

- I. GROWTH AND COMPOSITION OF THREE GRASSES AS AFFECTED  
BY POTASSIUM AND NITROGEN
- II. UPTAKE OF POTASSIUM AS INFLUENCED BY TEMPERATURE,  
CONCENTRATION OF SOLUTE, AND SPECIES

by

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## GENERAL INTRODUCTION

Recent experiments at the Virginia Agricultural Experiment Station and elsewhere have shown that alfalfa-orchardgrass mixtures tend to revert to orchardgrass as the potassium supply becomes limited. It was observed at the Blacksburg station that Kentucky bluegrass replaced both orchardgrass and alfalfa on a four year old alfalfa-orchardgrass mixture on plots without potassium. This Kentucky bluegrass came from volunteer stands. It was theorized that bluegrass survives under potassium stresses better than orchardgrass or that it withdraws potassium from sources unavailable to orchardgrass.

Orchardgrass and tall fescue stands make excellent growth in Western Virginia, but bluegrass usually encroaches. This change in botanical composition of pastures might be due to differential potassium absorption among the species under low soil potassium.

The field experiment reported herein was designed primarily to determine if low soil potassium would favor bluegrass in plant associations. Information was also obtained on the competition between orchardgrass and tall fescue under different nitrogen and potassium stresses. Different levels of nitrogen were used to speed up the depletion of soil potassium and to study production of the

species. Data were collected on yield, botanical composition, chemical composition of soil and plants, and various other information as it was affected by grass species, nitrogen applications, and potassium levels.

It is known that species, particularly legumes and grasses, differ in their capacity to take up potassium. Scientists do not agree on the reason for these differences. One school of thought suggests that potassium absorption decreases as cation exchange capacity of the plant roots increases. Since cation exchange is strictly a chemical phenomenon, it seems that it should be changed very little by small changes in temperature, respiration rate, and other factors which affect the physiological condition of plants. Recent work dealing with ion carriers suggests a much more complex mechanism for potassium uptake than simple cation exchange.

Another school of thought suggests that the physiology of the plant is of prime importance. It further suggests that cool season grasses are competitive toward legumes for potassium in a grass-legume association because these grasses grow at a lower temperature than legumes, thus they have the first access to potassium in the spring. The same argument would apply for competition between two grasses for potassium.

The author does not discount the fact that certain

species have a greater cation exchange capacity than other species. He suggests, however, that the cation exchange capacity is a reflection of the highly dynamic physiological or biochemical activity of the plant and as such has only a secondary effect on ion uptake. More specifically the author suggests that organic acids, particularly those of the Krebs cycle, are responsible in large part for the cation exchange capacity. Physiological factors which cause the production of these acids, therefore, would control ion uptake.

Species respond differently to temperature; hence, it was anticipated that cool season species would take up more cations at cool temperatures than warm season species, while the reverse would occur at warm temperatures. The early spring growth of bluegrass, for example, may enable it to capture much of the soil potassium. Laboratory experiments were designed to test this hypothesis. Facilities and equipment for refined studies of this nature were very limiting; therefore, the technique had to be worked out, and the equipment had to be improvised to do the job. These limitations necessitated the conduction of several laboratory experiments. Since it was difficult to obtain sufficient roots of the small seeded grasses used in the field tests, larger seeded warm and cool season species were used. Legume roots have a higher cation exchange capacity than grasses; therefore,

comparisons were also made between grasses and legumes. The results of these experiments are presented under the heading of laboratory studies.

