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SUMMARY

The influence of a number of factors on the mineral composition of forages grown in the area of Morgantown, West Virginia, has been examined over a period of nine years. The major effects studied were (1) species and variety of plant, (2) stage of growth, (3) season and cutting management, (4) fertilization.

Comparison of the mineral composition of five grass (orchardgrass, smooth brome, tall fescue, timothy, sudangrass) and three legume (alfalfa, red clover, crownvetch) forages showed differences between classes, species, and varieties. The legumes contained higher levels of calcium than the grasses and the highest concentrations of magnesium were found in red clover. Levels of magnesium and sodium were uniformly low. Timothy, among the grasses, contained particularly low levels of magnesium. The concentration of the minor elements — copper, zinc, boron, iron, molybdenum, manganese, aluminum, strontium, and barium — was highest in red clover; but, with the exception of boron, alfalfa and the grasses contained comparable levels of the minor elements.

The stage of maturity of the forage during the first growth cycle generally had a direct effect on the concentration of minerals, although there were species differences in this respect. Potassium, phosphorus, calcium, magnesium, silicon, iron, manganese, aluminum, zinc, molybdenum, and boron showed a signi-

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ficant decrease with advancing maturity, while the levels of copper, strontium, and cobalt remained relatively constant.

The levels of minerals in first and regrowth cuttings of hay and of herbage were determined in a number of studies with orchardgrass and tall fescue. In general, the concentration of potassium was higher in first growth than in regrowth forage, while the levels of calcium and magnesium were lower. There was little effect of cutting time on phosphorus values, and effects on the minor elements were generally inconsistent. Where the mineral composition of orchardgrass pasture grazed by sheep was determined at monthly intervals over a two-year period, marked seasonal effects on certain elements were noted. Peak concentrations of potassium and phosphorus were found in the early spring growth of grass, while levels of calcium and magnesium tended to be low at this time and to increase through the summer and fall. Among the minor elements, seasonal changes were observed in the concentrations of zinc, iron, aluminum and, to some degree, molybdenum; relatively minor fluctuations were noted for copper, manganese, and boron.

Increasing the level of nitrogen fertilizer applied to forages increased the concentration of potassium in the plant. There was also a tendency for nitrogen to increase the levels of calcium, magnesium, and sodium, and to depress the concentration of phosphorus, although these effects were not obtained in all studies. The application of nitrogen, potassium, or phosphorus fertilizer had no consistent effect on the levels of minor elements in the forage.

An attempt has been made to relate the effects of the different factors studied to the mineral requirements of ruminant animals. By comparing the mineral composition of the forage crops studied with levels recommended for adequate animal nutrition, it may be suggested that cattle or sheep maintained primarily on pasture and hay without mineral or concentrate supplementation would be receiving sub-optimum levels of certain minerals at certain periods of the year. The major elements found to be potentially limiting under the conditions of this study were phosphorus, calcium, magnesium, and sodium. Of the minor elements examined, only zinc was present at marginally deficient levels. The need for further studies on the composition and availability of minerals in forages grown on different soil types in West Virginia is apparent.

The mineral components of forage crops have not, in general, been implicated as primary limiting factors in the efficient utilization of the forage by domestic livestock. Yet, under certain circumstances, a deficiency or excess of a specific element, or an imbalance of two or more elements, can cause profound effects on animal performance and on the economic returns from a livestock operation. A survey study (Horvath, personal communication) indicated, for example, an estimated loss to the beef cattle industry of approximately $355,000 over the 11-year period 1957-1968 due to hypomagnesemic tetany in West Virginia.

This situation may well become more critical in the future through changing agricultural practices at the local and national levels. The problem of plant disease and the difficulty of maintenance of legume forages such as white clover and alfalfa in pastures and meadows have been responsibile for a decline in the acreage of legume crops in West Virginia. Legumes contain comparatively high levels of the minerals essential for animal nutrition. The logical alternative, under a continuing national and world demand for livestock products, will be an increased use of nitrogenous fertilizer on grass pastures and hay crops. More intensive management systems and the use of higher levels of more purified fertilizers may serve both to deplete the mineral reserves of the soil and to create specific metabolic mineral problems in animals consuming forage crops grown on the soil.

Comparatively little information is available on the mineral composition of forage crops grown in West Virginia, or on the effect of management practices on mineral balance in pasture herbage and hay. The following study was designed as part of an assessment of the nutritive quality of grass and legume crops grown in the vicinity of Morgantown, West Virginia, during the period 1960-1969. Forage mineral composition was determined in relation to, (1) the effects of plant species, (2) the influence of growth stage and cutting management, (3) effects of different levels and types of fertilizer applied to pasture and hay crops.

Literature Review

In discussing the concentration of trace elements in plants, Underwood (1962) suggested that the four most influential factors controlling mineral concentrations were (1) the genus, species, or strain of plant, (2) the type of soil on which the plant was grown, (3) the climatic or seasonal conditions during growth, and (4) the stage of maturity of the plant.

Probably the most marked differences in mineral concentration between economically important forage species occur between the grasses and the legumes. Thomas **et al.** (1952) determined the ash constituents of several species of legumes, herbs, and grasses and concluded that the legumes were generally superior in mineral efficiency to the grasses, particularly in terms of calcium, phosphorus, and magnesium. Loneragan **et al.** (1968), in examining the calcium concentration of 21 species of herbs, legumes, and grasses, found that the legumes contained higher levels of calcium than the grasses at all periods of the growing season and that the mineral concentration of the plant tops was related to the cation exchange capacity of their roots. The work of Todd (1961) and Jones (1963) showed that leguminous species generally had higher magnesium contents than were found in grasses.

Differences between the grasses and legumes in micro-element levels have been reported by a number of authors, **e.g.** Thomas **et al.** (1952), Williams (1963), Fleming (1965), and Whitehead (1966). A review by Fleming (loc. cit.) indicated that pasture legume species generally contained higher levels of cobalt, copper, iron, molybdenum, and zinc than did the grasses. This author has also pointed out the difficulties of interpretation of such data without an adequate knowledge of the effect of the different regulatory factors which may be involved, for example, stage of growth of the plant, soil reaction, plant part, effects of competition, indoor or outdoor growth, and vegetative cycle. Species differences in mineral composition within the grasses and legumes have been noted. Lehr (1960), for example, found marked differences in the ability of grass species to absorb sodium, and Griffith and Walters (1966) also observed consistent differences in sodium and potassium content between grass genera and species. The latter workers, in fact, have suggested that the sodium content may be used as a means of chemical characterization of the grasses. Species differences in the concentration of phosphorus, calcium, sodium, and potassium have been reported in temperate grass species by Coppenet and Calvez (1962) and Miles **et al.** (1964). Similar differences in micro-element levels have been found by Mitchell (1960) and Fleming (1965). In examining the mineral composition of the first growth of eight varieties of three legume species — alfalfa, red clover, and white clover — Davies **et al.** (1967) found significant species differences in all the elements tested; they also observed that there were considerable changes in mineral components between years.

Beeson (1941) reviewed the earlier studies relating to varietal differences in the mineral composition of plants and suggested that definite conclusions could not be reached on this factor, particularly in light of the non-uniformity of soil conditions. In more recent investigations of the composition of ryegrass, Johnson and Butler (1957) reported large differences in the iodine content of different varieties, and Butler **et al.** (1962) found differences in 10 out of 12 minerals studied in the herbage of seven ryegrass clones. These authors obtained a significant genetic correlation between root cation exchange capacities and the plant content of iron, aluminum, titanium, nitrate, and acid-soluble phosphorus. In a similar study of white clover clones grown on different soils, Robinson (1942) showed clonal differences in the uptake of calcium, phosphorus, and potassium. Vose (1963) has discussed the mechanisms which may lead to the differential uptake of nutrients by varieties of crop plants.

The effects of stage of growth of forage plants on their mineral content have been well documented, although, as Whitehead (1966) has pointed out, it is sometimes difficult to distinguish maturation changes from seasonal and climatic effects. A general decline in the ash components of plants with increasing age was noted early in the 19th century (Beeson, 1941).

Working with a range of forage crops, Kivimae (1959) showed a linear rate of decline of the ash content of different forage species with time, and found that the rate of decline varied with the species. Alfalfa was shown to have a rather constant content of calcium from leaf stage to full flower, as did the clover varieties; the calcium content of timothy was highest at the leaf stage and declined slowly towards flowering. Phosphorus levels in the different species were found to be related closely to the plant protein content. Kirchgessner **et al.** (1967) determined the changes in mineral composition of alfalfa and red clover cut at five-day intervals from early spring growth to seeding, and demonstrated that in both species the content of phosphorus, magnesium, and potassium decreased with age, and that silicon declined in the early growth period and later increased again. The sodium concentration of alfalfa increased after an early decrease, but this trend was not apparent in red clover. Whitehead (1966) concluded that, in grasses, potassium, calcium, magnesium, and sodium generally tended to be present at lower concentrations in mature than in young plant tissue, although peak values sometimes occurred at an intermediate stage of growth. For a variety of grass species, Thomas **et al.** (1952) and Fleming and Murphy (1968) showed that the levels of nitrogen, phosphorus, potassium, calcium, and sodium decreased with age of the plant; the latter workers, however, found that magnesium exhibited little change in content with advance in maturity.

Reports on the trends in micro-element concentration in plants with increase in maturity have been conflicting. Beeson and MacDonald (1951) found that there was an increase in the iron content of birdsfoot trefoil, ladino clover, alfalfa, and timothy as the plants matured; the copper concentration in timothy decreased with age, while in the legumes (except birdsfoot trefoil) it reached a peak value at an intermediate growth stage. Cobalt in timothy increased slightly, but in the legumes showed no significant change with advance in maturity. There was some increase in manganese level in most species with increasing age in this study, although Thomas **et al.** (1952) found that in grasses and herbs manganese content was generally negatively correlated with age, while in the legumes it stayed fairly constant. In a Wisconsin study of changes in the trace element content of alfalfa, alfalfa-bromegrass, bromegrass, red clover, and ladino clover, Loper and Smith (1961) showed a marked decrease in the concentration of iron and a slight decrease in the level of copper in all species from early spring growth to maturity. Zinc levels in alfalfa and bromegrass decreased, and in red clover and ladino clover increased, with increase in age of the plant and, in the legumes, the concentration of cobalt decreased. Manganese levels did not change greatly. In a recent study in Ireland, Fleming and Murphy (1968) confirmed the finding of a rapid decline in iron content and a decrease in copper and cobalt concentrations with advancing maturity. The level of zinc did not alter significantly through the growth cycle and the pattern of manganese concentration varied between years.

Where forage plants are not allowed to grow to maturity, but are defoliated at regular intervals by grazing or cutting during the growing season, seasonal effects may be detected. In an experiment where herbage at six sites was cut five times in each of three years, Reith **et al.** (1964) found marked seasonal increases in the percentages of calcium and magnesium in the plant, little seasonal variation in phosphorus, and a small increase in potassium when potassium fertilizer was applied at each cut, but not when it was applied once in early spring. Several workers, **e.g.** Stewart and Holmes (1953), Reith (1954), and Todd (1961), have reported that there is a significant increase in the plant content of magnesium with advance of the growing season, and Todd (loc. cit.) noted that the increase in magnesium content in the clovers was not as great as in the grasses. Fleming and Murphy (1968) made 13 cuts on stands of three grasses, sown alone and with white clover, and found a general pattern of seasonal decline in phosphorus and potassium content, although increases in phosphorus were observed between the seventh and ninth cuts and an increase in potassium was obtained in October. The calcium content of all species increased throughout the season, and the magnesium concentration increased steadily from approximately 0.2 per cent in April to approximately 0.7 per cent in September. Thereafter it declined to 0.35 per cent in December. The sodium level in timothy and tall fescue showed little change between

April and June, but then increased in content to December. Perennial ryegrass contained higher amounts of sodium in all cuttings, and there was a very sharp rise in this element between the end of May and the beginning of July.

Seasonal trends in micro-element levels have also been reported (Williams, 1959). Kirchgessner (1957) found an increase in boron, related to changes in calcium and magnesium, in meadow grass as the season progressed. Hemingway (1962) made four cuts of grasses and clovers at the silage stage in each of three years and found that the later cuts contained higher levels of copper, molybdenum, manganese, and iron than did the samples taken early in the season. In subterranean clover, cut at monthly intervals, Piper and Beckwith (1951) observed a steady increase in the concentration of copper and a decrease in the level of molybdenum. A seasonal effect on the cobalt content of pastures in New Zealand has been suggested by the work of Askew and Watson (1946).

The effects of liming and of fertilization practices on the concentration of major and minor elements in forage crops have been the subject of active investigation for nearly a century, and the early work in this area has been reviewed in detail by Beeson (1941) and will not be considered. Whitehead (1966) has made several points which need to be considered in evaluating the effects of a given treatment on the mineral concentration of plants: (1) the addition of a nutrient to the soil can be expected to cause an increase in the level of that element in the plant unless growth had previously been limited by a deficiency of the element; (2) addition of a nutrient can cause secondary effects on plant composition, **e.g.** by dilution or by antagonistic or synergistic effects; (3) the degree of change in plant mineral composition may be affected by the time period between application and harvesting or grazing; (4) the effects of a given fertilizer treatment on plant mineral uptake and concentration may be significantly related to the effects which the treatment has on soil pH.

The effects of liming on the availability of trace elements in plants grown on Scottish soils were examined by Mitchell (1954) and Reith and Mitchell (1964). The major changes noted were a reduction in the uptake of cobalt, manganese, zinc, and occasionally copper, and an increase in molybdenum uptake. Taylor **et al.** (1956) found that liming caused little change in copper concentration, an increase in molybdenum, and a decrease in manganese, and Robinson **et al.** (1951) showed that liming increased molybdenum concentration to a greater degree in legumes than in ryegrass. In an interesting demonstration of the carryover effects of liming, Price and Moschler (1965) reported a significant decrease in the content of copper, cobalt, manganese, iron, and zinc, and an increase in molybdenum, in orchardgrass, peanut, and soybean tissues seven and nine years after the application of lime. Reith (1965) has noted that while the liming of acid soils in humid temperate climates usually tends to increase the percentage of calcium, magnesium, and phosphorus in the plant, this by no means invariably happens.

The changes in the mineral composition of grassland herbage brought about by heavy dressings of nitrogen were studied by Stewart and Holmes (1953). High levels of nitrogen were found to decrease the potassium content and to increase the levels of calcium, magnesium, and sodium; relatively little effect of nitrogen on plant concentrations of phosphorus, manganese, and trace elements other than copper was obtained. Potassium fertilization gave large increases in the potassium content of the herbage, but depressed the uptake of sodium, magnesium, and calcium — an instance of ion antagonism. Similar results were reported by Kemp (1960). Reith **et al.** (1964) found that the application of nitrogen caused little change in the phosphorus concentration of grass-legume swards. Treatment with nitrogen and potassium fertilizers separately had a variable effect on the level of calcium, but when applied together, calcium was decreased. Magnesium tended to increase in the herbage under nitrogen applications, but was reduced by potassium fertilization; this effect of potassium, however, was less pronounced in the presence than in the absence of nitrogen. The sodium content of the herbage was depressed by the application of potassium, but increased by nitrogen. In a limited study of the effects of fertilization on trace elements concentration, it was found that a high level of nitrogen reduced the levels of cobalt, manganese, and strontium in the herbage. Black and Richards (1965) concluded that the application of nitrogen fertilizer alone, even on soils with a high potassium reserve, had little effect on the level of magnesium in herbage. In mixed pastures, part of the effect of nitrogen fertilization on magnesium concentration may be attributed to a change in botanical composition; Wolton (1960), for example, suggested that while nitrogen applied to a grass sward increased the percentage of magnesium in the grass, the depression in the clover content of a mixed pasture due to fertilization might well result in no overall change of magnesium status. Reith (1965), in reviewing the work of several authors, concluded that the application of potassium fertilizer at levels just sufficient to produce optimal yields had no effect on the concentration of herbage magnesium, but that potassium at higher levels might reduce the magnesium percentage by up to 30 per cent.

