, after mid July on native range pastures grazed seasonlong in western North Dakota, and on all pastures grazed late summer, fall, or winter.

The macrominerals required by beef cattle are phosphorus (P), calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), chlorine (Cl), and sulfur (S). Phosphorus and calcium make up about 70% to 75% of the mineral matter in beef cattle and over 90% of the mineral matter in the skeleton. Calcium is the most abundant mineral in the cow's body, with 98% of the calcium in the bones and teeth and the remainder in the extracellular fluids and soft tissue (NRC 1996). About 80% of the phosphorus in the cow's body is in the bones and teeth; the remainder occurs in soft tissue, mostly in organic forms. Phosphorus and calcium function together with magnesium in bone formation, and these minerals are required for normal skeletal development and maintenance (NRC 1996). Phosphorus exists in blood serum both in organic forms, as a constituent of lipids, and in inorganic forms. Phosphorus is a component of phospholipids, which are important in lipid transport and metabolism and in cell-membrane structure and cell growth. As a component of AMP, ADP, ATP, and creatine phosphate, phosphorus functions in energy metabolism, utilization, and transfer. Phosphorus is required for protein synthesis as phosphate, a component of RNA and DNA. Calcium exists in blood serum in both organic and inorganic forms. Slight changes in calcium, potassium, magnesium, and sodium concentrations control the transmission of nerve impulses and muscle contractions. Calcium and sulfur are required for normal blood coagulation (Church and Pond 1975, NRC 1996). Phosphorus, calcium, potassium, and magnesium are constituents of several enzyme systems. Phosphorus, calcium, potassium, magnesium, sodium, chlorine, and sulfur function in regulating fluid balance by maintaining osmotic pressure and the acid-base balance of the entire system. The blood contains more sodium and chlorine than other minerals. Sodium and chlorine are electrolytes and function in maintaining osmotic pressure in the body cells. Chlorine is required to form hydrochloric acid in gastric juice (Church and Pond 1975, NRC 1996). Phosphorus and sulfur are required by ruminal microorganisms for their growth and cellular metabolism (NRC 1996).

Relative levels of calcium and phosphorus are important. Dietary calcium to phosphorus ratios between 1:1 and 7:1 result in similar normal animal performance. Dietary phosphorus absorption (NRC 1996) occurs rapidly in the small intestine, by passive diffusion across the intestine cell membrane against a concentration gradient in the presence of calcium. Cattle are not known to have an active transport system for phosphorus. About 68% of dietary phosphorus is absorbed. Dietary calcium absorption (NRC 1996) occurs in the first two sections of the small intestine both by passive diffusion and by active transport with a vitamin D-dependent protein carrier. About 50% of dietary calcium is absorbed. Calcium is maintained at a relatively constant concentration in the blood plasma by an elaborate control system that involves calcium deposition in and resorption from the bones, variations in reabsorption rate by the kidneys, and variations in the levels of absorption in the intestines. During periods when blood phosphorus or calcium concentrations are low, the kidney tubules can reabsorb an increased amount of the deficient minerals and the body can thereby conserve them. The skeleton of mature animals provides a large reserve of phosphorus and calcium that can be drawn on during periods of inadequate phosphorus or calcium intake. Skeletal reserves can subsequently be replaced during periods when phosphorus and calcium intake are high relative to requirements (Church and Pond 1975, NRC 1996).

A deficiency of either calcium or phosphorus can adversely affect the skeletal system. In young growing animals inadequate calcium or phosphorus can cause rickets, which occurs when the blood becomes low or deficient in calcium, phosphorus, or both, and normal deposition of calcium and phosphorus cannot occur in growing bones. The bones become soft and weak. In severe cases, bones can become deformed, and with increased severity of the condition, bones can break or fracture readily. A deficiency of calcium or phosphorus in older mature animals can cause osteoporosis, which occurs when large amounts of calcium and phosphorus are withdrawn from the bones to meet other systems' needs for these minerals. During prolonged periods of calcium and phosphorus deficiency, the bones become porous and weak, and in severe cases, they can break easily (Church and Pond 1975, NRC 1996).