## REVIEW OF LITERATURE

**Effect of Potassium and Nitrogen Fertilizers on  
the Botanical Composition of Forages**

When grasses and legumes are grown in association on low potassium soils, the plots tend to revert to grasses and weeds. Sprague (1948), working with ladino clover-Kentucky bluegrass mixtures, reported that after six years the no potassium plots contained only one-third as much ladino clover as plots receiving 166 pounds per acre. Similar results were obtained with ladino clover-dallis grass (Brown and Rouse, 1953); alfalfa-orchardgrass (Blaser, 1955; Carter et al., 1957); ladino-orchardgrass (Carter et al., 1957); and orchardgrass-tall fescue-ladino associations (Doll, 1957). Brown and Rouse concluded that dallis grass has a greater capacity than white clover to absorb potassium from the soil, possibly due to the greater soil coverage by its fibrous root system or because it is able to absorb potassium from sources that are less available to clover. Increased potassium fertilization usually decreases the percentage of weeds in the sward (Blaser and Brady, 1950). This decrease probably applies mainly to grassy weeds (Doll, 1957), because sometimes weeds encroach on high potassium plots (Carter et al., 1957).

In a legume-grass association, increasing nitrogen rates



improves the grass stand (Blaser and Brady, 1950 and 1953; Blaser, 1955; Ward and Blaser, 1957). Blaser and Brady found that nitrogen applications are especially harmful to the legumes in the spring when grass production is at its peak. They stressed the importance of applying adequate potassium when applying nitrogen. The above workers gave the following explanation for the increase in grass due to nitrogen applications. Grass starts growth earlier in the spring than the legume associate; therefore, it has the first opportunity to absorb nutrients, including potassium. Nitrogen applications stimulate grass while they affect legumes very little. This stimulative grass production causes an even greater competition for the factors limiting growth.

Grass species differ in their capacity to compete with legumes for potassium. Gray et al. (1953) studied the competition for potassium when ladino clover was grown in association with smooth bromegrass, Kentucky bluegrass, and bentgrass. The relative compatibility was smooth bromegrass best, Kentucky bluegrass intermediate, and bentgrass poorest. They associated the different compatibilities with the cation exchange capacity of the roots of the different species. Those with high root cation exchange capacity took up less potassium and offered less competition to the ladino. It seems that the morphological differences between the three

grass species might influence compatibility more than the cation exchange capacity.

Chamblee and Lovvorn (1953) observed that alfalfa showed potassium deficiencies when grown with tall fescue but did not when grown with orchardgrass. Alfalfa growing with tall fescue analyzed 1.38 percent potassium while with orchardgrass the analysis was 1.64. They concluded that tall fescue was apparently more competitive with alfalfa for available potassium than was orchardgrass, even though orchardgrass analyzed higher in potassium than tall fescue and the yields of orchardgrass were also higher. They suggested that the root system of tall fescue was more heavily concentrated in the surface layers of the soil than the root system of orchardgrass, thus the tall fescue was more competitive to the applied potash. The cation exchange theory could not account for these differences if the figures of Drake et al. (1951) are valid. Their figures show fescue to have a greater cation exchange capacity than orchardgrass.

It has become well established that liberal rates of potassium are required to maintain stands of legumes. Recent work shows that potassium is important for the maintenance of stands of grasses, also. Parson et al. (1953), working with pure stands of orchardgrass and bromegrass, found that after three years these species accounted for more than 90 percent

of the stands on high potassium plots. On low potassium plots, however, these grasses had declined to 30 percent for orchardgrass and 10 percent for Bromegrass. Drake and Colby (1949) tested eleven common forage grasses for their relative capacity to grow on soil low in available potassium. Kentucky bluegrass produced the highest yields. Assigning a value of 100 to the bluegrass the relative yields for the other grasses were: timothy, 91; Reed's canary, 88; commercial orchardgrass, 81; perennial ryegrass, 76; redtop, 71; late maturing orchardgrass, 70; tall fescue, 68; tall meadow oat grass, 67; meadow fescue, 66; and smooth bromegrass, 47. Since Kentucky bluegrass, timothy, and orchardgrass produce considerably greater growth than bromegrass when grown on a soil low in available potassium, this may help to explain why these grasses crowd out alfalfa and clover to a greater extent than does bromegrass. It also helps to explain why grasses such as orchardgrass and tall fescue are replaced by Kentucky bluegrass when the potassium supply is lowered.