The form of nitrogen fertilizer used has been shown to affect the level of certain minerals in forage crops. Mulder (1956) and Wolton (1960) found that nitrate nitrogen increased the magnesium level in plants to a greater degree than did ammonium nitrogen. Nielsen and Cunningham (1964) suggested that differences in root development and distribution with different forms of nitrogen fertilizer might be responsible for the differences in ion uptake which they observed in Italian ryegrass. Increasing levels of nitrate nitrogen decreased the concentrations of phosphorus, sulfur, and chloride, while ammonium nitrogen decreased the percentage of calcium in the ryegrass. Kershaw and Banton (1965) determined the effect of ammonium sulfate, calcium nitrate, and muriate of potash on the mineral content of ryegrass and found that the nitrate form of nitrogen gave higher levels of magnesium, calcium, and sodium in the grass; the potassium content was not altered by the form of nitrogen used. In a review of the effects of high levels of nitrogen fertilizer on the mineral balance of dairy cows, de Groot (1967) concluded that when nitrogen was applied to herbage as ammonium salt the uptake of phosphorus, sulfur, chloride, and silicon was stimulated.

Reports on the effects of nitrogen, phosphorus, and potassium fertilizers on the micro-element content of forages have been conflicting. Reith and Mitchell (1964) found that the application of these elements had relatively little effect on the plant content of trace elements. Nitrogen tended to reduce cobalt and manganese levels, cause little change in copper and zinc, and increase molybdenum in clover but decrease it in grasses. Neither superphosphate nor potassium applications resulted in appreciable changes in plant micro-element levels. This had been observed earlier in herbage studies by Hemingway (1962), although this author found that the application of ammonium sulfate increased the amounts of copper, manganese, and iron and decreased the levels of molybdenum at each cutting of the herbage. Miller **et al.** (1964) showed that while nitrogen treatments up to 400 lb. per acre caused little change in the zinc content of coastal bermudagrass, higher levels of nitrogen significantly increased the zinc concentration. Analysis of the regrowth of three grass species (perennial ryegrass, timothy and orchardgrass) indicated that nitrogen fertilizer caused a reduction in the iodine content of herbage (Alderman and Jones, 1967), and the authors attributed this change to a simple dilution effect. In a study of the effect of different combinations of phosphorus and potassium treatment, with or without nitrogen, on the trace element content of grasses, Kabata-Pendias **et al.** (1966) found that the micro-nutrient content of grasses was generally highest where no phosphorus or potassium was applied, and that increasing levels of phosphorus resulted in a greater decline in trace element concentration than did increases in potassium fertilization.

Experimental

(1) **Plant Species and Stage of Growth.** In 1960 and 1961 pure stands of grass and legume species were established on the W.V.U. Agronomy Farm, Morgantown. These stands were harvested at several stages of maturity within the first growth and regrowth periods, and fed in intake and digestibility trials to wether sheep. Samples of herbage at each stage of growth

were also dried in a forced draft oven at 65° C, ground through a brass screen in a Wiley mill, and retained for proximate and mineral analysis.* In 1960, mineral composition was determined on tall fescue (Kentucky 31), timothy (common), alfalfa (Narragansett), and red clover (Dollard). In 1961, the species studied were orchardgrass (Potomac), bromegrass (Lincoln), tall fescue (Kentucky 31), timothy (common), sudangrass (Piper), and alfalfa (Narragansett). In both years all stands were treated with an 0:20:20 fertilizer at the rate of 500 lb. per acre, and the grasses were given an additional 100 lb. nitrogen per acre. In 1961 the sudangrass plots were subdivided and half of each was treated with additional nitrogen at the level of 300 lb. per acre. The dates on which the forages were harvested, the stage of maturity, the height of the plant and the dry matter yield (in tons/acre) are recorded in Appendix Tables 1 and 2.

Species and varietal differences in the mineral composition of leguminous forages were examined in 1966 in trials in which alfalfa and three varieties of crownvetch (Chemung, Emerald, Penngift) were fed in three cuttings to sheep and cattle. A first cutting hay was made on June 21, 1966, and two regrowth cuttings were taken on September 10 and October 3. Samples for mineral analysis were obtained and prepared as already described.

(2) **Seasonal and Fertilization Effects.** The mineral composition of different cuttings of tall fescue (Kentucky 31) and orchardgrass (Potomac) hays was determined in 1963 and 1964 on stands established at the W.V.U. Livestock Farm, Morgantown. The tall fescue was grown under different fertilization treatments and was harvested on May 27 at the heading to full-head stage, and again as regrowth on July 15. The fertilizer treatments were (1) no fertilizer, (2) low nitrogen (50 lb. N/acre), (3) medium nitrogen (150 lb. N/acre), (4) high nitrogen (450 lb. N/acre), (5) high potassium (450 lb. K_2O/acre), (6) high phosphorus (450 lb. P_2O_5/acre). The nitrogen was applied in the form of urea, potassium as muriate of potash, and phosphorus as superphosphate.

The orchardgrass hay was treated with different levels of nitrogen (0, 50, 100, 200, 400 lb. N/acre) and with nitrogen applied at a constant level, 100 lb. N/acre, but in the form of sodium nitrate, ammonium nitrate, ammonium sulfate, diammonium phosphate, or urea. A first hay cutting was made on May 16 and a regrowth cutting on July 20.

The mineral composition of herbage was also studied in pasture evaluation trials carried out in 1964 and 1965-66. In the first study, herbage samples were taken from a tall fescue pasture during the periods May 5-9, May 20-24, and June 6-10 in the first growth period, and on July 15-19, July 27-31, and August 9-13 in the regrowth period. The pasture was sub-divided into the following fertilization treatments: (1) no fertilizer, (2) low nitrogen (50 lb. N/acre), (3) high nitrogen (450 lb. N/acre), (4) high nitrogen-high phosphorus (450 lb. N, 200 lb. P/acre), (5) high potassium (400 lb. K/acre), (6) high phosphorus (200 lb. P/acre). In the second series of trials, an orchardgrass pasture was fertilized at four levels of nitrogen (0, 50, 150, 450 lb. N/acre) and herbage was sampled during grazing trials which were conducted during the periods May 13-18, June 25-30, and September 4-9, 1965, and March 12-17, 1966. After each trial the grazing plots were clipped, and the grass allowed to grow back to a height of 8-10 inches.

Finally, seasonal and fertilization effects on the mineral composition of an orchardgrass pasture were determined by taking herbage samples at approximately monthly intervals over the period from May, 1967, to April, 1969. The plots were maintained under four fertilization treatments: (1) low nitrogen (50 lb. N/acre), (2) medium nitrogen (150 lb. N/acre), (3) high nitrogen (450 lb. N/acre), (4) high nitrogen + micro-elements (450 lb. N/acre + Cu, Co, Mo, Zn, S). The micro-elements were incorporated in an 11:22:22 fertilizer prepared and donated by the Tennessee Valley Authority and the percentage content of the individual elements was as follows: Cu, 0.41; Co, 0.08; Mo, 0.25; Zn, 0.93; S, 1.8. The high levels of nitrogen were applied in split applications in early spring and late summer of each year. The pastures were clipped to a height of three to four inches

*Where samples were taken from pastures or pure species stands, cuttings were taken from at least six different areas and combined for analysis. Where hay samples were analyzed, they were normally collected in the course of a feeding trial with sheep or cattle. Samples were taken daily from different bales on at least 10 different days and composited for analysis.

each year when the first growth had reached the late bloom stage.

Mineral analysis on forage samples was run spectrographically at the Plant Analysis Laboratory, Ohio Agricultural Experiment Station, using a Jarrell-Ash Atomcounter for 15 elements. Data for cobalt are included in a limited number of analyses.

Results and Discussion

Before considering the results of natural and management factors on the mineral composition of forage crops, it is desirable to have some appreciation of the level of minerals required in the diet for adequate animal nutrition. This will obviously be influenced profoundly by many factors, **e.g.** the physiological state of the animal, type of diet being fed, form and availability of the mineral, and the presence of interfering compounds in the diet. It is therefore only possible to present a working approximation to the mineral requirements of any class of livestock, and one such approximation is presented in Table 1, which is taken from the work of Whitehead (1966). This gives the calculated requirements of a 500 kg. (c. 1,100 lb.) cow giving 15 kg. (c. 33 lb.) milk per day, a moderate level of production. The results of the following studies will be discussed in relation to the estimated requirements of minerals for ruminant animals on a predominantly forage diet.

Species and Varietal Effects. Mineral composition data for four grass and legume species harvested in 1960, and for six species harvested in 1961, are given for a number of growth stages in Appendix Tables 3 and 4. For the purpose of making inter-species comparisons, mean values were calculated for each species, and the results for potassium, phosphorus, calcium, magnesium, copper, zinc, molybdenum, boron, iron, manganese, aluminum, and strontium are summarized graphically in Figures 1, 2, 3, and 4.

It may be seen that there were both inter-species differences and, where a given species was sampled in two successive years (tall fescue, timothy, alfalfa), between-year differences in the concentration of a number of mineral elements. In general, the legumes, alfalfa, and red clover, contained higher levels of calcium at all stages of growth than did the grasses; the highest levels of magnesium (0.16-0.26 per cent) were found in red clover harvested in 1960, but there was no indication that alfalfa contained higher concentrations of this element than the grasses. Certain of the grass species, timothy for example, were consistently low in magnesium content, a range of 0.07-0.14 per cent being observed in 1960, and 0.06-0.14 per cent in 1961. In spite of the fact that the forage plots were treated with N:P:K fertilizer in both years, there were marked differences in the concentration of potassium and phosphorus in alfalfa in 1960 and 1961. In 1961, orchardgrass contained the highest levels of potassium and phosphorus among the grass species considered.

Fleming (1965) concluded that legume species generally contained higher levels of micro-

TABLE 1

Recommended Dietary Content of Mineral Elements and Nitrogen for a Dairy Cow Weighing 500 kg (c.1,100 lb.) and Yielding 15 kg (c. 33 lb.) Milk

Element	% or p.p.m. in DM of Diet	Reference
N	1.4 %*	A.R.C. (1966)
P	0.36%*	A.R.C. (1966)
K	0.31-0.44%*	A.R.C. (1966)
Ca	0.43%*	A.R.C. (1966)
Mg	0.12%*	A.R.C. (1966)
	0.2 %	Wolton (1963a)
S	0.1 %	Cunningham, I. J. (1954)
Na	0.13%*	A.R.C. (1966)
Cl	0.21%*	A.R.C. (1966)
Fe	30 p.p.m.	A.R.C. (1966)
Mn	40 p.p.m.	A.R.C. (1966)
Zn	50 p.p.m.	A.R.C. (1966)
Cu	4-6 p.p.m.	Underwood (1962)
	10 p.p.m.	A.R.C. (1966)
Co	0.1 p.p.m.	A.R.C. (1966)
I	0.8 p.p.m.	A.R.C. (1966)
Se	0.05 p.p.m.	Gardiner and Gorman (1963)

*Calculated from allowances given in g/day, assuming that dry matter intake amounts to 2.8 per cent of body weight (Jones, Drake-Brockman, and Holmes, 1965).

elements than did the grasses. The red clover sampled in 1960 had relatively high concentrations of copper, zinc, molybdenum, boron, iron, manganese, aluminum, strontium, and barium (not presented in graph), when compared with grass species in either year. With the exception of boron, however, the micro-element levels in alfalfa were generally comparable to those of the grasses. Among the grass species, timothy and sudangrass contained relatively high con-

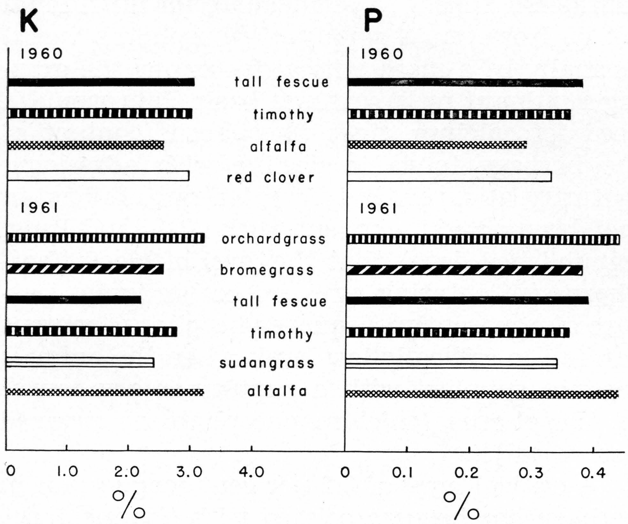

FIGURE 1. Potassium and phosphorus content of pure stands of grasses and legumes harvested in 1960 and 1961. Data represent mean values for several growth stages in first cutting and regrowth forage.

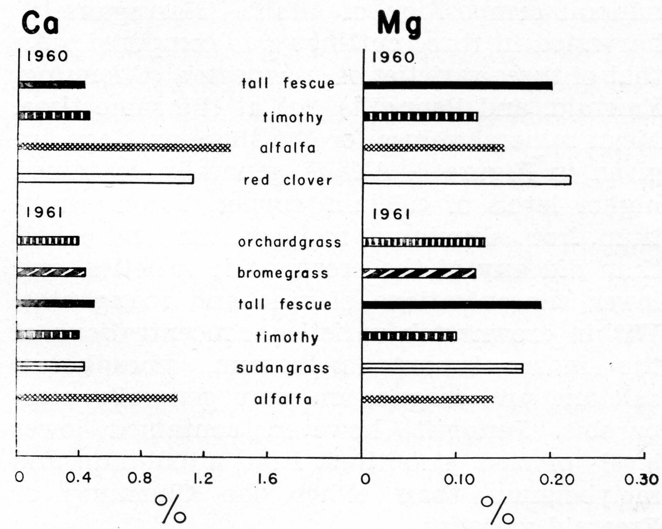

FIGURE 2. Calcium and magnesium content of pure stands of grasses and legumes harvested in 1960 and 1961. Data represent mean values for several growth stages in first cutting and regrowth forage.

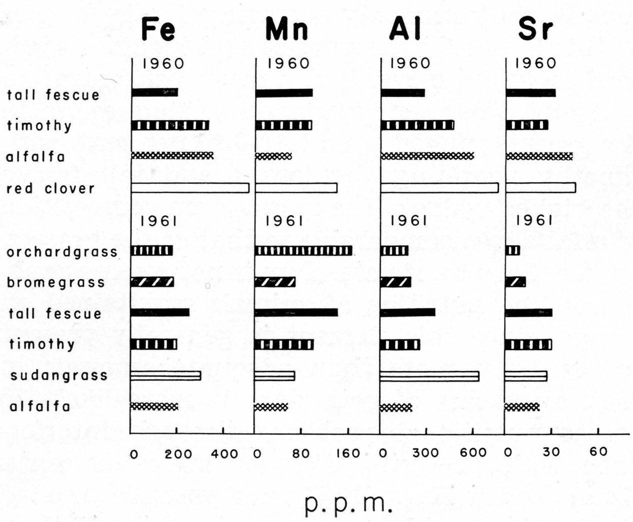

FIGURE 3. Concentration of iron, manganese, aluminum, and strontium in pure stands of grasses and legumes harvested in 1960 and 1961. Data represent mean values for several growth stages in first cutting and regrowth forage.

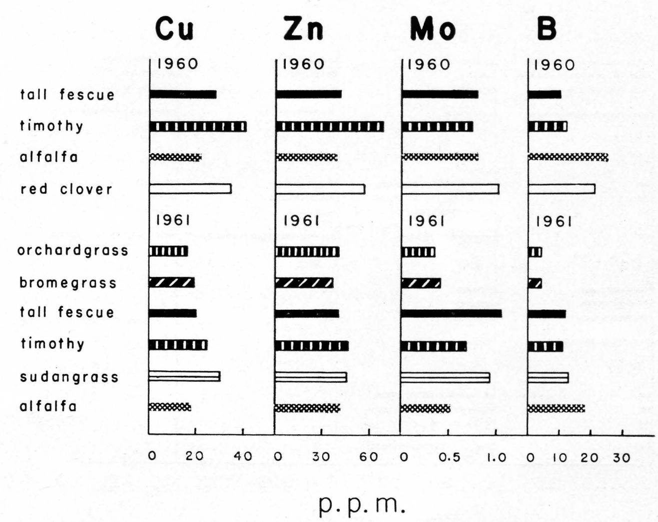

FIGURE 4. Concentration of copper, zinc, molybdenum, and boron in pure stands of grasses and legumes harvested in 1960 and 1961. Data represent mean values for several growth stages in first cutting and regrowth forage.

centrations of the micro-elements; the observation on the latter species is of interest since, with its habit of growth, sudangrass might be expected to remove large quantities of mineral elements from the soil.