Pregnancy and lactation have high demands for calcium and phosphorus. Milk production requires 0.020 ounces calcium per pound of milk and 0.015 ounces phosphorus per pound of milk (NRC 1996). Calcium deficiency usually occurs early in lactation, during the period of large drains on body calcium reserves for milk production. Calcium deficiency during lactation causes milk fever. Severe calcium deficiency produces hypocalcemia (low blood calcium) and interferes with the role calcium plays in normal muscle contractions, including those of the heart, and normal transmission of nerve impulses; this condition results in tetany, convulsions, and, if not treated early, possibly death (Church and Pond 1975, NRC 1996).

Even when cattle diets are only slightly deficient in calcium or phosphorus, animal performance may suffer. Calcium deficiency causes reduced feed intake, loss of body weight, and failure of cows to come in heat regularly. Calcium deficiency also causes a reduction in the quantity of milk produced, but the quality of the milk is not changed, and the mineral content of the milk remains relatively constant. Reduction in the quantity of milk produced by a cow results in lower calf daily gain (Manske 1998a). Phosphorus deficiency in beef cattle results in reduced growth and feed efficiency, decreased feed intake, impaired reproduction, reduced milk production, and weak, fragile bones. Cattle grazing forages low in phosphorus experience lower fertility and lighter calf weaning weights (NRC 1996).

Deficiencies of other macrominerals are also detrimental to beef cattle. Magnesium deficiency causes grass tetany (hypomagnesemia or low blood magnesium), occurring commonly in lactating cows grazing lush spring pastures high in protein and potassium. Magnesium deficiency in beef cattle results in nervousness, reduced feed intake, muscular twitching, and staggering gait. In advanced stages of magnesium deficiency, convulsions occur, the animals cannot stand, and death soon follows (Church and Pond 1975, NRC 1996). Intake of proper amounts of potassium, the third most abundant mineral in beef cattle, is important. Deficiency of potassium causes decreased feed intake and reduced weight gain. Cattle consuming diets with more than 3 percent potassium while grazing lush spring pastures experience reduced magnesium absorption and the related magnesium deficiency symptoms (Church and Pond 1975, NRC 1996). Deficiency of sulfur, a component of some amino acids and some vitamins, causes reduced feed intake and decreased microbial digestion and protein synthesis. Severe sulfur deficiency results in diminished feed intake, major loss of body weight, weak and emaciated condition, excessive salivation, and death (Church and Pond 1975, NRC 1996). Adequate quantities of supplemental minerals should be provided to livestock during periods when forages do not contain sufficient levels.

Grazing cattle require supplemental salt (sodium and chlorine) because all forages are deficient in salt. Severe salt deficiency causes reduced feed intake, rapid loss of body weight, and reduced milk production. In some arid and semi-arid regions of the country, a portion of the required amount of salt is provided by the alkali water. Supplemental salt can be provided free-choice in loose or block forms. Cattle grazing pastures consume more salt during spring and early summer when the forage is more succulent than later in the season when the forage is drier. High levels of dietary salt reduce feed intake. Cattle occasionally consume greater amounts of salt than required but will generally not consume too much except after experiencing periods without sufficient quantities (Church and Pond 1975, NRC 1996).

Conclusion

This report summarizes the limited published data reporting sequential phosphorus content of domesticated cool-season grasses, native range upland sedges, native range cool-season grasses, and native range warm-season grasses used on the Northern Great Plains and interprets the relationships between the changes in phosphorus content and the phenological development of ungrazed plants. This report also summarizes the beef cow daily requirements for phosphorus and calcium, which change with cow size, level of milk production, and production period.

The changes in mineral content of ungrazed domesticated cool-season grasses, native range upland sedges, native range cool-season grasses, and native range warm-season grasses follow the phenological stages of the plants. Plants contain the highest levels of phosphorus in the early stages of development. As seed stalks develop, phosphorus content decreases. During the mature seed stage, phosphorus content drops below 0.18%, the level required by lactating cows with average milk production. The mature seed stage occurs in late July for domesticated cool-season grasses, in mid May for native range upland sedges, in late July for native range cool-season grasses, and in late August for native range warm-season grasses. Supplemental phosphorus should be provided to livestock during periods when forages do not contain sufficient levels.

Grazing and haying affect the biological mechanisms that regulate vegetative reproduction in grass plants. These effects are not the same at all phenological growth stages during the growing season. Additional research should be conducted to study the effects defoliation by grazing and haying has on phenological development, vegetative reproduction, and changes in mineral content of forage plants during the growing season.

The mineral requirements for beef cows change during the year with the production periods. The mineral content of perennial forage grasses and sedges changes as the plants develop and mature through phenological stages. At some phenological stages, forage plants have insufficient mineral content to meet nutritional requirements of cattle.