#### Optimum and Critical Potassium

##### Content in Plant Tissue

A great deal of work has been done to determine the most desirable potassium content in plant tissues. Most of the work has dealt with legumes; however, some information is

available for grasses. The critical potassium content in the plant is the level at which further reductions will cause reduced yield or other physiological malfunctions within the plant. The values reported for this level vary considerably, but they are usually between one and two percent.

It is well known that clover in a mixture with grass tends to deteriorate and show signs of potassium deficiency. Plant analyses generally show that grasses absorb potash to a greater extent than clovers. It does not follow, however, that clovers have a greater intrinsic need for potash. In both grasses and clovers a minimum content of two percent potash in the dry matter from their tissues appears to be adequate for healthy and vigorous growth. The simple explanation of the usually higher potash content in grasses compared with clovers is that they freely absorb potash and often in excess of their actual requirements (Cowie, 1956).

Chandler et al. (1945) reported that yield responses usually resulted from potassium applications if the potassium content of alfalfa at the early bloom stage was less than 1.25 percent. He stated that significant yield responses could be realized if more than 15 percent of the alfalfa plants show deficiency symptoms. Gerwig et al (1958) found the critical percentage to vary from season to season but

probably lies between 1.42 and 1.84 percent, while the potassium content needed for survival is one percent. Similar values of 0.9 to 1.1 percent were obtained by Stivers and Ohlrogge (1952) for the minimum level of potassium required for survival of alfalfa. Tucker and Smith (1952) reported that approximately one percent potassium was considered the critical lower limit for the element in red clover. McNaught (1958) found that this critical or minimum level for near-maximum growth was 1.8 percent potassium for whole leaves of white and red clover at grazing height.

The critical potassium content is about the same for grasses and legumes. McNaught (1958) found this level to be approximately 1.6 percent for ryegrass, orchardgrass, and Yorkshire fog. Kresge and Younts (1960) found that orchardgrass with one percent potassium showed severe potassium deficiency symptoms.

The age of the plant tissue is very important when considering the optimum or critical potassium content. Generally, young tissue contains the highest content of potassium (Bryant et al., 1954).

Rogers (1958) reported results which differed considerably from most other workers. He concluded that less than one percent potassium was sufficient for most species to

obtain optimum yields and that luxury absorption, which sometimes amounted to ten times that needed for maximum growth, was toxic to some species. Annual lespedeza absorbed nearly two percent potassium when large amounts were available, but yields were severely retarded when the potassium content was above one percent. He stressed that this damage was not a salt effect on seedling establishment but a toxic effect on the metabolism of the plant.

Thomas (1958) observed similar effects on ladino and concluded that the damage was probably due to low calcium. Many workers have shown that high applications of potash cause a decrease in magnesium and calcium in the plant and if the soil magnesium and calcium are low, a deficiency of these elements occurs.

#### Optimum and Critical Levels of Available Potassium in the Soil

Hundreds of papers have been published concerning the optimum levels of potassium fertilization. These levels, of course, vary considerably depending on the species grown, management used, rainfall, yield, potassium supplying power of the soil, and many other factors. Only a few of these papers will be mentioned here. Brown (1954) stated that 149 pounds of potassium per acre is optimum for alfalfa and ladino grass meadows. Other figures are: 125 pounds per

acre (Petersen and Attoe, 1958); 149 pounds (Wallace and Bear, 1948; Wood, 1956); 415 pounds (Woodhouse and Chamblee, 1951); 66 pounds (Chandler et al., 1945); 42 pounds (Drake and Colby, 1958); 25 to 66 pounds, depending on soil type (Evans et al., 1949); 166 pounds (Gerwig, 1957; Gerwig and Ahlgren, 1958; and Gross and Ahlgren, 1950). Evans et al. (1949) found that the rate of potassium application necessary for maximum yields was inversely related to the amount of potassium released from soil minerals. Mullison and Mullison (1942) found that 30 to 40 ppm potassium was optimum for growth of young barley seedlings. Washko (1949), working with nutrient solutions, observed that 80 ppm potassium gave highest yields of bromegrass when harvested at three months of age, but 40 ppm gave highest yields at two months of age. Evidently the length of the growing season influences the optimum concentration of potassium in the nutrient solution.