Species and variety differences were also noted in a study performed in 1966, when the mineral composition of alfalfa (Narragansett) harvested in three cuttings was compared with that of three varieties of crownvetch (Chemung, Emerald, and Penngift) cut at the same time. Mean mineral values for the three cuttings are given in Figure 5. Alfalfa generally contained higher levels of calcium, copper, boron, strontium, iron, aluminum, molybdenum, and cobalt than did any of the crownvetch varieties, and lower concentrations of zinc and manganese. Within crownvetch varieties, concentrations of the macro-elements potassium, phosphorus, calcium, and magnesium were generally comparable. Penngift, however, contained lower levels of zinc, strontium, iron, aluminum, and molybdenum than either the Chemung or Emerald varieties.

The level of mineral elements present in this range of forage species may be considered in relation to the dietary requirements of ruminant animals. It is generally recognized that

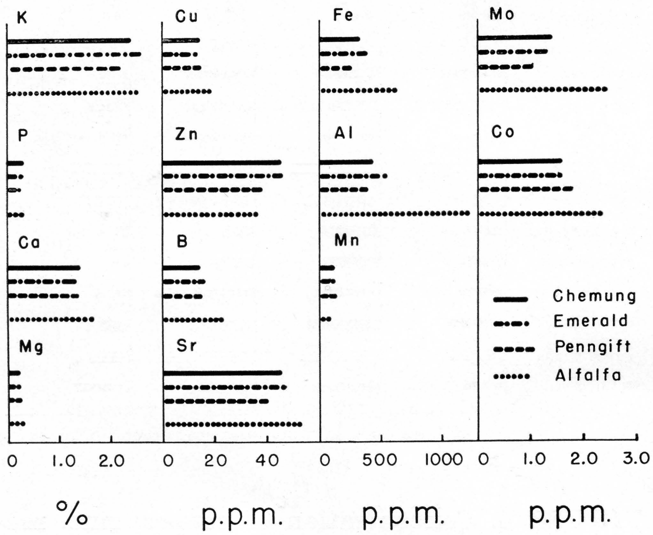

FIGURE 5. Mineral composition of three varieties of crownvetch (Chemung, Emerald, Penngift), compared with alfalfa. Data represent mean values for three cuttings of hay.

the function of calcium and phosphorus in animal metabolism is as much dependent on the ratio in which these elements are present, and on the supply of vitamin D, as it is on the absolute amounts of each element in the diet. By either criterion, the average levels of calcium and phosphorus in the grass and legume species considered appear to be adequate for nutritional needs. However, a supply of phosphorus would normally be a more critical factor for the grazing ruminant on a seasonal basis than would a need for calcium, since phosphorus content of the herbage tends to decline with advancing maturity at a relatively greater rate. It has, in fact, been noted in current work (Reid and Jung, unpublished data) that the level of blood phosphorus in lactating ewes on orchardgrass pasture of apparently adequate phosphorus content can fall to critically low levels when the animals are not supplied with a supplementary source of phosphorus (calcium phosphate or steamed bone meal).

A critical level of 0.2 per cent magnesium in herbage has been associated with the incidence of hypomagnesemia in ruminant animals (Wolton, 1963). Grass tetany is a chronic problem of ruminant animals in West Virginia and is particularly associated with the period when animals are turned out to pasture in early spring. Undoubtedly a major factor involved in grass tetany is the low concentration of magnesium present in the commonly occurring forage species in this State. Of the grasses and legumes analyzed, only red clover had a mean concentration of over 0.2 per cent magnesium. Magnesium in the grasses ranged from 0.10-0.20 per cent, with timothy providing the lowest and tall fescue the highest values. The magnesium composition of alfalfa was comparable to that of the grasses.

A deficiency of potassium is not often a problem in the nutrition of animals maintained on forage, since this element is generally present in plants in more than adequate amount; in fact, an excess of potassium is more likely to create nutritional problems through interference with the utilization of other elements. Kemp and 't Hart (1957), for example, related the incidence of hyomagnesemia in the Netherlands to the K/(Ca + Mg) ratio in the herbage. The situation with regard to sodium is quite different. Underwood (1966) placed the minimum requirements of milking cows for sodium between 0.16 and 0.22 per cent, depending on feed consumption and milk yield. This may be compared with the very low concentrations of sodium, usually less than 0.01 per cent, recorded for all species in this study. These values are comparable to those obtained on tropical and sub-tropical forages (Underwood, loc. cit.), and would represent a condition of severe deficiency if animals were not supplemented with loose or block salt.

In general the mean levels of most of the essential micro-elements analyzed tended to be higher than those suggested by Whitehead (Table 1) as adequate for dairy cows. The concentration of iron in all species was several times the accepted maximum requirement, and the levels of copper, manganese and molybdenum fell within the normal range. Estimates of the need of ruminant animals for zinc have varied widely. Ott **et al.** (1964) calculated that the requirement of lambs for maintenance of normal zinc blood concentrations was 18-33 p.p.m., while the A.R.C. (Table 1) has recommended a level of 50 p.p.m. zinc for lactating cattle. By the latter standard, the amounts of zinc supplied by different forage species in this study might be considered marginal, falling generally within the range of 30-45 p.p.m. In another study (Reid **et al.**, 1969) an increased concentration of zinc in orchardgrass has been noted in response to zinc fertilization, and zinc treatment also resulted in an increased dry matter digestibility of the grass by wether sheep. Cobalt concentrations were determined for orchardgrass, bromegrass, and alfalfa in 1961 (Appendix Table 4) and all values fell within the range of 0.23-1.04 p.p.m. The minimum level of cobalt in the diet to meet the requirements of sheep and cattle appears to be of the order of 0.1 p.p.m. It would therefore appear that, with the possible exception of zinc, the mean concentrations of micro-nutrients found in the grass and legume species analyzed exceeded the minimum requirements suggested for ruminant animals on forage diets.

Stage of Growth. The effects of maturation on the mineral composition of several species of grass and legume is summarized in Appendix Tables 3 and 4, and typical growth effects for a grass (orchardgrass) and a legume (alfalfa) are shown graphically for certain macro- and micro-elements in Figures 6, 7, 8, and 9. Regression equations and correlation coefficients were calculated for each species in each year to relate the concentration of individual elements to the time of cutting the forage (number of days after May 1 for the perennial species, and number of days after July 1 for the annual). The results are given in Tables 2 and 3.

In most cases there was a significant effect of maturation in the period of first growth on the concentration of the major elements, potassium, phosphorus, calcium, and magnesium. For the 1961 forages, in which a wider range of growth stages was analyzed, potassium in the plant increased to the boot or bud stage, and thereafter declined sharply. The level of phosphorus tended to decrease through the growing cycle, although the rate of decline varied with species. Calcium and magnesium also showed a regular decline in concentration with advancing maturity in most species, although again there were species differences in the rate of change. Magnesium in tall fescue in 1960, and in orchardgrass and bromegrass in 1961, showed little difference in concentration between the vegetative and seeding stages. The levels of sodium were consistently low at any stage of the growth cycle, while the concentration of silicon, perhaps surprisingly, showed a rather regular decline in most species with increasing age of the plant. Within the regrowth periods, the concentration of the major elements tended to show relatively less change with time than in the first growth cycle.

It should be noted that during the later growth stages of the plant, the concentration of phosphorus, calcium, and magnesium frequently fell to values lower than those recommended for the adequate nutrition of ruminant animals. In orchardgrass, for example, which is frequently cut for hay at the late bloom stage in West Virginia, the levels of phosphorus, calcium, and magnesium at this stage of growth were 0.30 per cent, 0.26 per cent and 0.11 per cent, respectively, as compared to the 0.36 per cent, 0.43 per cent and 0.20 per cent recommended by Whitehead (Table 1). Alfalfa at a comparable growth stage contained adequate levels of phosphorus and calcium, but was still deficient in magnesium.

There has been little unanimity in the literature concerning the effect of stage of growth of forage plants on their content of micro-elements. Unlike the earlier findings of Beeson and MacDonald (1951), in this study there was a general decrease with age in the concentration of iron and aluminum in the different species, although occasional discrepancies were noted; these may have been due to contamination of the sample. There was some indication of a decline in manganese in both the 1960 and 1961 series, but this was not as marked as for iron and aluminum. The Wisconsin workers (Loper and Smith, 1961) showed a differential effect of maturation on zinc concentration with plant species. There was for all species in both years a consistent decrease in the level of zinc with increasing age of the plant. The concentration of copper, however, did not appear to change appreciably with growth stage. Cobalt was determined for orchardgrass, bromegrass, and alfalfa harvested in 1961 and there was no marked effect of maturation on the level of this element, although samples taken at the more advanced growth stages tended to contain less cobalt than samples taken early in the season. The concentration of molybdenum and boron decreased with age of the plant for most species in both years, and barium levels remained rather constant. In comparison with the other grasses and legumes, the concentration of strontium in orchardgrass and bromegrass in 1961 was consistently low, and there was a decrease in concentration of this element with increasing maturity; in other species the level of strontium remained relatively constant.

Within regrowth periods, the number of growth stages analyzed was limited and it is not possible to draw general conclusions concerning the effect of stage of maturity on mineral composition. In sudangrass, harvested in 1961, there appeared to be a definite trend for the concentration of manganese, iron, boron, copper, zinc, aluminum, molybdenum, and bar-

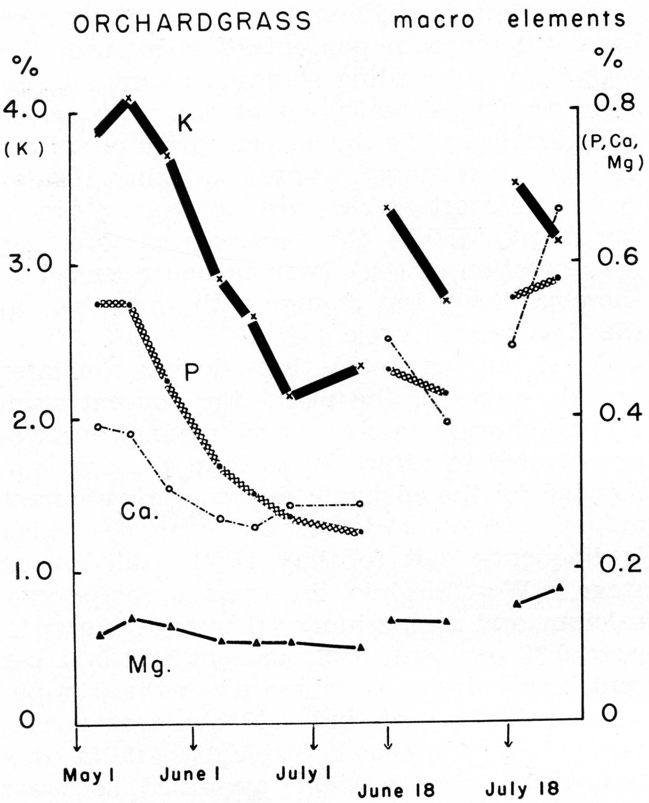

FIGURE 6. Stage of growth effects on the content of potassium, phosphorus, calcium, and magnesium in orchardgrass harvested in 1961. Physiological growth stages corresponding to harvest dates are supplied in Appendix Table 2.

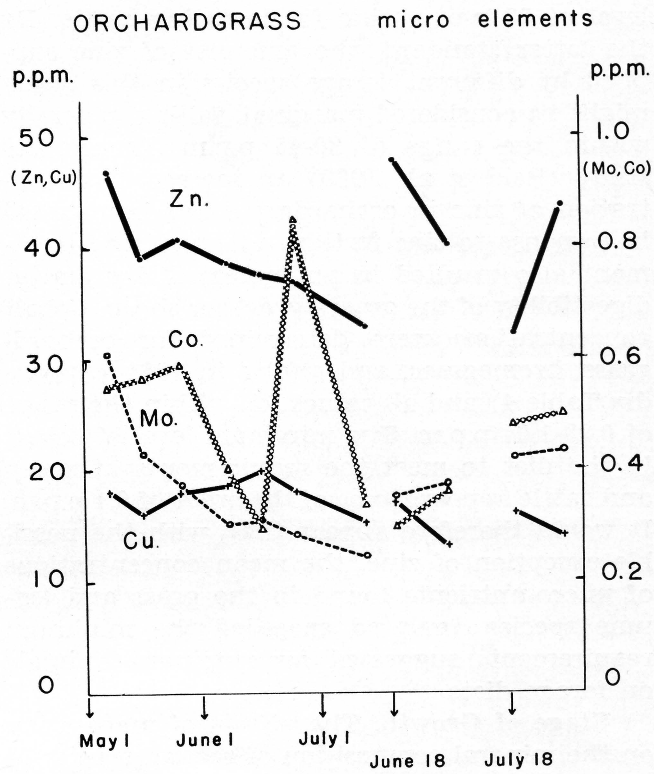

FIGURE 7. Stage of growth effects on the content of zinc, cobalt, copper, and molybdenum in orchardgrass harvested in 1961. Physiological growth stages corresponding to harvest dates are supplied in Appendix Table 2.

ium to decrease with increasing maturity of the plant. In other species this effect was not apparent.

In contrast to the major elements, the concentration of the minor elements appeared to be less critically affected by the stage of maturation of the forage species, at least in relation to the nutritional requirements of livestock. If orchardgrass at a late bloom stage is again considered as a typical hay crop in West Virginia, the p.p.m. levels were: manganese, 168; iron, 84; copper, 20; zinc, 38; molybdenum, 0.31; and cobalt, 0.30. With the possible exception of zinc, these levels exceed the concentrations required by milking cows (Whitehead, 1966). This was still generally true for all species even at the most advanced stage of growth of the plant.

Seasonal Effects. It has been pointed out that seasonal effects on the mineral composition of forages are frequently confused with stage of growth effects. In the present context, seasonal effects will first be discussed in terms of the compositional differences noted between hay cuttings made from the first growth and regrowth of tall grass species (tall fescue and orchardgrass) and these are illustrated in Figures 10 and 11. Complete data are given in Appendix Tables 5 and 6. Secondly, the composition of different growths of tall fescue and orchardgrass pasture used in sheep evaluation trials was determined in 1964 and 1965. In the tall fescue study, mineral data were obtained from three maturity stages and six fertilizer treatments within spring and summer growth periods. Mean values are given in Figure 12 and complete data in Appendix Table 7. In the orchardgrass trials, mineral composition was de-

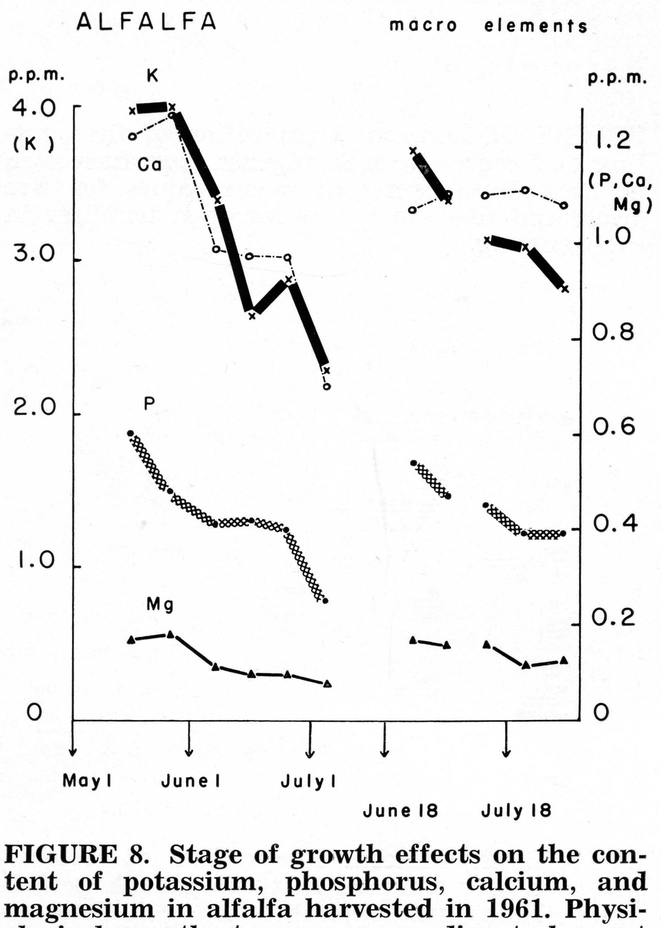

FIGURE 8. Stage of growth effects on the content of potassium, phosphorus, calcium, and magnesium in alfalfa harvested in 1961. Physiological growth stages corresponding to harvest dates are supplied in Appendix Table 2.