During these times, forage diets must be supplemented to meet livestock mineral needs. Effective management strategies efficiently supply combinations of forages and supplements to provide the quantities of minerals livestock require at each production period. Such strategies can be developed through coordination of annual mineral quality curves, which illustrate the changes in forage plant mineral content during the year, and livestock mineral requirement curves, which illustrate beef cow mineral requirements at each production period.

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Table 1. Daily phosphorus and calcium requirements in pounds and percent dry matter for beef cows with average milk production during four production periods (data from NRC 1996).

Production Periods		**1000 lb cows**		**1200 lb cows**		**1400 lb cows**	
		Phosphorus	Calcium	Phosphorus	Calcium	Phosphorus	Calcium
Dry Gestation	pounds (lb) percent (%)	0.02 0.11	0.03 0.15	0.03 0.11	0.04 0.15	0.03 0.12	0.04 0.16
3rd Trimester	pounds (lb) percent (%)	0.03 0.15	0.05 0.24	0.04 0.16	0.06 0.25	0.05 0.17	0.07 0.26
Early Lactation	pounds (lb) percent (%)	0.05 0.20	0.07 0.30	0.05 0.19	0.08 0.29	0.06 0.19	0.08 0.28
Lactation	pounds (lb) percent (%)	0.04 0.18	0.06 0.27	0.05 0.18	0.07 0.26	0.05 0.18	0.08 0.26

Table 2. Weekly percent phosphorus content of graminoids in western North Dakota, means of 1946 and 1947, data from Whitman et al.

(1951).

		Domesticated		Native Range					
		cool-season		upland sedge		cool-season		warm-season	
		uncut	hayed[1]	ungrazed	grazed	ungrazed	grazed[2]	ungrazed	grazed
Apr	1								
	13	0.263	0.269	0.270		0.315	0.314		
	19	0.280	0.244	0.317		0.346	0.313		
	25	0.289	0.264	0.210		0.320	0.232		
May	4	0.306	0.302	0.210		0.301	0.299		
	10	0.285	0.285	0.185		0.303	0.258	0.267	
	16	0.246	0.236	0.170		0.276	0.280	0.226	
	23	0.253	0.260	0.176		0.239	0.268	0.231	
	28	0.247	0.247	0.162		0.237	0.264	0.264	
Jun	6	0.248	0.264	0.160		0.253	0.258	0.299	
	13	0.254	0.253	0.160		0.258	0.287	0.286	
	19	0.233	0.240	0.179		0.244	0.267	0.286	
	26	0.222	-	0.152		0.232	0.231	0.275	
Jul	2	0.211	-	0.153		0.228	0.272	0.245	
	8	0.210	0.302	0.155		0.205	0.243	0.245	
	16	0.202	0.277	0.128		0.203	0.246	0.222	
	24	0.178	-	0.122		0.186	0.238	0.226	
	30	0.189	0.220	0.115		0.176	0.229	0.208	
Aug	6	0.148	-	0.097		0.149	0.237	0.175	
	13	0.158	0.184	0.109		0.157	0.255	0.186	
	20	0.169	-	0.118		0.153	0.145	0.194	

	26	0.167	0.190	0.091		0.141	0.189	0.150	
Sep	3	0.132	-	0.135		0.124	-	0.153	
	12	0.106	-	0.085		0.119	-	0.121	
	21		-				-	0.189	
	29	0.106	0.127	0.083		0.120	0.234	0.076	
Oct									
Nov	5	0.100	0.109	0.096		0.116	0.155	0.085	

Table 3. Monthly percent phosphorus content of grasses in eastern Montana, means of 1948-1953, data from Marsh et al. (1959).		
Dates	**Native Range**	
	cool-season	**warm-season**
Jan 24	0.073	-
Feb 21	0.058	0.060
Mar 24	0.070	0.073
Apr 23	0.102	0.088
May 20	0.186	0.155
Jun 15	0.176	0.200
Jul 14	0.119	0.158
Aug 9	0.111	0.154
Sep 6	0.089	0.118
Oct 5	0.095	0.106
Nov 4	0.087	0.100
Dec 1	0.077	0.073
Dec 27	0.088	0.085

Figure 1. Mean percent phosphorus of ungrazed crested wheatgrass in western North Dakota, data from Whitman et al. 1951.