Doll (1957) obtained an increase of 2700 pounds dry matter per acre from an orchardgrass-tall fescue-ladino clover pasture mixture when 212 pounds potassium per acre was applied. Griffith et al. (1960) reported orchardgrass yield increases of 3700 and 5500 pounds per acre over the control for 150 and 300 pounds nitrogen per acre, respectively. Yield increases due to 200 or 400 pounds potassium per acre were about 1000 pounds for each nitrogen level. Kresge and

Younts (1960) obtained maximum yields of orchardgrass when 400 pounds of nitrogen and 166 pounds of potassium per acre were applied. They observed that if only 200 pounds of nitrogen were applied, 42 pounds of potassium was as good as 166 pounds. Brown and Carpenter (1958) found that there was a severe potassium deficiency in timothy when 200 and 300 pounds nitrogen per acre were applied with only 42 pounds potassium. The 125 pounds per acre rate of potassium increased dry matter considerably.

Nitrogen has been shown to reduce the level of available potassium in the soil. Therefore, when nitrogen is increased potassium should be increased also. The increased yield resulting from nitrogen applications is one of the main factors contributing to the reduced potassium supply. Hileman (1959) found that 42 and 83 pounds of potassium per acre gave no buildup of potassium in the surface soil of a common bermudagrass sod when 100 or more pounds of nitrogen was applied. At the end of five years high rates of nitrogen had reduced available potassium by one half.

Legumes require a heavier rate of potassium application than grasses when grown in association. Even higher rates are required if nitrogen is added. Blaser and Brady (1950) found that potassium fertilization stimulated growth of ladino clover but did not directly affect the productivity of the non-leguminous plants in association. Nitrogen



fertilization increased growth of grasses and decreased growth of legumes in mixtures. The same workers (1953) found that 50 pounds of nitrogen applied with 42 pounds of potassium reduced yields and potassium content of both grass and ladino clover below that when 42 pounds of potassium was applied alone. Blaser (1955) found that alfalfa was increased by the use of potassium, but nitrogen actually decreased the alfalfa yields. Both nitrogen and potassium applications gave increases in the total yield of the alfalfa-orchardgrass mixture. Ward and Blaser (1957) attributed the retarded growth of alfalfa associated with nitrogen fertilization to stimulated grass growth and competition for potassium, moisture, and light.

The source of the nitrogen carrier might be responsible for some of the adverse effects of nitrogen on the potassium nutrition of plants. For instance, Jackson (1960) observed that increasing nitrogen reduced growth rate of several plants when potassium was low (0.05 to 0.50 meq/l) but increased it when the potassium supply was high (5.0 meq/l). He found that the  $\text{NH}_4^+$  ion rather than the  $\text{NO}_3^-$  ion was responsible for the toxic effects on plants when the potassium supply was low.

It is well known that addition of one element to the soil increases the level of that element in the plant, thus reducing the level of other elements if they are not applied

also. Often harmful effects result from large applications of a single element. Whittaker et al. (1959) pointed out that if potassium is too high a deficiency of calcium and magnesium might occur. Haas and Gruppe (1959) reported that this situation was likely to occur on soils of low exchangeable potassium and magnesium contents combined with low calcium saturation. The work of Bear and Toth (1948) showed that conditions approach optimum for the cation nutrition of alfalfa when 65 percent of the exchange complex of the soil is occupied by calcium, 10 percent by magnesium, 5 percent by potassium, and 20 percent by hydrogen. It was pointed out that plants tend to take up more potassium than they need unless the calcium content of the soil is maintained at a relatively high level. Hoagland and Martin (1933) and many others have also emphasized that high replaceable potassium in the soil tends to induce luxury consumption.