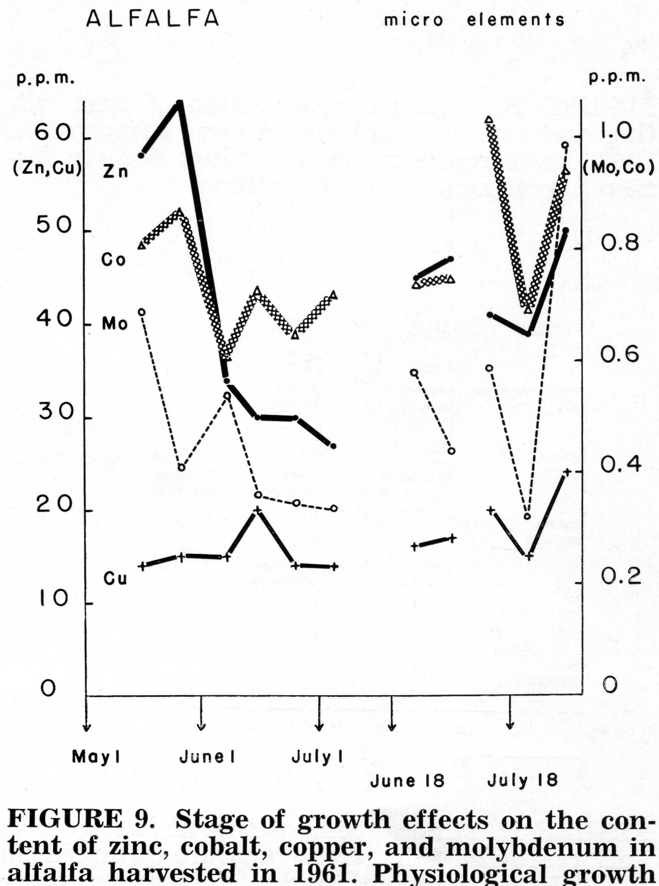

FIGURE 9. Stage of growth effects on the content of zinc, cobalt, copper, and molybdenum in alfalfa harvested in 1961. Physiological growth stages corresponding to harvest dates are supplied in Appendix Table 2.

termined for three growth cycles, in May, June, and September of 1965, and for four fertilizer treatments within each growth period. Mean values are presented in Figure 13 and complete results in Appendix Table 8.

Finally, seasonal differences are considered from a somewhat different viewpoint in a current study, some results of which are summarized in Figures 14, 15, 16, and 17. In this work, compositional changes in orchardgrass pasture under different levels of nitrogen fertilization are related to the nutritional status

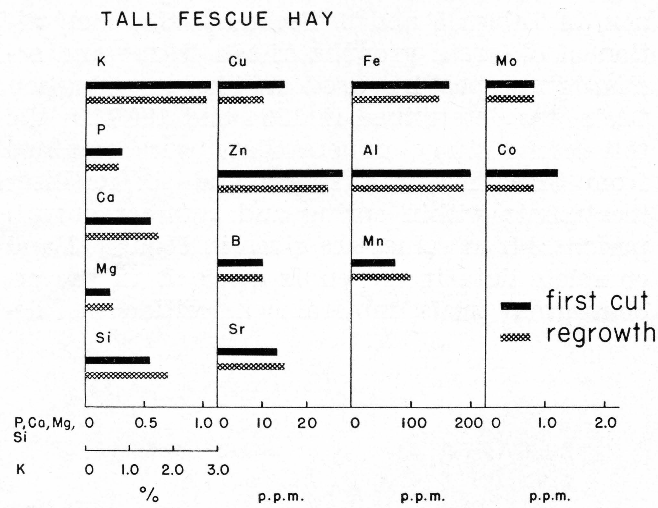

FIGURE 10. Mineral composition of first cutting and regrowth tall fescue hays harvested in 1963. Data represent mean values for six fertilizer treatments in each cutting.

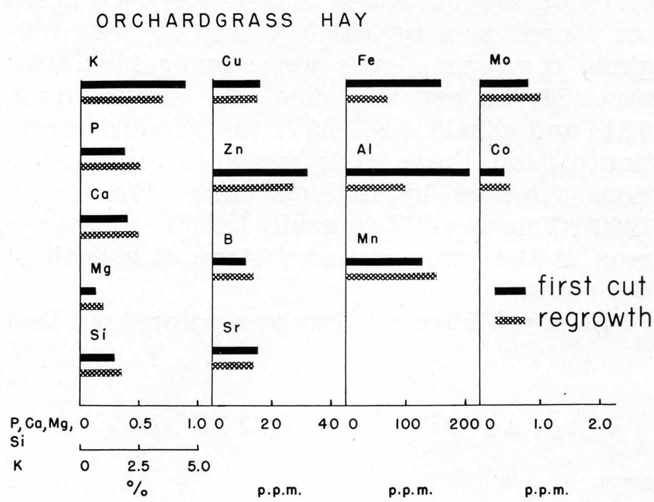

FIGURE 11. Mineral composition of first cutting and regrowth orchardgrass hays harvested in 1964. Data represent mean values for five levels and five sources of nitrogen fertilizer in each cutting.

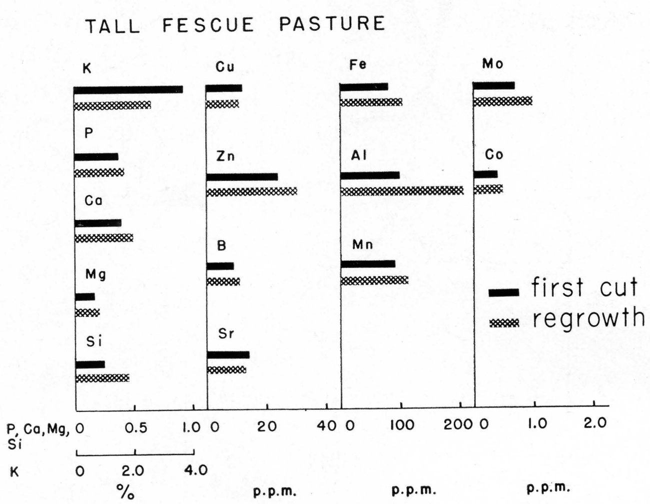

FIGURE 12. Mineral composition of first growth and regrowth tall fescue pasture sampled in 1964. Data represent mean values for three growth stages and six fertilizer treatments within each growth period.

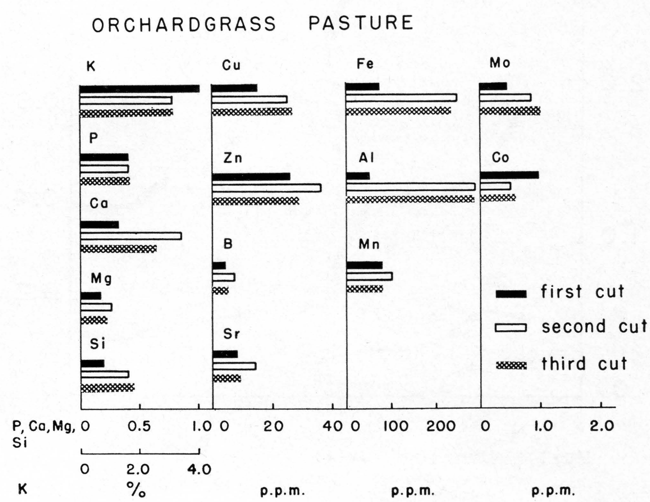

FIGURE 13. Mineral composition of orchardgrass pasture sampled in three growth periods (May, June, and September) in 1965. Data represent mean values for four fertilizer treatments within each growth period.

TABLE 2

Relationship Between Mineral Composition and Date of Cutting in Grass and Legume Species Harvested in 1960

Mineral	Statistic	Tall Fescue	Timothy	Alfalfa	Red Clover
Potassium	R.E.	Y = 2.981 – 0.0159X*	Y = 3.910 – 0.0210X	Y = 6.113 – 0.0852X	Y = 3.964 – 0.0231X
	r^2	0.934	0.386	0.618	0.749
Phosphorus	R.E.	Y = 0.356 – 0.0004X	Y = 0.512 – 0.0040X	Y = 1.901 – 0.0363X	Y = 0.441 – 0.0032X
	r^2	0.046	0.603	0.474	0.861
Calcium	R.E.	Y = 0.570 – 0.0043X	Y = 0.595 – 0.0036X	Y = 3.992 – 0.0582X	Y = 1.403 – 0.0068X
	r^2	0.956	0.800	0.521	0.626
Magnesium	R.E.	Y = 0.184 – 0.0003X	Y = 0.131 – 0.0008X	Y = 0.951 – 0.0179X	Y = 0.282 – 0.0018X
	r^2	0.361	0.807	0.471	0.813
Silicon	R.E.	Y = 0.348 – 0.0036X	Y = 0.255 – 0.0028X	Y = 0.443 – 0.0087X	Y = 0.212 – 0.0029X
	r^2	0.714	0.364	0.490	0.785
Manganese	R.E.	Y = 117.10 – 0.5854X	Y = 128.03 – 0.7915X	Y = 336.71 – 6.3282X	Y = 143.56 – 0.1915X
	r^2	0.949	0.563	0.466	0.692
Iron	R.E.	Y = 300.95 – 3.0640X	Y = 737.81 – 10.1082X	Y = 281.21 – 0.8651X	Y = 1342.73 – 23.299 X
	r^2	0.524	0.453	0.067	0.707
Boron	R.E.	Y = 10.259 + 0.0079X	Y = 15.136 – 0.0788X	Y = 30.048 – 0.1097X	Y = 28.031 – 0.1877X
	r^2	0.079	0.651	0.897	0.791
Copper	R.E.	Y = 18.604 + 0.2261X	Y = 12.960 + 0.6663X	Y = 22.396 – 0.0337X	Y = 36.028 + 0.0353X
	r^2	0.886	0.658	0.024	0.012
Zinc	R.E.	Y = 46.606 – 0.2166X	Y = 97.833 – 0.7448X	Y = 39.875 – 0.0701X	Y = 70.169 – 0.4690X
	r^2	0.297	0.774	0.173	0.648
Aluminum	R.E.	Y = 557.56 – 7.3462X	Y = 879.33 – 10.2511X	Y = 635.59 – 5.0133X	Y = 1237.86 – 18.7187X
	r^2	0.525	0.362	0.470	0.835
Strontium	R.E.	Y = 34.948 – 0.1130X	Y = 30.184 – 0.0590X	Y = 45.486 – 0.0705X	Y = 49.658 – 0.0801X
	r^2	0.951	0.110	0.321	0.156
Molybdenum	R.E.	Y = 0.852 – 0.0011X	Y = 0.854 – 0.0040X	Y = 0.928 = 0.0039X	Y = 1.156 – 0.0036X
	r^2	0.796	0.785	0.247	0.230
Cobalt	R.E.	——	——	——	——
	r^2				
Barium	R.E.	Y = 16.518 – 0.0158X	Y = 20.771 – 0.1396X	Y = 23.761 + 0.0554X	Y = 42.081 – 0.1711X
	r^2	0.079	0.655	0.177	0.341

Y = % or p.p.m. element, X = number of days after May 1.

TABLE 3

Relationship Between Mineral Composition and Date of Cutting in Grass and Legume Species Harvested in 1961

Mineral	Statistic	Orchardgrass	Bromegrass	Tall Fescue	Timothy	Sudangrass	Alfalfa
Potassium	R.E.	Y = 4.252 – 0.0306X	Y = 3.553 – 0.0282X	Y = 2.339 – 0.0064X	Y = 3.941 – 0.0326X	Y = 3.364 – 0.0264X	Y = 4.658 – 0.0356X
	r^2	0.866	0.938	0.250	0.879	0.600	0.904
Phosphorus	R.E.	Y = 0.582 – 0.0052X	Y = 0.483 – 0.0039X	Y = 0.556 – 0.0045X	Y = 0.482 – 0.0042X	Y = 0.338 – 0.0009X	Y = 0.657 – 0.0056X
	r^2	0.912	0.930	0.716	0.979	0.379	0.862
Calcium	R.E.	Y = 0.375 – 0.0017X	Y = 0.518 – 0.0047X	Y = 0.619 – 0.0025X	Y = 0.428 – 0.0026X	Y = 0.600 – 0.0042X	Y = 0.127 + 0.0136X
	r^2	0.580	0.914	0.256	0.872	0.486	0.516
Magnesium	R.E.	Y = 0.135 – 0.0005X	——	Y = 0.246 – 0.0017X	Y = 0.118 – 0.0009X	Y = 0.206 – 0.0012X	Y = 0.207 – 0.0019X
	r^2	0.660		0.565	0.945	0.569	0.884
Silicon	R.E.	Y = 0.258 + 0.0007X	Y = 0.522 – 0.0040X	Y = 0.285 – 0.0016X	Y = 0.088 – 0.00003X	Y = 0.237 – 0.0024X	Y = 0.115 + 0.0013X
	r^2	0.231	0.669	0.497	0.011	0.913	0.230
Manganese	R.E.	Y = 128.64 + 0.8761X	Y = 62.036 – 0.3407X	Y = 196.82 – 1.4328X	Y = 94.627 – 0.5594X	Y = 71.043 – 0.5259X	Y = 45.622 + 0.0377X
	r^2	0.654	0.720	0.538	0.659	0.567	0.007
Iron	R.E.	Y = 259.51 – 2.2045X	Y = 366.78 – 4.3111X	Y = 544.65 – 6.1896X	Y = 228.52 – 1.7987X	Y = 493.46 – 2.2470X	Y = 325.52 – 3.3380X
	r^2	0.264	0.414	0.733	0.284	0.057	0.717
Boron	R.E.	Y = 5.168 – 0.0350X	Y = 5.489 – 0.0627X	Y = 15.127 – 0.0805X	Y = 11.209 – 0.0215X	Y = 13.736 – 0.0348X	Y = 31.444 – 0.3279X
	r^2	0.848	0.699	0.541	0.199	0.111	0.790
Copper	R.E.	Y = 18.217 – 0.0134X	Y = 23.160 – 0.0615X	Y = 16.332 + 0.0209X	Y = 25.152 + 0.0156X	Y = 33.354 – 0.0253X	Y = 14.941 + 0.0096X
	r^2	0.035	0.157	0.016	0.025	0.001	0.006
Zinc	R.E.	Y = 45.237 – 0.1590X	Y = 44.615 – 0.2798X	Y = 54.008 – 0.3054X	Y = 54.132 – 0.2414X	Y = 49.071 – 0.0555X	W = 71.769 – 0.7627X
	r^2	0.776	0.690	0.623	0.399	0.010	0.793
Aluminum	R.E.	Y = 200.89 – 1.8673X	Y = 328.30 – 4.1034X	Y = 840.38 – 10.3444X	Y = 187.91 – 1.9318X	Y=1030.03 – 7.2321X	Y = 314.69 – 3.0861X
	r^2	0.414	0.319	0.678	0.407	0.236	0.463
Strontium	R.E.	Y = 11.166 – 0.0846X	Y = 17.691 – 0.1902X	Y = 24.087 + 0.1816X	Y = 32.822 – 0.1007X	Y = 35.074 – 0.1134X	Y = 26.708 – 0.1474X
	r^2	0.601	0.770	0.835	0.419	0.112	0.353
Molybdenum	R.E.	Y = 0.536 – 0.0046X	Y = 0.676 – 0.0083X	Y = 1.505 – 0.0123X	Y = 0.650 – 0.0012X	Y = 0.940 – 0.0025X	Y = 0.692 – 0.0059X
	r^2	0.764	0.690	0.569	0.171	0.085	0.642
Cobalt	R.E.	Y = 0.580 – 0.0016X	Y = 0.669 – 0.0022X	——	——	——	Y = 0.856 – 0.0030X
	r^2	0.044	0.054				0.350
Barium	R.E.	Y = 13.558 + 0.1263X	Y = 12.385 – 0.0637X	Y = 19.148 + 0.0844X	Y = 13.787 + 0.1731X	Y = 19.442 – 0.0316X	Y = 21.498 + 0.0163X
	r^2	0.675	0.401	0.271	0.873	0.063	0.018

Y = % or p.p.m. element, X = number of days after May 1, or July 1 (Sudangrass).

of livestock maintained on the pasture, and on hays produced from the same treatments, over an extended period of time. The mineral composition of these pastures was determined at approximately monthly intervals, and changes shown in the Figures are represented as mean values for four fertilizer treatments.