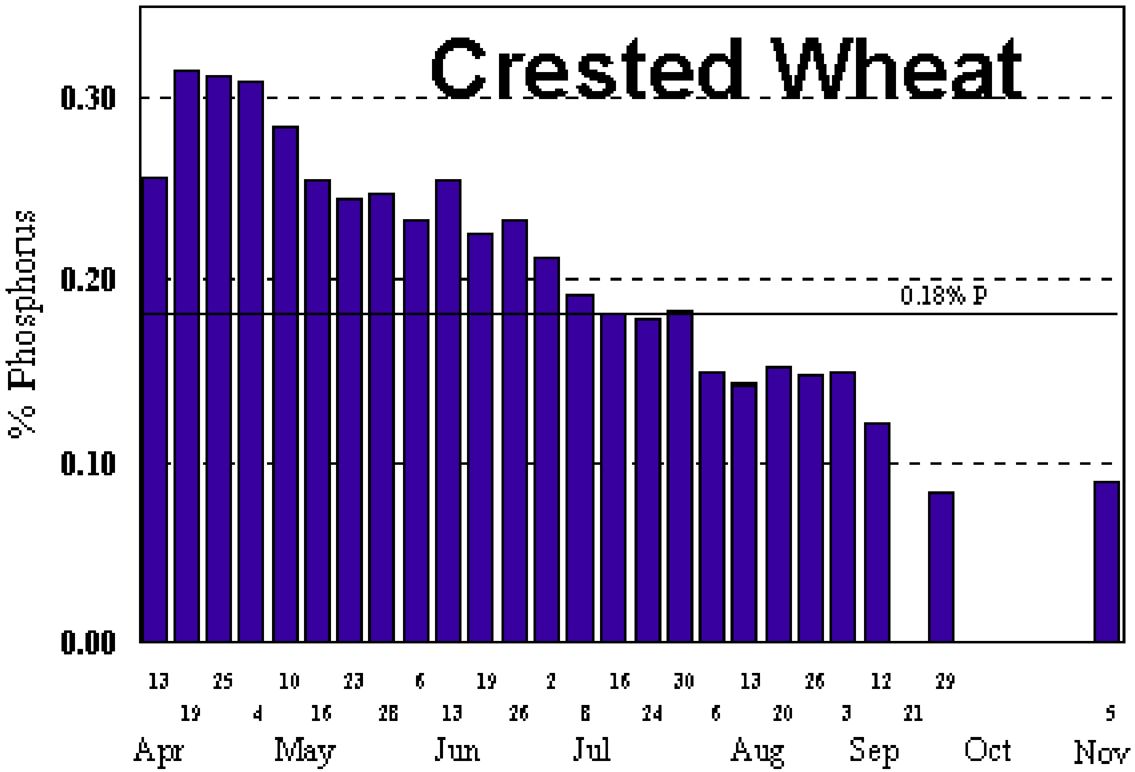


Figure 2. Mean percent phosphorus of smooth bromegrass not cut for hay in western North Dakota, data from Whitman et al. 1951.