Scientists have observed toxic effects from high concentrations of fertilizer for many years. Most of the damage has been attributed to the nitrogenous constituent of the fertilizer. For instance, Olson and Dreier (1956) observed that serious stand reductions of winter wheat occurred when 10 or more pounds of nitrogen were placed in partial contact with the seed under dry field conditions. Similar results were obtained by Ward and Blaser (1961) with alfalfa and ladine stands during the seedling year. They found that

as little as 20 pounds nitrogen per acre reduced stands even when the fertilizer was mixed well with the soil.

Recent work has shown that potassium also causes damage to seedlings if it is too high. Brown et al. (1958) reported damages when 106 and 212 pounds of potassium per acre were used to establish alfalfa. Carter et al. (1957) reported injuries to ladino when 332 pounds of potassium per acre was applied in the spring. Olson and Dreier (1956) obtained injuries with as little as 25 pounds potassium per acre when applied with the seed. Similar results were obtained by Rogers (1958) with soybeans when potassium was applied in the drill row. Fribourg (1958) reported that 15-120-120 when placed in bands one to one and one-half inches below the seed or closer reduced the stand of forage crops. He recommended placing the bands one and one-half to two inches below the seed and one to one and one-half inches to the side.

The amount of any salt in the soil when toxic conditions develop is dependent to a large extent on the water content of the soil. During dry periods when water is very low the salt concentration can be very high; therefore, it would be difficult to set up a universal rule telling which rates of fertilizer application would cause toxic conditions.

Jackson (1958) found that for a silt loam soil 1500 ppm in the soil is often the maximum salt content for growth of

soft-stemmed plants. He calculated that a content of 0.1 percent salts in a silt loam corresponds to 1000 ppm in the soil or 4000 ppm in the soil solution at the field moisture capacity of 25 percent.

Small amounts of potassium are seldom harmful to seedlings if they are not in direct contact with the seed. Bromegrass seedlings in fact respond to small amounts of potassium when grown in a nutrient solution. Washko (1949) found a high correlation between the amount of potassium available to bromegrass seedlings and the amount of growth made during the initial three month period of development. He concluded that this response might be a significant factor in insuring seedling establishment under field conditions.

#### Availability of Soil Potassium to Plants

Potassium exists in the soil in three states of availability: (1) readily available (exchangeable and water soluble); (2) moderately available (fixed); and (3) slowly available (potassium minerals) (Truog, 1951). The readily available potassium tends to reach a fairly stable equilibrium with its environment, and changes induced by adding fertilizers are short-lived unless continued applications are made. If a crop is grown which removes potassium faster than it is released from the fixed form, the available potassium supply is lowered. Bradfield et al. (1945) found

that exchangeable soil potassium levels decreased from spring to fall, but the original amount was restored again by the next spring. They suggested that the constancy of the amount of exchangeable potassium found from year to year in many soils indicates that losses due to cropping, leaching, and fixation are restored through the winter by conversion of potassium from nonexchangeable to exchangeable forms. They failed to get a buildup of exchangeable potassium from applications of manure and potassium over several years. Blue (1959) also failed to get much accumulation of exchangeable potassium from year to year from potassium applications, but he was able to get a retention of exchangeable potassium from October to February. Chandler et al. (1945) obtained decreases in exchangeable potassium on both the check and potassium treated plots during the first year, but after three years the exchangeable potassium level in all plots approached that in the check.

Carter et al. (1959) studied the effect of fertility levels on exchangeable potassium in the soil. They found that potassium levels increased proportionally for each respective level of potassium fertilization at the beginning of the study but then decreased rapidly. Only the plots that received 166 and 332 pounds of potassium showed an increase over the original level. McLean and Simon (1958b), in short term laboratory studies, found that increased applications of

potassium increased the exchangeable potassium in the soil. It seems that added potassium raises the exchangeable potassium level in the soil for a short period but eventually is fixed, removed by cropping, or leached. Eventually the soil returns to its original level of potassium if the same crop is grown.