Certain seasonal effects common to both the hay and pasture experiments in 1963-1965 may be noted in Figures 10, 11, 12, and 13. In all cases, the concentration of potassium was higher in the first cutting than in the regrowth cuttings. There was comparatively little effect of time of cutting on the level of phosphorus. In agreement with the findings of other workers (Stewart and Holmes, 1953; Todd, 1961;

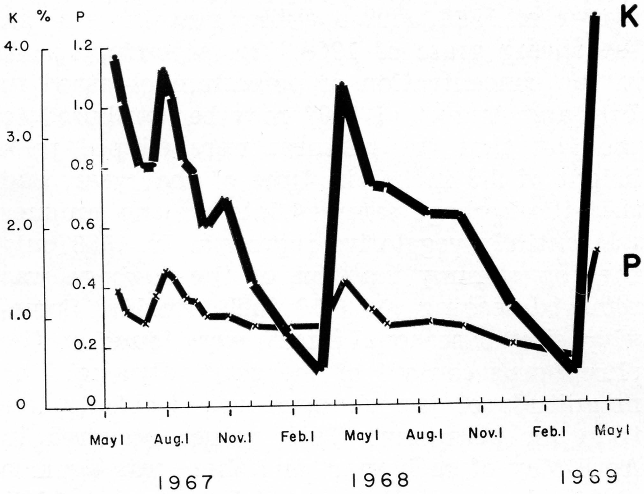

FIGURE 14. Seasonal differences in the potassium and phosphorus concentration of orchardgrass pasture sampled at regular intervals during the period May 1967 to April 1969. Data represent mean values for four fertilizer treatments at each time of sampling.

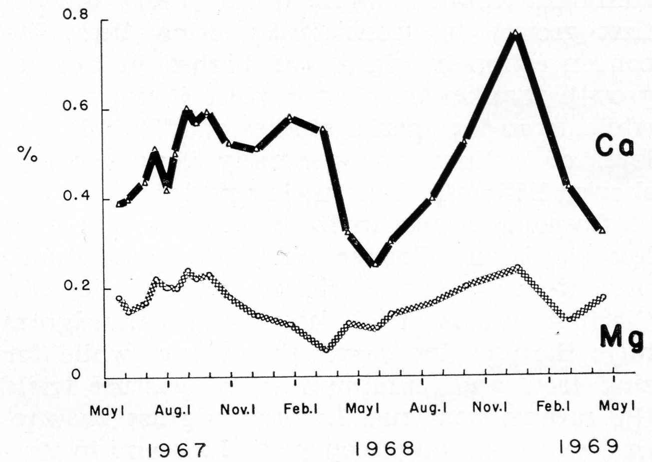

FIGURE 15. Seasonal differences in the calcium and magnesium content of orchardgrass pasture sampled at regular intervals during the period May 1967 to April 1969. Data represent mean values for four fertilizer treatments at each time of sampling.

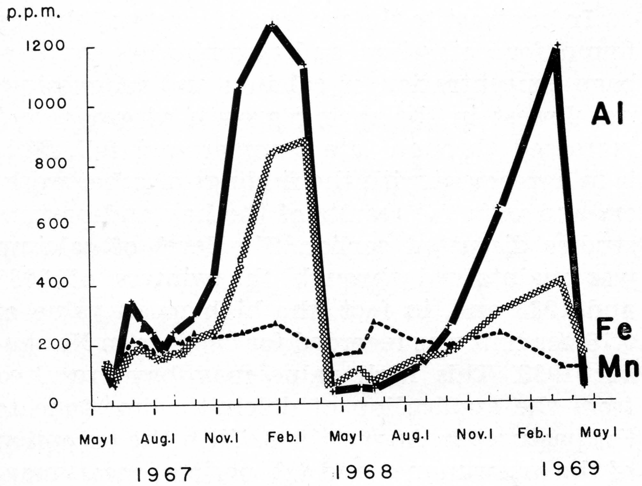

FIGURE 16. Seasonal differences in the iron, manganese, and aluminum content of orchardgrass pasture sampled at regular intervals during the period May 1967 to April 1969. Data represent mean values for four fertilizer treatments at each time of sampling.

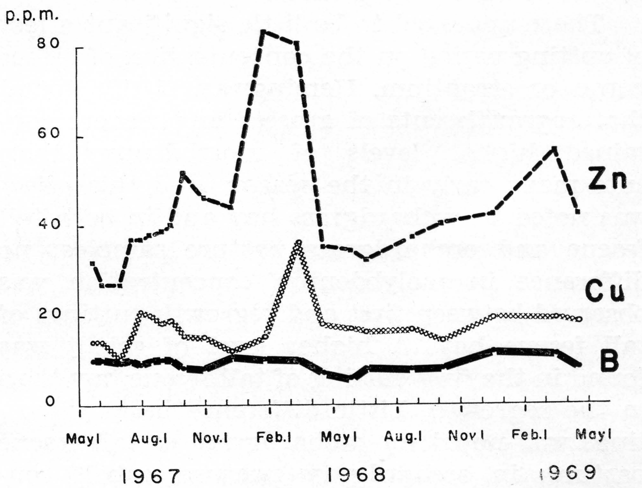

FIGURE 17. Seasonal differences in the zinc, copper, and boron concentration of orchardgrass sampled at regular intervals during the period May 1967 to April 1969. Data represent mean values for four fertilizer treatments at each time of sampling.

Reith **et al.**, 1964; Fleming and Murphy, 1968), the concentration of calcium and magnesium was higher in regrowth cuttings than in the first growth cycle; for calcium, this increase was particularly marked in the orchardgrass pasture study (Figure 13). Magnesium levels in the regrowth forage generally approached the 0.2 per cent level recommended for the maintenance of serum magnesium concentration in ruminant animals, while mean values for the first growth fell consistently below this. The concentration of silica was higher in the regrowth than in the first growth of the grasses while, as in the species studies of 1960-1961, the level of sodium was generally very low and showed little effect of cutting period.

Seasonal trends in the micro-elements were less consistent. Copper, zinc, iron, and aluminum were present at higher concentrations in the first cutting of tall fescue and orchardgrass hays than in the regrowth cutting, while for zinc, iron, and aluminum in the pasture trials the reverse was true. In orchardgrass pasture, the concentration of copper in June and in September was higher than in May. Mean values for zinc in forages used in these trials were of the order of 20-30 p.p.m., levels which may be considered marginal for livestock feeding. The concentration of manganese was consistently higher in the regrowth cuttings than in the first cutting of the grasses.

There appeared to be little significant effect of cutting period on the concentration of either boron or strontium. Hemingway (1962) found that regrowth cuts of grasses and clovers contained higher levels of molybdenum than cuts made early in the season, and this effect was noted in orchardgrass hay and in both tall fescue and orchardgrass pasture samples; no difference in molybdenum concentration was observed between first and regrowth cuttings of tall fescue hay. A higher level of cobalt was found in the first cutting of tall fescue hay than in the regrowth. Little difference between cuttings was noted for orchardgrass or tall fescue pasture; in orchardgrass pasture, cobalt concentration was higher in the May herbage than in either June or September.

In the trials in which pastures were sampled at regular intervals, very marked seasonal variations in the potassium concentration of orchardgrass grazed by sheep were noted during a two-year period (Figure 14). The pastures were treated with 100 lb. P_2O_5 and 200 lb. K_2O per acre in March and November of 1967, and again in March 1969. The potassium content of the herbage declined from a mean value of 3.91 per cent in May 1967 to a low of 0.40 per cent in March 1968. There was then an increase to 3.56 per cent in the spring growth of 1968, followed by a similar steep decline in the late fall and winter of 1968, and a subsequent increase in the spring grass of 1969. The secondary peak in the concentration of potassium observed in July and August of 1967 may be attributed to the fact that the pastures were clipped to a height of 2-3 inches in June of that year, and that the herbage sampled later in the summer was entirely vegetative regrowth. In 1968 only the top stemmy fraction of the herbage was removed leaving an 8-10 inch stubble. Somewhat similar seasonal effects were found on the phosphorus content of the grass, although the magnitude of the changes was decidedly less than for potassium. Peak values occurred in April-May of each year, and there was again a rise in the regrowth grass of July-August, 1967. It should be noted that, following the increase in phosphorus obtained in spring and early summer, the phosphorus content of the grass decreased to less than 0.30 per cent for the remainder of the year, a level lower than that recommended for adequate nutrition.

In contrast to the pattern of seasonal change found for potassium and phosphorus, the herbage concentration of calcium and magnesium was lowest in the spring growth of grass, and increased through late summer and fall. This is in agreement with the findings of other workers and with the results of the hay and pasture studies discussed earlier. The level of calcium was maintained through the winters of 1967 and 1968 and, in fact, the high mean value of 0.76 per cent was recorded for calcium in November 1968. This high value may have resulted from the application of dolomitic limestone to the pastures in August 1968. With the exception of the late summer and fall periods, mean magnesium concentration of the pastures fell consistently below 0.2 per cent on a dry matter basis. The lowest level of magnesium (0.06 per cent) was recorded in March 1968.

Definite seasonal fluctuations were also observed for certain of the micro-elements (Figures 16 and 17). Low concentrations of iron, aluminum, and zinc were found in the spring and early summer growth of the pastures each year. There was then a steady increase in each element to peak values in grass sampled during the winter. The level of iron never declined to values lower than the 30 p.p.m. recommended for dairy cattle feeding, but the concentration of zinc in the herbage was lower than 50 p.p.m. for much of the year. While there was a minor peak for copper in March 1968, coinciding with those of iron, aluminum, and zinc, the concentration of this element tended to remain fairly constant during the year. There was also little apparent seasonal change in the levels of manganese and boron. At no time in the year did the concentrations of copper and manganese fall beneath the levels (10 p.p.m. copper, 40 p.p.m. manganese) recommended for ruminant animals (Table 1). There was some seasonal fluctuation in the plant concentration of molybdenum, a low range of 0.65-0.66 being recorded in the period from the end of March to June, 1968. There was, however, no evidence for the type of seasonal increase reported by Hemingway (1962). Plant levels of cobalt were not determined in this study.

Effects of Fertilization. The influence of different levels and types of fertilizer on the mineral composition of hay and pasture crops has been examined in several studies. Complete data for fertilizer treatments are presented in Appendix Tables 5, 6, 7, and 8, and some of the major effects of fertilization on mineral composition are illustrated in Figures 18, 19, 20, and 21.

Figure 18 shows the effects of four levels of nitrogen (0, 50, 150, 450 lb. N/acre), and of a high level of potassium (450 lb. K_2O) and of phosphorus (450 lb. P_2O_5), on the concentration of potassium, phosphorus, calcium, and magnesium in two cuttings of tall fescue hay. Ramage **et al.** (1958) showed that, where potassium in the soil was not a limiting factor, the application of high levels of nitrogen fertilizer increased the concentration of potassium in orchardgrass. A similar effect was noted in this study, and in a subsequent experiment in which three levels of nitrogen (0, 50, 450, lb. N/acre), a high level of nitrogen with phosphorus (450 lb. N + 200 lb. P), and high levels of potassium and phosphorus (400 lb. K, 200 lb. P) were applied to tall fescue pasture (Figure 19). Results in Figure 19 are mean values for three stages of maturity within each growth period. In every growth period, increasing levels of nitrogen markedly increased the concentration of potassium in the grass over that in either the unfertilized fescue, or in the fescue treated with potassium or phosphorus alone. When compared with the control treatment, the tall fescue, in fact, showed little or no response in potassium uptake to the application of a high level of potassium fertilizer.

There was a tendency, particularly in tall fescue pasture, for increasing levels of nitrogen to depress the plant content of phosphorus, but this was not noted in the first cutting of fescue hay. In each growth period, the highest con-

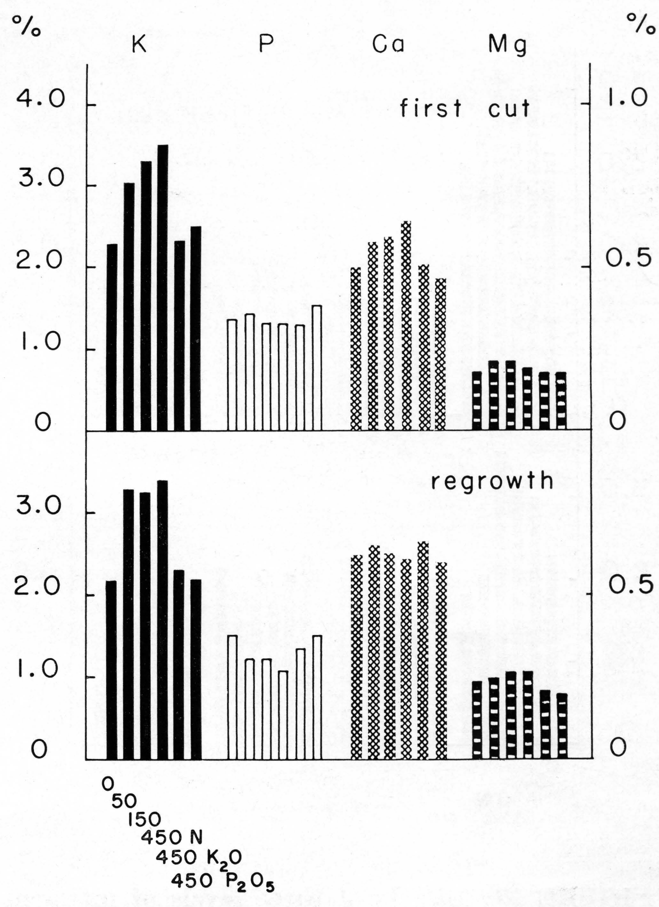

FIGURE 18. Effects of four levels of nitrogen (0, 50, 150, 450 lb. N per acre), and a high level of potassium and phosphorus fertilizer, on the concentration of potassium, phosphorus, calcium, and magnesium in two cuttings of tall fescue hay.

centration of phosphorus in the grass was obtained with the treatment of superphosphate alone. In the first cutting of fescue hay, and in the May-June sampling periods for fescue pasture, there was an increase in calcium concentration in the grass in response to increasing levels of nitrogen fertilization. This effect was not observed in the regrowth periods. There was some increase in magnesium at higher levels of nitrogen application in both cuttings of tall fescue hay, but this effect was not marked, nor was it apparent in the fescue pasture study. Instances of ion antagonism have been noted by different workers. Potassium fertilization depressed the uptake of calcium at each growth stage in tall fescue pasture, but had no apparent consistent effect on the plant content of magnesium or sodium. While sodium concentrations were low in all periods, there was a consistent increase in sodium level in both hay cuttings and herbage in response to increased levels of nitrogen fertilization.