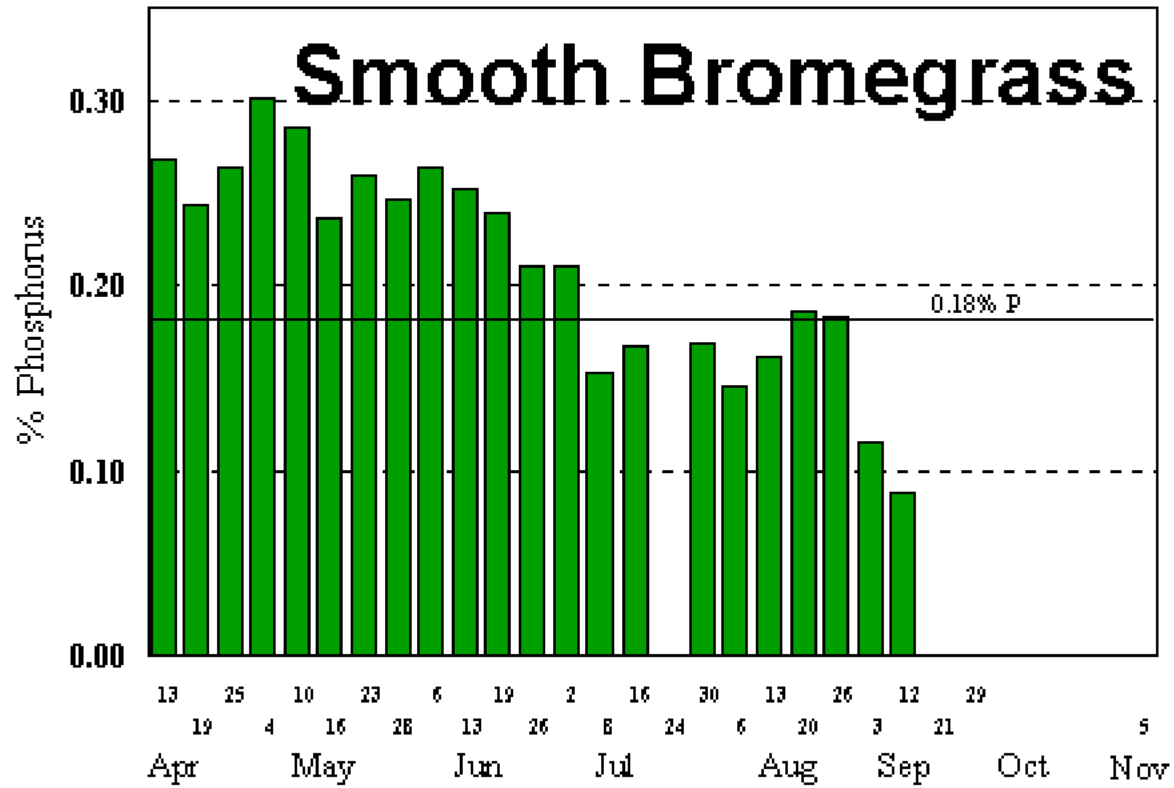


Figure 3. Mean percent phosphorus of smooth bromegrass cut for hay at flowering stage in mid June in western North Dakota, data from Whitman et. al. 1951.

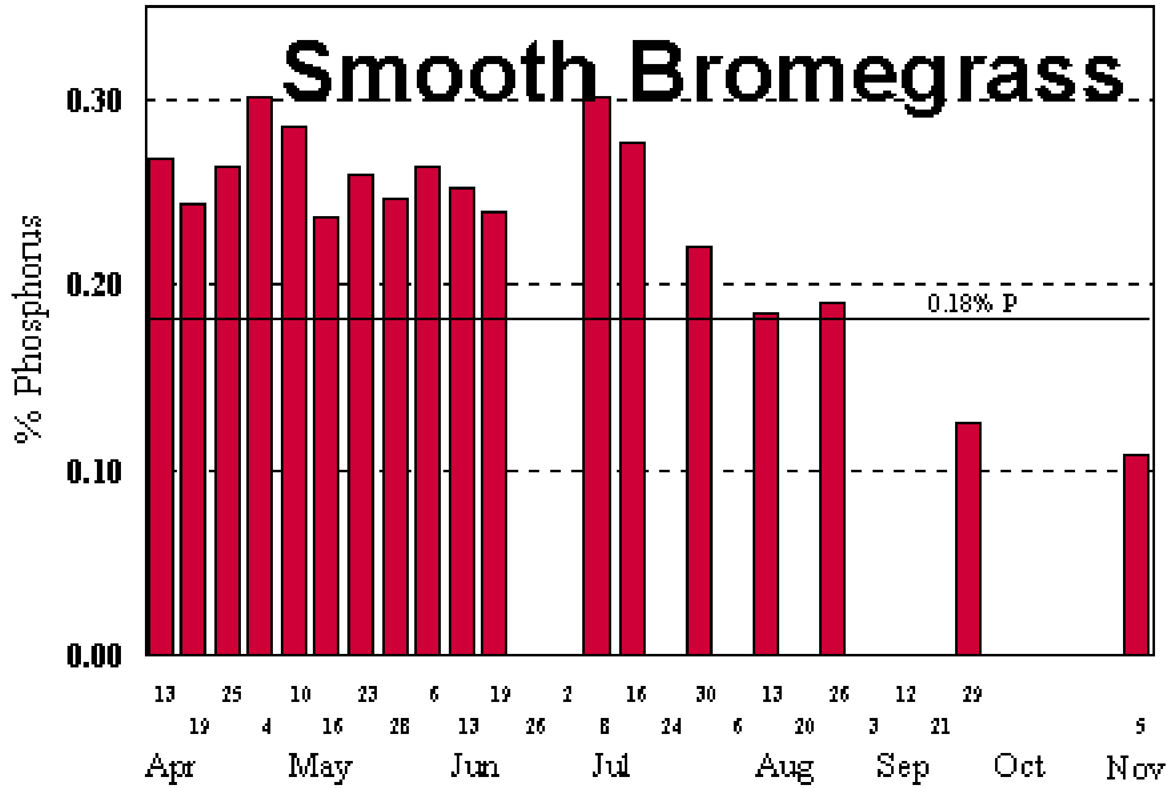


Figure 4. Mean percent phosphorus of ungrazed native range upland sedge in western North Dakota, data from Whitman et al. 1951.