A great deal of work has been done dealing with the effects of temperature, wetting, and drying on fixation and release of nonexchangeable potassium. For instance, Burn and Barber (1960) observed that moisture differences did not influence the release of potassium from fixed to exchangeable forms, but increasing temperatures stimulated release. Laboratory studies by McLean and Simon (1958b) on ten Ohio soils showed that exchangeable potassium reflected closely the potassium applied at all levels of application. Some potassium was fixed against  $\text{NH}_4\text{Ac}$  in almost all soils, even when kept moist. This fixed potassium was largely beyond recovery by boiling with  $\text{HNO}_3$ . Drying at  $105^\circ\text{C}$  generally increased exchangeable potassium at zero and low rates of potassium application but fixed increasing amounts at higher rates. They found that the acid extractable potassium was affected much less by drying than was the exchangeable potassium. This might mean that potassium fixed by drying is largely recoverable by cropping while that fixed under moist conditions is not. The amount of potassium fixed under

moist conditions increased with increased rate of application, but the percentage of that applied decreased with increased rates of application. In summation it seems that there is an equilibrium between the various forms of potassium in the soil, and factors such as wetting, drying, heating, (Deturk et al., 1943) freezing, and thawing (Attoe, 1946) can increase or decrease the level of exchangeable potassium, depending on whether the initial exchange level is high or low.

Ammonium can also be fixed by soils in a manner similar to potassium. The radii of the two ions are quite similar; therefore, they can both fit into the hexagonal holes in the surface oxygen sheets of the clay particles (Russel, 1950). Prior fixation of either potassium or ammonium has a depressive effect on the subsequent fixation of the other (Joffe and Levine, 1947). These ions evidently block the release of each other. Scott and Welch (1959) found that ammonium fertilizer could almost completely block the release of "fixed or nonexchangeable" potassium by plants. Additions of potassium also blocked the release of fixed potassium.

The "available" soil potassium is supposed to be the amount which is available to plants. Chemical extraction methods have been worked out which have a high correlation with the amount of potassium removed by plants. Different species of plants, however, differ greatly in their capacity

to take up potassium from the same soil. Drake and Scarseth (1939) pointed out that different species of plants are able to absorb different rates of potash when no KCl is applied. Timothy removes three times the amount of potassium found in exchangeable form. Sudangrass removes twice as much, and wheat, carrots, and buckwheat removes more than is found in exchangeable form. Spinach, oats, and alfalfa are low in potassium extracting power. McLean and Simon (1958a) found that potassium from the exchangeable and acid soluble phases was about as available to alfalfa as the same amount of potassium from KCl. Tyner (1935) found that clovers and alfalfa were more efficient feeders on feldspar potassium than plants such as sudangrass, oats, and soybeans. It was concluded that clovers, being slower growing plants, could utilize potassium from a dilute medium. Lewis and Eisenmenger (1948) found that plants in lower stages of evolution were able to extract potassium from feldspar better than higher plants. They assumed that in early stages of evolution plants obtained their nutrients from unweathered rock.

Only a very small portion of the work reported in the literature on availability of soil potassium has been mentioned here. For a more comprehensive review of the literature on this subject the reader is referred to the section by Reitemeier (1951).



### Potassium Deficiency Symptoms of Plants

Different species of plants show different potassium deficiency symptoms. In general the first deficiency symptom is a yellowing of the tips and edges of old leaves. As the deficiency becomes more severe, yellowing moves toward the center of the leaf and young tissue begins to show this symptom. Later leaf edges become necrotic and the leaf tissue breaks down, leaving ragged edges to the leaves.

Janssen and Bartholomew (1929) and Nightingale et al. (1930) found potassium deficient tomato plants to be a darker green than healthy plants. They stated that the color was so pronounced that a casual observer could easily pick out the low potassium plants from the high potassium plants on this basis. Janssen and Bartholomew also reported that the low potassium plants had a lower percentage of water.