Similar effects of different levels of nitrogen on the plant concentration of major elements were found in trials with orchardgrass hay and with orchardgrass pasture (Appendix Tables 6 and 8). With increasing nitrogen, there was an increase in plant potassium, a depression in phosphorus, and a variable effect on calcium and magnesium. In the first cutting of orchard-

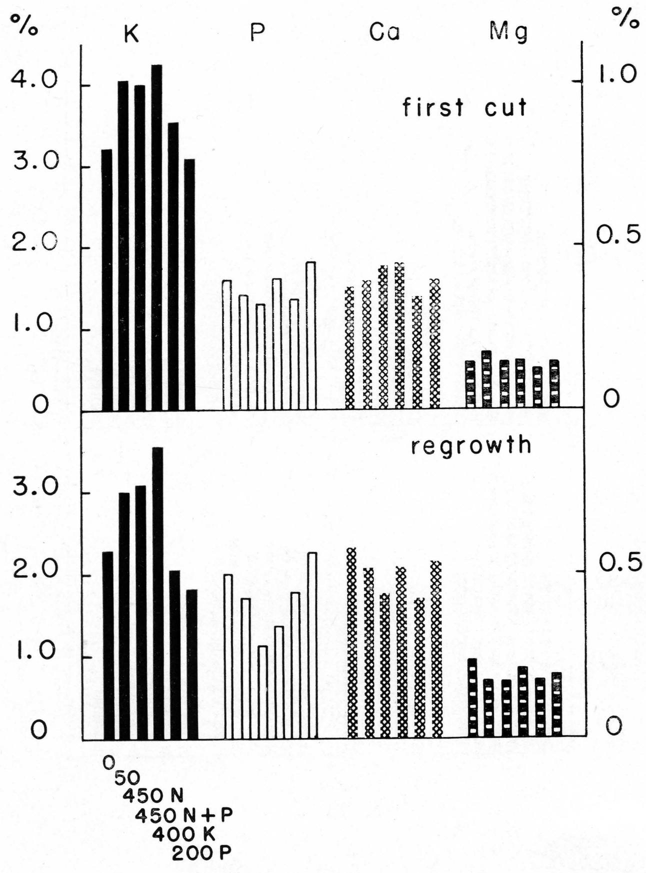

FIGURE 19. Effects of three levels of nitrogen (0, 50, 450 lb. N per acre), a high level of nitrogen + phosphorus, and high levels of potassium and phosphorus, on the content of potassium, phosphorus, calcium, and magnesium in tall fescue pasture. Data represent mean values for three stages of maturity in each growth period.

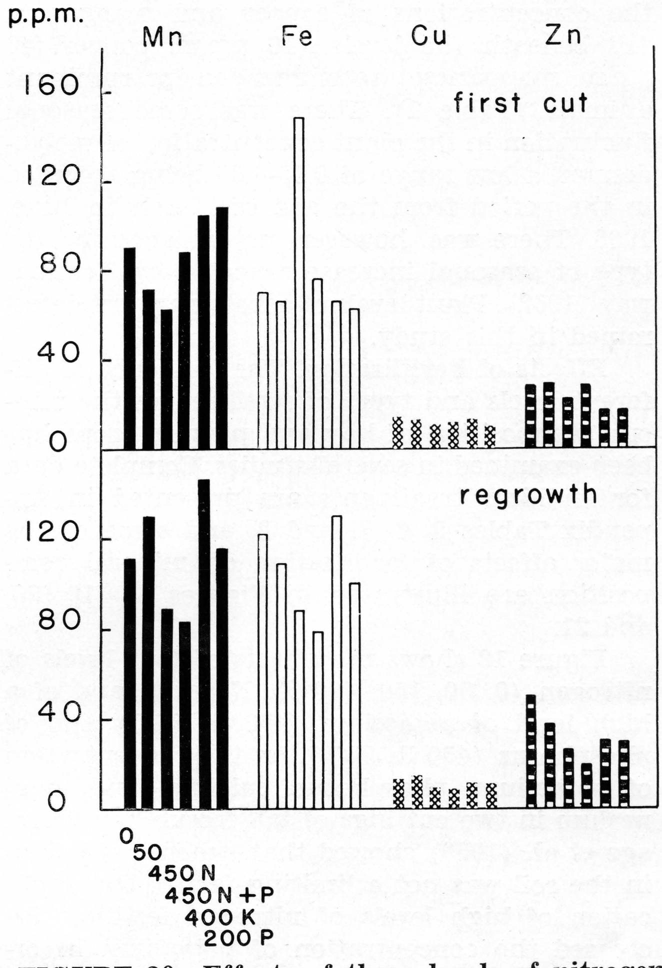

FIGURE 20. Effects of three levels of nitrogen (0, 50, 450 lb. N per acre), a high level of nitrogen + phosphorus, and high levels of potassium and phosphorus, on the concentration of manganese, iron, copper, and zinc in tall fescue pasture. Data represent mean values for three stages of maturity in each growth period.

grass hay, magnesium increased from a concentration of 0.12 per cent in the unfertilized treatment to 0.17 per cent at 400 lb. nitrogen per acre. In the first growth of orchardgrass pasture, the content of magnesium increased from 0.14 per cent for zero fertilization to 0.20 per cent at a level of 450 lb. nitrogen. Similar changes were observed in the regrowth herbage. Nitrogen increased the calcium content of the early pasture growth in May, but had no marked effect on the regrowth sampled in June and September.

Whitehead (1966) has concluded that fertilization has comparatively little influence on the micro-element concentration of herbage, apart from effects brought about by changes in soil pH. The levels of certain micro-elements under different fertilization treatment are summarized graphically for the tall fescue pasture study in Figures 20 and 21. Considering these results, and the complete micro-element data recorded in Appendix Tables 5, 6, 7, and 8, it may be concluded that level of nitrogen, or treatment with potassium or phosphorus, had no consistent effect on the plant concentration of manganese, iron, boron, copper, zinc, aluminum, strontium, molybdenum, cobalt, or barium.

Finally, the results of an experiment in which nitrogen was applied to cuttings of orchardgrass hay at equal levels (100 lb. nitrogen per acre) but in different forms, may be considered. The fertilizers used were sodium nitrate, ammonium nitrate, ammonium sulfate, diam-

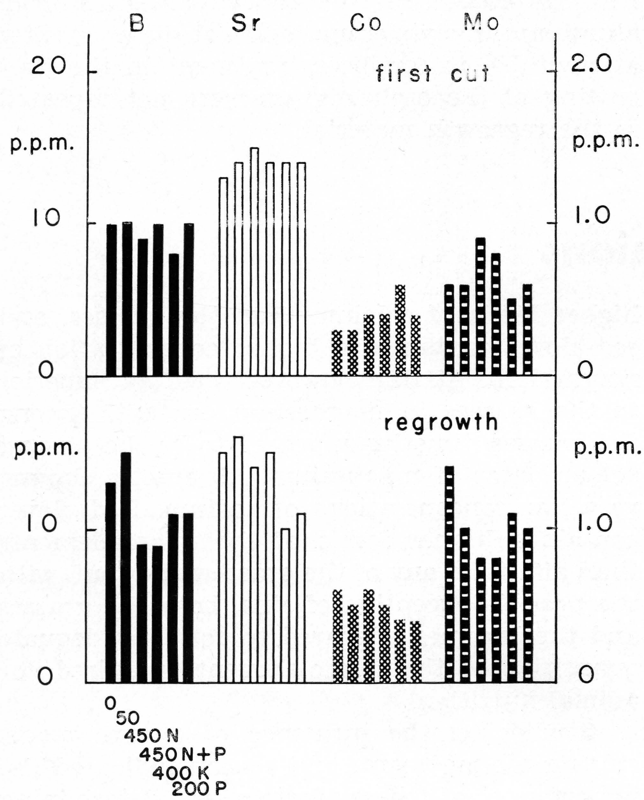

FIGURE 21. Effects of three levels of nitrogen (0, 50, 450 lb. N per acre), a high level of nitrogen + phosphorus, and high levels of potassium and phosphorus, on the concentration of boron, strontium, cobalt, and molybdenum in tall fescue pasture. Data represent mean values for three stages of maturity in each growth period.

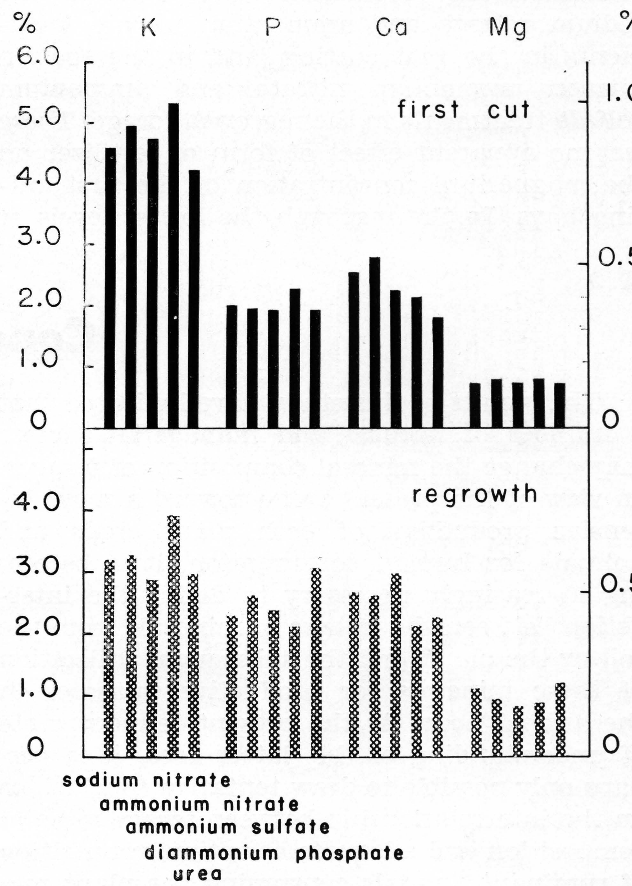

FIGURE 22. Effects of applying nitrogen at equal levels (100 lb. N per acre), but in the form of sodium nitrate, ammonium nitrate, ammonium sulfate, diammonium phosphate, or urea, on the content of potassium, phosphorus, calcium, and magnesium in two cuttings of orchardgrass hay.

monium phosphate, and urea. The effects of these treatments on the content of potassium, phosphorus, calcium, and magnesium in orchardgrass are illustrated in Figure 22, and complete data are given in Appendix Table 6.

In both cuttings of the orchardgrass hay the highest level of potassium was obtained in the forage treated with diammonium phosphate, although the reason for this effect is not apparent. A response in phosphorus uptake to the application of diammonium phosphate was noted in the first cutting of hay, but not in the regrowth. Several authors (Wolton, 1960; Nielson and Cunningham, 1964; Kershaw and Banton, 1965) have recorded an effect of the ammonium vs. nitrate ion on plant uptake of calcium and magnesium. In this study, higher concentrations of calcium were found in the sodium nitrate and ammonium nitrate treatments in the first cutting, and in the sodium nitrate, ammonium nitrate, and ammonium sulfate treatments in the regrowth forage. There was no apparent effect of form of fertilizer on the magnesium concentration of the first cutting hays. In the regrowth the lowest levels of magnesium were obtained on the ammonium sulfate and diammonium phosphate treatments. In both cuttings there was an increase in the concentration of plant sodium when nitrogen was applied in the form of sodium nitrate.

There was a consistent effect of fertilizer treatment on the concentration of manganese in the first cutting and regrowth forage. Manganese increased in the order, sodium nitrate, ammonium nitrate, ammonium sulfate, urea, and diammonium phosphate. Copper was present in highest amount on the sodium nitrate and diammonium phosphate treatments, and strontium in lowest concentration with urea fertilizer. In both cuttings, the highest level of barium was found where the grass had been treated with sodium nitrate. With these exceptions there were no clear-cut and consistent effects of form of fertilizer on the micro-element content of both cuttings of the orchardgrass hay. Differences in the concentration of iron, aluminum, molybdenum, and cobalt apparently attributable to fertilizer treatment in the first cutting of the orchardgrass were not repeated in the regrowth material.

Conclusions

The results of this study have indicated that a number of natural and managerial factors may change the mineral composition of forages. In view of the present trend toward a more intensive production of both plant crops and animals for human consumption, it is becoming increasingly necessary to define the interaction between the uptake of minerals from the soil by the plant, and the subsequent utilization of these minerals for productive purposes in the animal body. At the present tenuous state of understanding of this latter area, it is perhaps only possible to draw tentative conclusions on the interrelationship between forage mineral composition and adequate or optimum nutrition of ruminant animals consuming the plant material.

The first phase of this work indicated that grass and legume species commonly used in pasture and hay production in West Virginia may differ in their relative content of mineral elements. The legumes contained consistently higher levels of calcium than the grasses, and red clover contained a higher concentration of magnesium. Alfalfa, however, was not superior to the grasses in magnesium content. Among the grasses, timothy appeared to be the poorest accumulator of magnesium. All species showed very low concentrations of sodium. Red clover contained higher levels of the micro-elements than alfalfa or any of the grass species but, with the possible exception of zinc, both the grasses and the legumes appeared to contain adequate quantities of the micro-elements required for animal nutrition.

Studies on the influence of growth stage, cutting management, and season indicated the importance of these factors in determining mineral composition. Within the first growth period there was a steady decline in the concentration of most of the major elements, although the rate of decline varied with species. In most cases, the rate of decrease resulted in critically low concentrations of phosphorus, calcium, and magnesium in the plant at the more advanced stages of maturity, particularly in the grasses. While several of the micro-elements also showed a regular decrease in concentration with advancing maturity, the lowest values recorded still generally exceeded the levels considered adequate for feeding livestock. It should, however, be emphasized again that little experimental evidence has been available to define what are nutritionally adequate concentrations of micro-elements in the diet.

Marked seasonal effects on mineral composition were noted in both hay and pasture trials. Regrowth cuttings of grass hays were shown to contain higher levels of calcium and magnesium, and lower concentrations of potassium, than first growth cuttings. The concentration of phosphorus was affected relatively little by cutting management, and there was a variable effect of cutting on individual micro-element concentrations. In a pasture experiment in which orchardgrass herbage was sampled at regular intervals during a period of two years, cyclic changes in both major and minor elements were observed. Potassium and phosphorus concentrations increased to peak values in spring herbage and thereafter showed a regular decline into the fall and winter periods. The calcium and magnesium content of the grass, on the other hand, was lowest in the spring growth and increased during the periods of summer and fall. Cyclic changes were also observed in certain of the micro-elements, for example, iron, aluminum, and zinc, while the concentration of other micro-elements such as manganese and copper tended to remain rather constant. It was again apparent in this study that for considerable periods of the year the levels of phosphorus, calcium, magnesium, and sodium, and possibly zinc, would have been inadequate by published standards for the adequate nutrition of grazing ruminant animals receiving no mineral supplement.

The influence of different rates and forms of nitrogen fertilizer, and, to a limited extent, of potassium and phosphorus fertilization, was determined in a number of trials with grass hays and pasture. Such effects must be considered to be of special importance in future years as it becomes increasingly necessary to produce higher yields of quality forage from marginal land areas. With adequate potassium status of the soil, increased levels of nitrogen fertilization consistently increased the potassium content of the herbage, but also showed a tendency to depress phosphorus concentration. While the effects of nitrogen fertilization on the calcium and magnesium status of the plant were not consistent from year to year or trial to trial, there was frequently an increase in concentration of these elements in response to nitrogen fertilization. A similar increase in magnesium concentration in orchardgrass pastures at high levels of nitrogen application has been observed in current grazing trials, and this effect is particularly significant in a state where hypomagesemic tetany in ruminant animals is a recurring problem. Nitrogen fertilization, or treatment with potassium or phosphatic fertilizers, had little apparent effect on the micro-element concentration of the forages studied.

The implication of these studies in relation to the nutrition of ruminant animals fed primarily forage diets must await further definition of the utilization and mineral requirements of livestock. It has been shown that, by present standards, certain minerals may be present in forages at potentially limiting levels for efficient animal production, and that the mineral concentration of hay crops and pastures may be altered by a number of factors. Extension of such studies to a wider range of soil types and climatic situations should help to define more clearly the mineral status of forage crops grown in West Virginia, to identify areas where deficiencies of either major or minor elements may exist, and to relate such conditions to the occurrence of metabolic disturbance and impaired productivity in ruminant animals consuming forage.