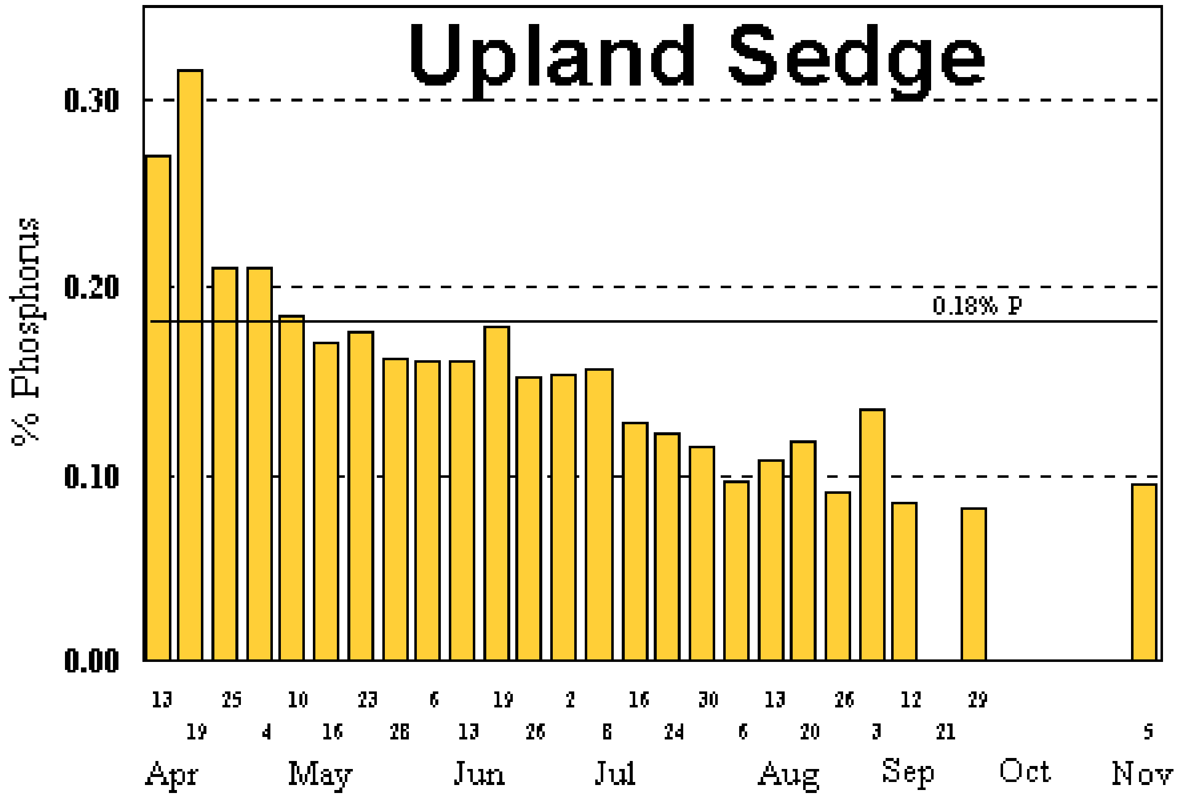


Figure 5. Mean percent phosphorus of ungrazed native range cool season grasses in western North Dakota, data from Whitman et al. 1951.