Hartt (1934b) found that potassium deficient sugar cane plants showed light, yellow-green laminae, yellow-brown edges, red midribs, red flecks in the laminae, and dieback. The first symptoms were red midribs. He attributed the red color to the decomposition of tannic acids, resulting in the formation of phloroglucin which causes reddening of saccharetin in the presence of  $H_2SO_4$ .

Potassium deficient barley plants have purplish spots which sometimes precede the marginal firing of leaves.

These dark areas may persist even until maturity (Cook and Millar, 1953). If the deficiency is severe the leaves become chlorotic and show white blotchy lesions (Lawton and Cook, 1954). Richards (1932) obtained light yellow leaves in potassium deficient barley plants. All cereal grains may show a bluish-green color of young leaves, excessive tillering, and shriveled and immature grain. The excessive tillering may be due to an excess of phosphorus over potassium (Lawton and Cook, 1954).

The Agronomy Department of V. P. I. (1959) summed up potassium deficiency symptoms as follows: "One of the most characteristic symptoms of potassium deficiency is a premature dying of the tips and margins of the older leaves. On tobacco a fine brown specking usually precedes the death of the leaf tips, and the margins of the leaves tend to curl under. The dead tissue usually falls out, leaving a ragged-looking leaf. There is a tendency for corn and small grains to blow down or lodge badly when they are suffering from potassium deficiency."

For a more detailed review of potassium deficiency symptoms the reader is referred to the section on potassium in plant nutrition by Lawton and Cook (1954).

**Chemical Composition of Species  
as Affected by Potassium and Nitrogen**

Increasing the rate of potassium fertilization almost always increases the percent potassium in the plant (Patrick and Sturgis, 1952; Blaser, 1955; and many others). It reduces the amount of calcium, magnesium, and sodium (Patrick and Sturgis, 1952; Van Itallie, 1938; Tucker and Smith, 1952; and others). Van Itallie (1938) found the sum of the four cations calcium, magnesium, sodium, and potassium to be constant in the plant when fertilizer applications of any of the four were varied. Potassium fertilization depressed the absorption of calcium and magnesium and was absorbed from the soil in greater amounts than the other ions. Similarly, Dijkshoorn (1959) reported that soil potassium had no effect on the total cation concentration of ryegrass but altered cation ratios. Hartt (1934) found that potassium deficient sugar cane plants absorbed more silicon, phosphorus, calcium, and magnesium than normal plants early in growth.

Potassium is absorbed in amounts far in excess of that necessary for optimum growth (Welsh, 1955; Patrick and Sturgis, 1952; and many others). The potassium content of various species varies considerably depending on the level of potassium and the species of the plant. Stewart and Bear (1951) reported values ranging from 1.8 to 2.9 percent

for orchardgrass. Brown and Mimsell (1956) gave values of over three percent for legumes on high potassium soils. Walsh (1955) suggested that orchardgrass is deficient in potassium when the level drops below 0.4 percent and that luxury consumption occurs when more than 1.5 percent potassium is present. He suggested corresponding values of 0.8 and 1.75 percent potassium for wild white clover. On the other hand, Kresge and Younts (1960) reported severe deficiency symptoms when orchardgrass contained one percent potassium.

Low potassium levels in plant tissue reduce the water content (Richards, 1932; Gregory and Richards, 1929; and many others). The potassium ion is believed to be partly responsible for the maintenance of the proper turgor of the plant cell; therefore, it would regulate the amount of water taken up (Hoffer, 1938). Potassium, due to its regulatory effect on the water economy of cells, might be important in increasing resistance of plants to drought and frost (Lawton and Cook, 1954).