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APPENDIX TABLE 1

Trial Date, Stage of Maturity, Height of Stand, and Dry Matter Yield of Forage Species Harvested in 1960

Species	Trial Date	Stage of Maturity		Height of Plant (inches)	Dry Matter Yield (tons per acre)
Tall fescue (Kentucky 31)	May 9-May 16	vegetative		10-14	0.61
	May 17-May 24	late boot	1st	14-18	0.59
	May 28-June 3	full bloom	growth	18	0.63
	June 25-July 2	seed formation		18	0.50
	July 23-July 30	vegetative	2nd	8-10	0.28
	August 8-August 15	vegetative	growth	8-10	0.57
	August 20-August 27	vegetative		14-16	0.97
Timothy (common)	May 9-May 16	vegetative		12	0.73
	May 17-May 24	jointing		16	1.09
	May 28-June 3	heads in boot	1st	22	1.57
	June 10-June 17	heading	growth	32	2.69
	June 25-July 2	full bloom		32	2.14
	July 9-July 16	60% heads mature		42	1.63
	August 8-August 15	vegetative	2nd	12-14	0.37
	August 20-August 27	vegetative	growth	12-14	0.57
Alfalfa (Narragansett)	May 9-May 16	vegetative		14	0.82
	May 17-May 24	bud	1st	16	1.32
	May 28-June 3	early bloom	growth	21	1.66
	June 10-June 17	late bloom		26	2.22
	June 25-July 2	seed formation		30	1.81
	July 23-July 30	bud	2nd	13-14	0.55
	August 8-August 15	early bloom	growth	17	0.93
	August 20-August 27	early bloom	3rd growth	20-22	0.89
Red clover (Dollard)	May 9-May 16	vegetative		10-12	0.80
	May 17-May 24	bud	1st	16	1.11
	May 28-June 3	early bloom	growth	22	1.65
	June 10-June 7	full bloom		26	2.33
	June 25-July 2	early seed formation		24	2.22
	July 23-July 30	early bloom	2nd	12-14	0.42
	August 8-August 15	full bloom	growth	17-18	0.75
	August 20-August 27	late bloom		22	1.27

APPENDIX TABLE 2

Trial Date, Stage of Maturity, Height of Stand, and Dry Matter Yield of Forage Species Harvested in 1961

Species	Trial Date	Stage of Maturity		Height of Plant (inches)	Dry Matter Yield (tons per acre)
Orchardgrass	May 4-May 11	vegetative		12-17	0.91
(Potomac)	May 12-May 19	late boot		24	2.11
	May 22-May 29	headed	1st	35	2.56
	June 4-June 10	early bloom	growth	38	2.78
	June 13-June 20	late bloom		40	2.51
	June 22-June 29	past bloom (seed)		42	3.32
	July 10-July 16	seed mature		48	3.37
	June 22-June 29	vegetative	2nd	13-15	0.42
	July 1-July 7	vegetative	growth	12-15	0.34
	July 20-July 26	vegetative	3rd	10-14	0.24
	July 31-August 6	vegetative	growth	14	0.40
	Sept. 6-Sept. 12	vegetative	4th growth	14-17	1.14
Bromegrass	May 4-May 11	vegetative		12-17	1.04
(Lincoln)	May 12-May 19	late boot		30	2.02
	May 22-May 29	early head	1st	34	1.90
	June 4-June 10	full head	growth	36-42	3.11
	June 13-June 20	40% bloom		40-48	2.98
	June 22-June 29	past bloom		44	3.34
	July 10-July 16	seed mature		40-48	3.69
	July 1-July 7	vegetative	2nd	12	0.43
	July 10-July 16	vegetative	growth	10-15	0.49
	August 10-August 16	vegetative	3rd	12	0.50
	August 23-August 29	vegetative	growth	12-14	0.52
	Sept. 6-Sept. 12	vegetative	4th growth	12-14	1.00
Tall fescue	May 4-May 11	vegetative		12-14	1.00
(Kentucky 31)	May 12-May 19	boot		18-20	1.00
	May 22-May 29	heading	1st	24-30	2.04
	June 4-June 10	early bloom	growth	37	2.29
	June 13-June 20	50% bloom		36-39	1.94
	June 22-June 29	past bloom		40	2.39
	July 20-July 26	seed mature		40	1.89
	July 1-July 7	vegetative	2nd	15	0.61
	July 10-July 16	vegetative	growth	15	0.89
	July 20-July 26	vegetative		15	1.02
Timothy	May 4-May 11	vegetative		12-15	1.09
(common)	May 12-May 19	vegetative		24	1.31
	May 22-May 29	early boot	1st	30	1.37
	June 4-June 10	boot	growth	36	2.49
	June 13-June 20	headed		36	2.81
	July 1-July 7	mature		36	3.56
	July 1-July 7	vegetative	2nd	15	0.64
	July 20-July 26	vegetative	growth	16	0.44
	July 31-August 6	vegetative	3rd growth	12	0.44

(Continued on Page 28)

APPENDIX TABLE 2 (Continued)

Species	Trial Date	Stage of Maturity		Height of Plant (inches)	Dry Matter Yield (tons per acre)
Sudangrass	July 10-July 16	vegetative		30-36	0.92
(Piper)	July 20-July 26	boot		60	1.61
100 lb. N/acre	July 31-August 6	early bloom	1st	84-96	2.77
	August 10-August 16	full bloom	growth	84-96	2.96
	August 23-August 29	early seed		84-96	4.20
	Sept. 6-Sept. 12	seed formed		84-96	4.52
	July 31-August 6	vegetative		36	1.50
	August 10-August 16	vegetative	2nd	42-48	1.45
	August 23-August 29	vegetative	growth	48-54	1.34
	Sept. 6-Sept. 12	boot		60	1.44
Sudangrass	July 10-July 16	vegetative		30	0.60
(Piper)	July 20-July 26	boot		60	2.29
300 lb. N/acre	July 31-August 6	early bloom	1st	84	1.90
	August 10-August 16	full bloom	growth	84-96	4.03
	August 23-August 29	early seed		84-96	5.00
	Sept. 6-Sept. 12	seed formed		84-96	4.52
	July 31-August 6	vegetative		36	1.45
	August 10-August 16	vegetative	2nd	48-54	1.55
	August 23-August 29	boot	growth	60	2.21
	Sept. 6-Sept. 12	heads in boot		60-72	1.59
Alfalfa	May 12-May 19	vegetative		20	1.48
(Narragansett)	May 22-May 29	bud		20	1.34
	June 4-June 10	early bloom	1st	28	1.96
	June 13-June 20	25% bloom	growth	28	1.55
	June 22-June 29	full bloom		33	2.17
	July 1-July 7	seed		35	1.76
	June 22-June 29	early bud	2nd	20	0.90
	July 1-July 7	50% bloom	growth	26	2.13
	July 10-July 16	10% bloom	3rd	24	1.80
	July 20-July 26	50% bloom	growth	26	1.85
	July 31-August 6	60-70% bloom		28	1.70

APPENDIX TABLE 3

Mineral Composition of Grass and Legume Species Harvested in 1960

Species and Growth Stage	%						p.p.m.								
	K	P	Ca	Mg	Na	Si	Mn	Fe	B	Cu	Zn	Al	Sr	Mo	Ba
Tall fescue (Kentucky 31)															
vegetative	2.83	0.39	0.54	0.19	<0.01	0.36	108	334	11	20	52	640	33	0.84	18
late boot	2.71	0.32	0.46	0.17	<0.01	0.22	105	167	10	23	34	248	33	0.84	16
full bloom	2.36	0.32	0.43	0.17	<0.01	0.22	103	190	10	28	38	270	32	0.80	16
seed formation	2.09	0.35	0.32	0.17	0.01	0.15	81	139	11	31	36	176	28	0.79	18
vegetative, regrowth	3.71	0.41	0.51	0.27	0.01	0.18	122	213	9	32	45	258	36	0.78	15
vegetative, regrowth	3.17	0.42	0.36	0.21	<0.01	0.26	101	200	8	40	44	229	26	0.75	13
vegetative, regrowth	3.68	0.41	0.41	0.21	0.01	0.21	109	151	8	22	38	125	34	0.77	17
Timothy (common)															
vegetative	3.00	0.34	0.61	0.11	<0.01	0.36	125	1032	16	17	75	1073	27	0.74	23
jointing	3.40	0.51	0.48	0.12	<0.01	0.08	107	170	12	24	98	142	28	0.85	20
heads in boot	3.74	0.46	0.44	0.11	<0.01	0.13	86	349	12	27	78	852	28	0.71	27
heading	3.89	0.36	0.47	0.11	<0.01	0.12	103	206	11	64	62	388	35	0.69	30
full bloom	2.73	0.26	0.37	0.08	<0.01	0.09	105	122	12	53	54	122	27	0.64	28
60% heads mature	1.79	0.19	0.35	0.07	<0.01	0.09	53	132	9	52	42	249	22	0.53	30
vegetative, regrowth	2.98	0.38	0.50	0.12	<0.01	0.17	96	320	13	45	68	470	26	0.75	30
vegetative, regrowth	2.53	0.38	0.53	0.14	<0.01	0.20	88	269	13	52	67	475	22	0.96	40
Alfalfa (Narragansett)															
vegetative	2.96	0.33	1.61	0.17	<0.01	0.08	65	361	29	26	41	702	42	0.89	27
bud	2.80	0.30	1.56	0.15	<0.01	0.07	53	320	29	22	39	540	46	0.86	24
early bloom	2.81	0.31	1.50	0.17	<0.01	0.06	52	304	28	19	39	533	45	1.03	21
late bloom	2.45	0.25	1.43	0.14	<0.01	0.03	43	170	25	14	31	245	45	0.55	26
seed formation	1.73	0.24	1.20	0.13	0.01	0.05	54	243	23	26	39	416	39	0.74	29
bud, regrowth	3.05	0.36	1.40	0.19	0.01	0.14	77	601	27	23	44	1020	44	1.00	26
early bloom, regrowth	2.76	0.31	1.07	0.14	<0.01	0.09	60	410	22	28	44	892	40	0.68	21
Red clover (Dollard)															
vegetative	3.90	0.43	1.32	0.26	<0.01	0.21	138	1441	28	40	73	1138	49	1.09	44
bud	3.30	0.35	1.20	0.24	<0.01	0.14	142	625	22	38	56	802	47	1.10	38
early bloom	3.00	0.32	1.20	0.22	<0.01	0.10	140	410	21	34	50	655	45	0.95	34
full bloom	3.26	0.32	1.26	0.23	<0.01	0.06	135	181	21	29	46	188	52	1.20	29
early seed	2.52	0.25	0.90	0.16	<0.01	0.07	131	189	17	45	48	299	42	0.84	37
early bloom, regrowth	2.23	0.29	1.03	0.20	<0.01	0.16	151	536	19	37	56	1018	41	0.92	36
full bloom, regrowth	3.10	0.38	1.11	0.25	<0.01	0.12	169	389	23	37	49	963	45	1.19	34
late bloom, regrowth	2.70	0.32	0.96	0.19	<0.01	0.10	120	386	20	26	44	904	41	0.80	35

APPENDIX TABLE 4

Mineral Composition of Grass and Legume Species Harvested in 1961

	%						p.p.m									
Species and Growth Stage	**K**	**P**	**Ca**	**Mg**	**Na**	**Si**	**Mn**	**Fe**	**B**	**Cu**	**Zn**	**Al**	**Sr**	**Mo**	**Co**	**Ba**
Orchardgrass (Potomac)																
vegetative	3.86	0.55	0.39	0.12	0.02	0.30	157	308	5	18	47	273	11	0.61	0.55	16
late boot	4.09	0.55	0.38	0.14	0.03	0.26	115	126	5	16	39	153	12	0.43	0.57	15
headed	3.72	0.45	0.31	0.13	0.02	0.26	158	302	4	18	41	107	8	0.37	0.59	17
early bloom	2.91	0.34	0.27	0.11	0.01	0.25	158	93	4	19	40	88	6	0.30	0.43	16
late bloom	2.67	0.30	0.26	0.11	0.01	0.28	168	84	3	20	38	65	7	0.31	0.30	17
past bloom (early seed)	2.16	0.27	0.29	0.11	0.01	0.37	173	235	3	18	37	129	5	0.27	0.85	24
seed mature	2.33	0.25	0.29	0.10	0.02	0.31	201	91	3	15	33	102	7	0.25	0.34	23
vegetative, regrowth	3.35	0.46	0.50	0.13	0.02	0.40	168	221	5	17	48	278	12	0.34	0.29	22
vegetative, regrowth	2.73	0.43	0.39	0.13	0.01	0.43	171	200	4	13	40	315	11	0.38	0.37	20
vegetative, regrowth	3.50	0.55	0.49	0.15	<0.01	0.40	189	165	5	16	32	219	9	0.42	0.48	23
vegetative, regrowth	3.12	0.58	0.67	0.17	0.01	0.42	177	172	6	14	44	267	10	0.43	0.50	22
vegetative, regrowth	3.16	0.51	0.45	0.16	0.02	0.37	144	148	5	14	33	173	11	0.38	0.61	22
Bromegrass (Lincoln)																
vegetative	3.19	0.44	0.45	<0.10	0.01	0.58	63	470	5	20	48	555	16	0.77	0.59	14
late boot	3.41	0.46	0.50	0.10	0.01	0.42	57	131	5	20	36	157	19	0.40	0.72	10
early head	2.89	0.40	0.39	0.10	0.01	0.38	57	369	4	23	32	87	9	0.46	0.44	10
full head	2.42	0.30	0.32	<0.10	0.01	0.30	41	89	3	24	40	79	9	0.27	0.58	9
40% bloom	1.99	0.28	0.29	<0.10	0.01	0.31	40	91	3	25	30	72	9	0.24	0.58	8
past bloom	2.02	0.28	0.30	<0.10	0.01	0.40	46	228	0	20	29	167	8	0.42	0.96	12
seed mature	1.55	0.21	0.15	<0.10	<0.01	0.21	41	60	2	14	24	106	4	0.00	0.23	7
vegetative, regrowth	2.42	0.38	0.55	0.11	0.01	0.63	71	184	6	19	36	269	14	0.52	0.59	18
vegetative, regrowth	2.63	0.43	0.53	0.12	0.01	0.59	90	168	5	21	39	242	14	0.50	0.65	18
vegetative, regrowth	2.91	0.41	0.67	0.14	0.01	0.45	105	122	8	12	33	192	20	0.44	0.61	19
vegetative, regrowth	2.63	0.45	0.66	0.16	0.01	0.50	96	102	7	13	38	140	24	0.45	0.66	21
vegetative, regrowth	2.45	0.48	0.41	0.17	0.01	0.56	93	282	6	15	53	315	13	0.61	0.58	22
Tall fescue (Kentucky 31)																
vegetative	1.88	0.62	0.80	0.29	<0.01	0.33	224	645	18	16	62	1002	23	1.93		25
boot	2.42	0.47	0.50	0.20	<0.01	0.26	177	359	12	12	44	704	26	1.13		20
heading	2.69	0.47	0.53	0.21	0.01	0.24	176	444	13	17	48	472	33	1.06		20
early bloom	1.96	0.26	0.38	0.12	0.02	0.19	81	243	10	17	35	461	31	0.72		17
50% bloom	2.06	0.29	0.45	0.17	<0.01	0.18	104	156	11	25	36	106	33	0.80		20
past bloom	1.80	0.30	0.48	0.14	<0.01	0.15	113	156	10	20	36	108	33	0.85		26
seed mature	1.82	0.25	0.50	0.14	0.02	0.21	113	126	10	13	34	216	39	0.69		29
vegetative, regrowth	2.60	0.43	0.45	0.22	<0.01	0.21	129	215	12	16	38	244	29	1.36		19
vegetative, regrowth	2.56	0.41	0.45	0.20	<0.01	0.16	152	148	10	46	37	198	34	0.91		18
vegetative, regrowth	2.08	0.40	0.45	0.20	<0.01	0.20	142	116	9	17	28	106	24	1.03		18