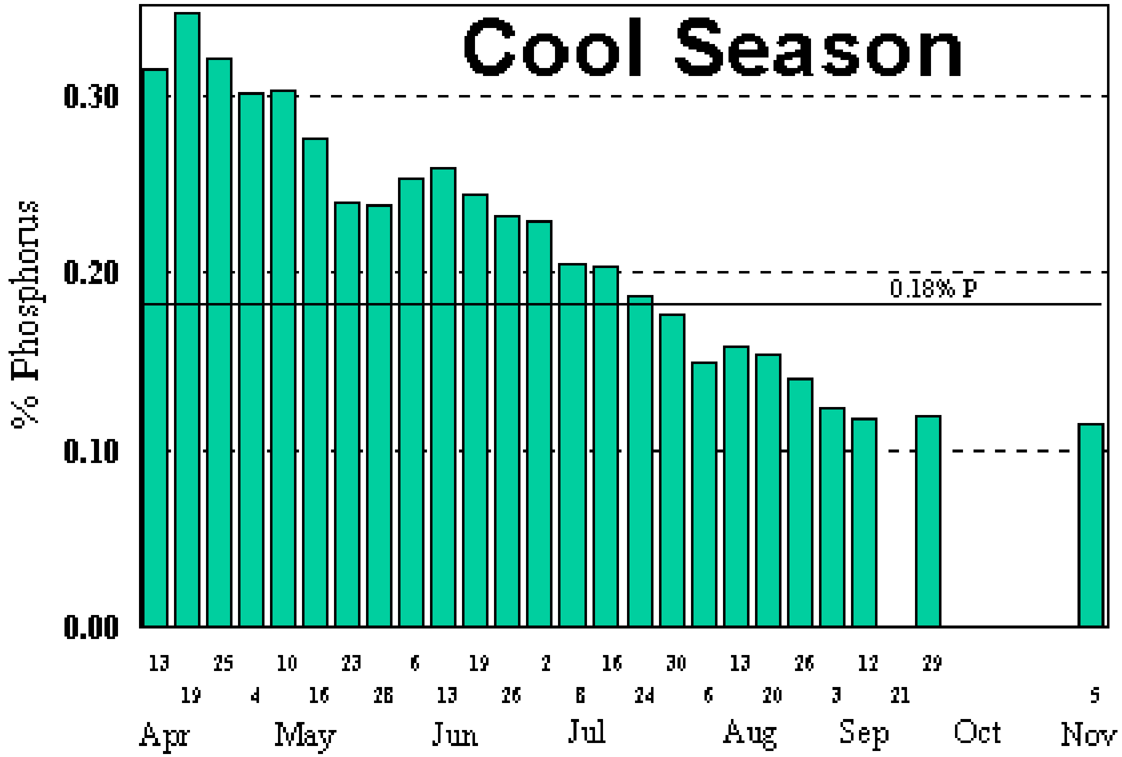


Figure 6. Mean percent phosphorus of grazed Kentucky bluegrass in western North Dakota, data from Whitman et al. 1951.