Timothy (common)																
vegetative	3.37	0.46	0.39	0.11	<0.01	0.09	97	206	12	25	62	214	29	0.72		15
vegetative	3.52	0.42	0.42	0.11	<0.01	0.09	72	140	10	24	41	179	32	0.58		15
early boot	3.35	0.36	0.34	0.09	<0.01	0.08	92	301	11	29	44	42	31	0.56		18
boot	3.06	0.34	0.35	0.09	<0.01	0.09	71	147	9	23	48	145	32	0.59		23
headed	2.28	0.27	0.30	0.08	<0.01	0.08	66	106	11	27	43	86	30	0.65		22
mature	1.61	0.21	0.25	0.06	<0.01	0.09	59	115	10	26	39	79	23	0.57		24
vegetative, regrowth	2.92	0.41	0.49	0.14	<0.01	0.23	169	259	13	25	51	426	36	0.84		27
vegetative, regrowth	2.45	0.39	0.44	0.11	<0.01	0.15	113	199	14	24	45	297	27	0.70		25
vegetative, regrowth	2.41	0.38	0.40	0.13	<0.01	0.19	149	334	13	20	46	834	31	0.91		31
Sudangrass (Piper)																
vegetative	3.24	0.36	0.69	0.21	<0.01	0.23	79	629	15	35	50	1093	35	1.04		23
boot	3.22	0.28	0.41	0.14	<0.01	0.17	49	417	12	51	61	940	40	0.62		17
early bloom	1.91	0.31	0.35	0.18	<0.01	0.14	41	216	10	21	39	498	22	0.84		15
full bloom	1.59	0.30	0.40	0.17	<0.01	0.12	50	207	12	17	37	409	23	1.08		17
early seed	2.01	0.28	0.39	0.14	<0.01	0.10	42	661	15	21	34	1046	35	0.70		18
seed formed	1.82	0.29	0.34	0.12	<0.01	0.08	38	287	10	49	60	444	28	0.75		19
vegetative, regrowth	2.71	0.44	0.58	0.26	0.03	0.94	194	404	24	37	54	1084	22	1.68		32
vegetative, regrowth	2.67	0.40	0.41	0.17	<0.01	0.21	71	298	10	26	39	506	21	0.84		19
vegetative, regrowth	2.75	0.41	0.39	0.18	<0.01	0.18	58	254	11	22	39	234	28	0.96		17
boot, regrowth	2.11	0.34	0.32	0.15	<0.01	0.12	43	122	8	20	38	106	20	0.79		15
Alfalfa (Narragansett)																
vegetative	3.98	0.60	1.22	0.17	0.02	0.17	55	295	59	14	58	344	22	0.69	0.81	22
bud	4.00	0.48	1.27	0.18	0.02	0.09	53	257	24	15	64	185	26	0.41	0.87	23
early bloom	3.38	0.41	0.98	0.12	0.02	0.18	44	165	15	15	34	190	24	0.54	0.61	19
25% bloom	2.65	0.42	0.97	0.11	0.02	0.21	56	108	12	20	30	89	14	0.36	0.73	22
full bloom	2.88	0.40	0.97	0.11	0.02	0.13	51	186	16	14	30	139	22	0.35	0.65	26
seed	2.30	0.25	0.70	0.08	0.01	0.23	44	121	12	14	27	182	16	0.34	0.72	21
early bud, regrowth	3.73	0.54	1.07	0.17	0.02	0.21	70	359	18	16	45	279	24	0.58	0.75	29
50% bloom, regrowth	3.40	0.47	1.10	0.16	0.01	0.18	62	188	19	17	47	208	23	0.44	0.76	24
10% bloom, regrowth	3.14	0.45	1.10	0.16	0.02	0.19	61	175	17	20	41	202	23	0.59	1.04	24
50% bloom, regrowth	3.10	0.39	1.11	0.12	0.02	0.11	49	118	17	15	39	139	30	0.32	0.69	19
60-70% bloom, regrowth	2.82	0.39	1.08	0.13	0.02	0.34	59	300	18	24	50	330	20	0.99	0.94	24

APPENDIX TABLE 5

Mineral Composition of Cuttings of Tall Fescue Hay Harvested in 1963

	%					p.p.m.										
Forage Treatment	**K**	**P**	**Ca**	**Mg**	**Si**	**Mn**	**Fe**	**B**	**Cu**	**Zn**	**Al**	**Sr**	**Mo**	**Co**	**Na**	**Ba**
Tall fescue (1st cutting)																
high nitrogen	3.49	0.32	0.64	0.19	0.49	69	157	10	15	29	160	16	0.4	0.2	344	16
medium nitrogen	3.33	0.34	0.59	0.21	0.66	74	250	10	15	30	310	15	1.3	1.2	348	16
low nitrogen	3.02	0.35	0.57	0.21	0.57	82	171	10	13	30	220	14	1.0	1.2	333	16
control	2.29	0.34	0.50	0.17	0.59	75	181	10	17	28	219	13	0.9	1.1	258	14
high potassium	2.33	0.32	0.51	0.17	0.55	75	119	10	16	25	163	12	0.7	1.6	297	14
high phosphorus	2.50	0.38	0.46	0.17	0.43	62	94	10	14	26	129	10	0.7	1.7	273	10
Tall fescue (regrowth)																
high nitrogen	3.40	0.26	0.61	0.26	0.68	90	149	10	18	25	195	15	1.1	1.8	400	16
medium nitrogen	3.24	0.30	0.62	0.26	0.70	81	225	10	14	25	278	16	1.2	1.4	327	18
low nitrogen	3.28	0.30	0.65	0.24	0.65	95	176	10	14	26	195	17	0.8	0.5	290	19
control	2.18	0.37	0.62	0.23	0.74	93	88	10	4	22	131	15	0.6	0.5	171	15
high potassium	2.30	0.33	0.66	0.21	0.74	115	136	10	7	23	183	16	0.6	0.4	163	22
high phosphorus	2.08	0.37	0.60	0.19	0.67	113	101	10	3	22	138	13	0.8	0.4	160	17

APPENDIX TABLE 6

Mineral Composition of Cuttings of Orchardgrass Hay Harvested in 1964

Date of		%						p.p.m.									
Cutting	**Fertilizer Treatment**	**K**	**P**	**Ca**	**Mg**	**Na**	**Si**	**Mn**	**Fe**	**B**	**Cu**	**Zn**	**Al**	**Sr**	**Mo**	**Co**	**Ba**
May 16, 1964	lb. N/acre																
	0 Urea	3.24	0.37	0.39	0.12	0.04	0.24	146	88	13	17	25	97	13	0.6	0.4	8
	50 Urea	4.25	0.38	0.36	0.13	0.06	0.26	111	202	9	23	22	232	14	0.7	0.6	9
	100 Urea	4.25	0.37	0.34	0.14	0.07	0.32	166	181	10	14	30	309	12	0.9	0.3	11
	400 Urea	4.81	0.34	0.40	0.17	0.08	0.25	83	113	8	16	20	66	17	0.6	0.5	10
	100 Sodium nitrate	4.58	0.38	0.48	0.14	0.12	0.20	75	74	12	16	24	35	18	0.6	0.5	20
	100 Ammonium nitrate	4.95	0.37	0.52	0.15	0.06	0.21	93	136	13	12	23	43	19	0.5	0.4	17
	100 Ammonium sulfate	4.76	0.37	0.41	0.14	0.11	0.35	111	161	12	15	29	143	14	0.9	0.7	11
	100 Diammonium phosphate	5.32	0.42	0.40	0.15	0.07	0.46	191	285	12	16	25	629	15	1.2	0.3	11
	100 Urea	4.25	0.37	0.34	0.14	0.07	0.32	166	181	10	14	30	309	12	0.9	0.3	11
July 20, 1964	0 Urea	3.78	0.57	0.56	0.17	0.05	0.40	161	115	17	15	32	294	16	1.6	0.3	14
	50 Urea	3.93	0.58	0.55	0.20	0.03	0.34	101	92	18	17	35	120	16	1.4	0.6	10
	100 Urea	2.91	0.58	0.42	0.22	0.02	0.39	169	83	14	12	31	168	9	1.2	0.9	10
	200 Urea	4.06	0.55	0.44	0.18	0.03	0.26	128	46	13	14	23	21	14	0.9	0.5	10
	400 Urea	5.07	0.51	0.57	0.20	0.07	0.25	123	65	14	18	23	23	25	1.1	0.7	12
	100 Sodium nitrate	3.19	0.43	0.50	0.21	0.08	0.33	143	52	12	16	18	29	14	0.7	0.6	17
	100 Ammonium nitrate	3.25	0.49	0.49	0.18	0.02	0.42	159	69	12	13	32	105	12	0.5	0.2	12
	100 Ammonium sulfate	2.86	0.46	0.56	0.16	0.02	0.42	169	51	16	14	29	37	13	0.7	0.6	11
	100 Diammonium phosphate	3.92	0.39	0.40	0.17	0.04	0.27	188	47	11	17	19	21	15	0.5	0.2	13
	100 Urea	2.91	0.58	0.42	0.22	0.02	0.39	169	83	14	12	31	168	9	1.2	0.9	10

APPENDIX TABLE 7

Mineral Composition of Tall Fescue Pasture Treatments in 1964

Trial Date and Growth Stage	Treatment (lb. N/acre)	%						p.p.m.									
		K	P	Ca	Mg	Na	Si	Mn	Fe	B	Cu	Zn	Al	Sr	Mo	Co	Ba
May 5-9	450 N	5.03	0.40	0.54	0.15	0.06	0.15	53	78	10	10	23	34	16	0.7	0.3	9
vegetative	450 N + 200 P	5.36	0.45	0.46	0.15	0.06	0.17	63	77	10	11	30	40	14	0.6	0.4	9
	50 N	5.12	0.42	0.44	0.16	0.05	0.27	51	81	10	10	23	56	17	0.6	0.3	11
	0	3.49	0.40	0.49	0.16	0.04	0.46	106	101	12	17	38	140	12	0.7	0.3	12
	400 K	4.41	0.38	0.39	0.13	0.05	0.20	136	70	9	9	17	58	17	0.4	0.5	34
	200 P	3.86	0.63	0.49	0.17	0.06	0.29	122	81	11	10	18	76	17	0.8	0.7	12
May 20-24	450 N	3.63	0.34	0.39	0.14	0.06	0.19	53	61	8	11	22	32	13	0.7	0.6	10
boot-	450 N + 200 P	4.30	0.44	0.49	0.19	0.06	0.26	86	68	11	11	25	38	15	1.1	0.6	18
early	50 N	4.33	0.36	0.39	0.18	0.06	0.18	66	55	11	13	28	25	16	0.5	0.2	9
head	0	3.74	0.34	0.37	0.15	0.04	0.22	71	55	9	12	19	36	17	0.7	0.4	12
	400 K	3.48	0.35	0.35	0.13	0.05	0.16	127	50	8	11	18	31	15	0.8	1.1	25
	200 P	2.69	0.49	0.39	0.14	0.03	0.18	109	48	11	12	21	29	13	0.5	0.5	9
June 6-10	450 N	3.32	0.25	0.35	0.12	0.05	0.42	82	304	8	13	23	821	15	1.3	0.4	15
late head-	450 N + 200 P	3.07	0.31	0.36	0.12	0.06	0.19	114	83	9	14	29	88	13	0.7	0.3	17
early	50 N	2.78	0.27	0.35	0.17	0.05	0.35	98	62	9	17	37	54	10	0.6	0.4	9
bloom	0	2.46	0.25	0.29	0.12	0.03	0.23	91	55	9	12	27	45	9	0.5	0.3	11
	400 K	2.68	0.26	0.29	0.10	0.04	0.20	51	76	7	18	15	95	10	0.4	0.1	15
	200 P	2.69	0.25	0.30	0.10	0.04	0.18	94	58	7	8	12	81	11	0.4	0.1	18
July 15-19	450 N	3.31	0.28	0.52	0.19	0.07	0.41	72	111	7	9	16	116	12	0.7	0.2	14
vegetative	450 N + 200 P	3.80	0.32	0.56	0.20	0.06	0.41	67	94	6	8	14	87	12	0.6	0.1	11
regrowth	50 N	3.02	0.39	0.51	0.16	0.04	0.63	114	139	18	12	44	269	12	0.8	0.2	11
	0	2.34	0.43	0.49	0.19	0.03	0.54	102	185	13	9	31	687	12	1.3	0.3	17
	400 K	2.10	0.40	0.40	0.17	0.02	0.58	155	217	11	8	28	927	11	1.4	0.6	28
	200 P	1.84	0.52	0.50	0.15	0.02	0.41	135	121	12	8	28	303	10	1.2	0.5	16
July 27-31	450 N	3.15	0.25	0.37	0.17	0.04	0.73	102	84	10	12	33	98	15	0.5	0.3	20
vegetative	450 N + 200 P	4.34	0.34	0.40	0.19	0.05	0.23	72	55	10	11	20	25	14	0.7	0.5	15
regrowth	50 N	3.47	0.42	0.45	0.17	0.04	0.35	111	86	12	14	34	123	17	0.9	0.4	23
	0	2.35	0.59	0.71	0.26	0.02	0.64	139	109	16	9	95	193	19	1.4	0.5	27
	400 K	1.94	0.49	0.40	0.17	0.02	0.43	178	111	10	18	37	256	10	1.1	0.5	28
	200 P	1.79	0.62	0.58	0.21	0.02	0.28	128	114	12	9	28	203	15	0.9	0.6	13
Aug. 9-13	450 N	2.79	0.31	0.39	0.15	0.06	0.25	92	68	11	14	26	37	15	1.1	1.4	29
vegetative	450 N + 200 P	2.55	0.36	0.60	0.25	0.06	0.43	110	86	10	15	23	50	18	1.1	0.8	39
regrowth	50 N	2.52	0.44	0.59	0.20	0.02	0.48	165	99	15	19	32	94	19	1.3	0.9	37
	0	2.14	0.48	0.52	0.25	0.03	0.35	94	72	11	9	21	101	14	1.6	1.1	12
	400 K	2.11	0.42	0.45	0.21	0.01	0.39	105	59	11	9	25	69	9	0.8	0.2	10
	200 P	1.84	0.54	0.52	0.21	0.01	0.30	85	62	10	14	30	61	9	0.9	0.2	5

APPENDIX TABLE 8

Mineral Composition of Orchardgrass Pasture Treatments in 1965

Time of Sampling	Level of Nitrogen (lb. N/acre)	%						p.p.m.									
		K	P	Ca	Mg	Na	Si	Mn	Fe	B	Cu	Zn	Al	Sr	Mo	Co	Ba
May 13-18	0	4.01	0.43	0.39	0.14	0.02	0.24	80	66	4	16	24	52	8	0.41	0.65	14
	50	4.09	0.42	0.43	0.19	0.02	0.16	70	69	4	16	26	43	6	0.42	1.39	19
	150	3.93	0.40	0.54	0.21	0.03	0.19	77	76	4	14	26	51	7	0.47	0.90	20
	450	4.18	0.41	0.49	0.20	0.03	0.17	81	74	4	15	30	46	10	0.49	0.87	24
June 25-30	0	2.91	0.60	0.88	0.23	0.01	0.48	103	260	8	23	39	358	13	0.99	0.51	25
	50	2.94	0.38	0.83	0.25	0.01	0.36	95	184	7	26	36	238	13	0.58	0.43	34
	150	2.98	0.35	0.88	0.28	0.02	0.46	108	363	8	30	37	387	13	1.14	0.63	38
	450	3.57	0.33	0.82	0.27	0.02	0.35	99	161	6	21	32	169	16	0.62	0.43	36
Sept. 4-9	0	3.06	0.49	0.64	0.19	0.01	0.63	85	330	5	26	30	482	6	1.07	0.44	19
	50	3.05	0.40	0.58	0.21	0.02	0.39	74	157	5	27	29	193	10	0.64	0.47	23
	150	3.01	0.42	0.73	0.29	0.03	0.48	79	327	5	30	29	368	8	1.66	0.76	22
	450	3.42	0.36	0.69	0.23	0.02	0.31	69	125	5	23	29	117	11	0.49	0.66	25

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