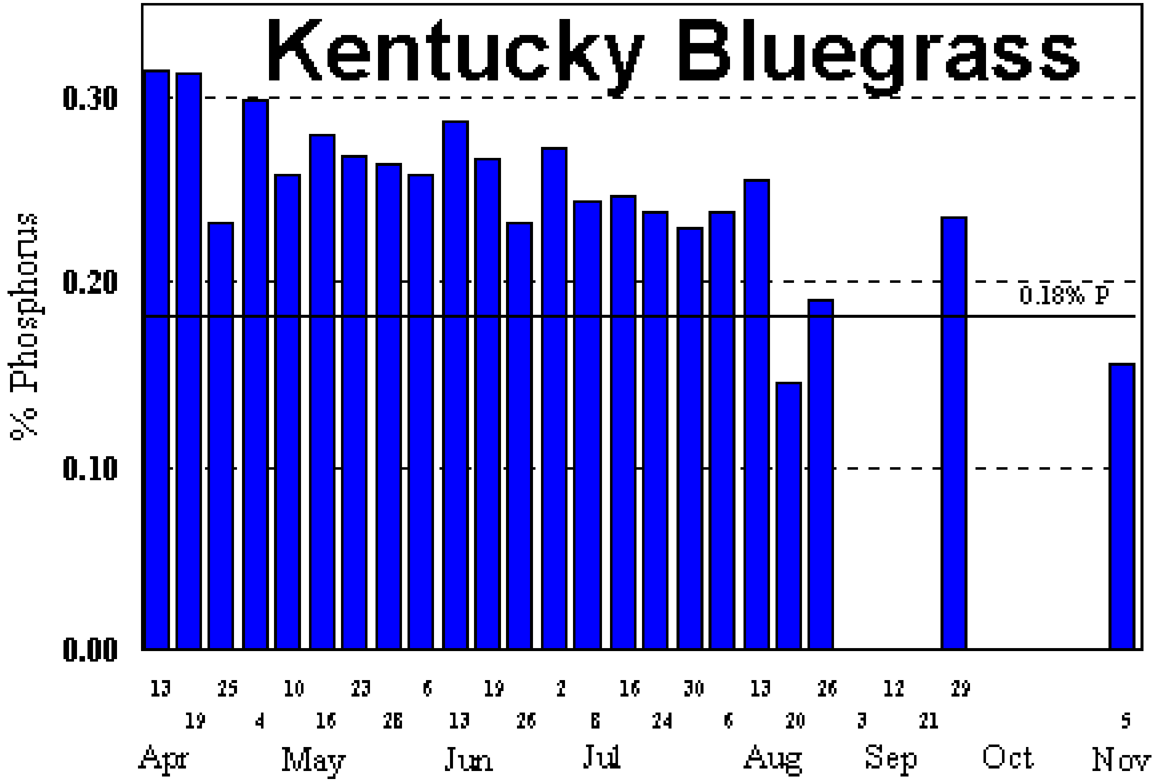
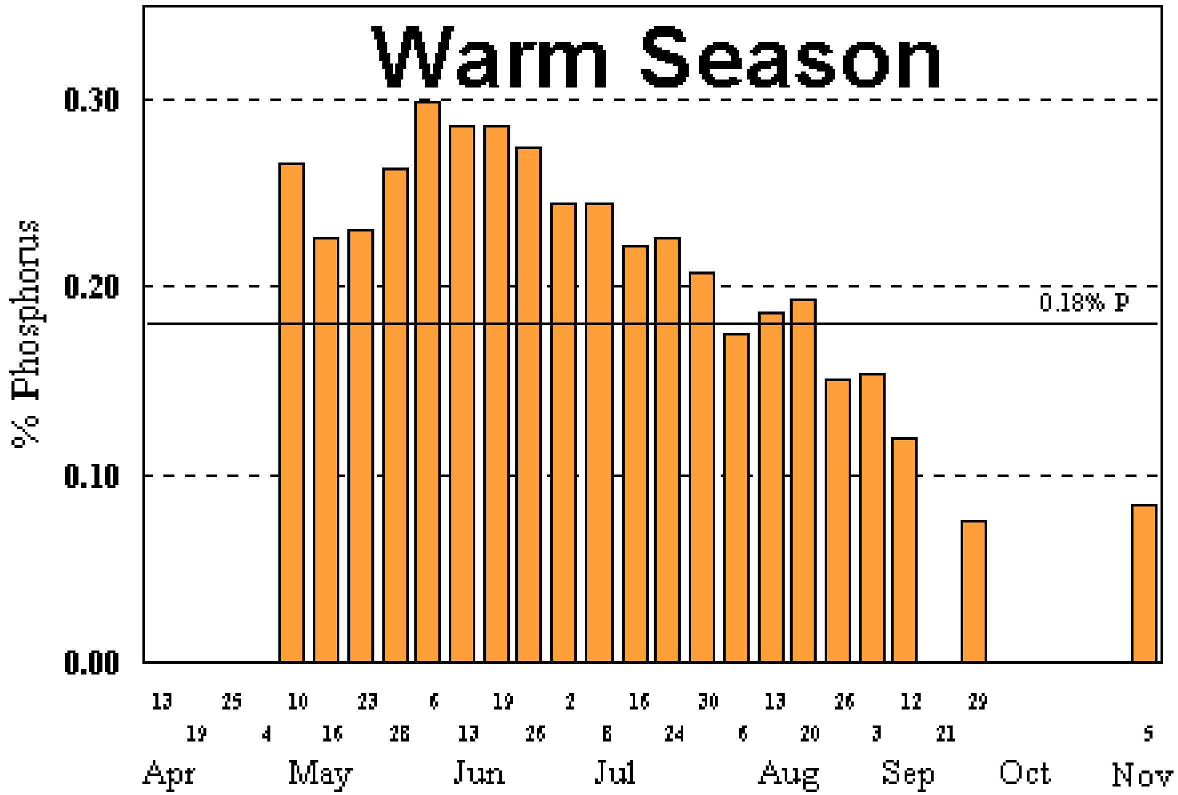


Figure 7. Mean percent phosphorus of ungrazed native range warm season grasses in western North Dakota, data from Whitman et at. 1951.



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