The effect of potassium levels on nitrogen nutrition is not very clear. Many workers have suggested that potassium has a marked influence on nitrate reduction, and it is generally agreed that potassium deficient plants are high in soluble organic nitrogen fractions. It is not clear

whether these fractions are of the synthesized or degraded form. Nightingale (1943) suggested that nitrate uptake is greatly accelerated by the presence of potassium. Washko (1949) reported that potassium up to 40 ppm in nutrient culture increased the nitrogen content. Blaser (1955) found in field tests that potassium applications depressed nitrogen content of grasses at low levels of nitrogen but did not at high levels. Janssen and Bartholomew (1932) conducted an extensive study of the effects of potassium on the organic fractions of the plant. They found that low potassium levels result in higher percentage of reducing sugars, total sugars, total nitrogen, protein nitrogen, and lower starch than high potassium levels. Low potassium levels did not affect amino nitrogen.

Nitrogen applications usually reduce the percentage of potassium in the plant, but they increase the nitrogen percentage (Blaser, 1955; Drake and Colby, 1958; and others). Dijkershoorn (1959) found that increasing soil nitrogen decreased the concentration of Cl + P + S ions and increased the nitrogen concentration in the plant. Nitrogen increased the total anion content (Cl + P + N + S) more than it did that of cations (K + Na + Mg + Ca). The work of McLean and Simon (1958a) showed that nitrogen decreased the percentage of potassium in sudangrass, although it increased yields and total uptake.

Blaser (1955) and others have found that high nitrogen rates increased the calcium content of plants. Many workers have reported that increasing nitrogen levels also increased uptake of magnesium. McLean (1955) found that additional nitrogen applications increased the cation exchange capacity of the roots and concluded that this higher cation exchange capacity enabled the plant to take up more divalent cations than monovalent cations. Smith and Wallace (1956) observed increases in calcium and magnesium contents of fescue (Festuca rubra) with increased nitrogen rates; this did not occur with cucumbers. Increases in cation exchange capacity also occurred in fescue with increases in nitrogen rates but did not with cucumbers. They attributed the differential responses of the two species to the high cation exchange capacity of the cucumber roots in comparison to that of the fescue. It seems that the effect of the increased nitrogen rate on increasing the respiration rate would be an important consideration in the uptake of ions. Smith and Wallace showed that the respiration rate of cucumbers was doubled by increasing the nitrogen rate, but they did not show the respiration rate of fescue.

### Function of Potassium in Plants

The role of potassium in plants has been a mystery for many years. Recently it has been found that potassium functions in plants in several ways, most of which seem to be enzymatic. Only very small amounts of potassium would be necessary for enzymatic processes; hence, these functions cannot account for the large quantities of potassium (over one percent) required for normal growth.

Effect of potassium on carbohydrates: Potassium seems to be involved in the condensation of long chained polymers of carbohydrates. It is well known that low potassium treatments result in an increase of reducing sugars (Coil and Slattery, 1948; Hartt, 1934; Janssen and Bartholomew, 1932). Wang et al. (1953) found that added potassium had little effect on reducing sugars, but it gave increased amounts of non-reducing sugars. Low potassium also causes decreases in levulins (Coil and Slattery, 1948), decreases in sucrose (Hartt, 1934), increases in total sugars (Bear, 1950), lowered starch (Janssen and Bartholomew, 1932), and increases in dextrans (Bear, 1950). Coil and Slattery (1948) reported that condensation of fructosan was more nearly related to the ratio of potassium to soluble calcium than to potassium level per se.

Effect of potassium on nitrogen compounds: Potassium affects

nitrogen transformation in plants, but the extent of this effect is not as evident as the effect on carbohydrates. Coe and Slattery (1948) found that leaves of high potassium plants contained less total organic nitrogen and more nitrate nitrogen than did plants of other treatments. Amide-nitrogen and  $\alpha$ -amino nitrogen fractions were highest in mature and expanding leaves of low potassium plants. There was no effect on insoluble and sap soluble organic nitrogen fractions. Hartt (1934) reported that a higher percentage of amino nitrogen, protein nitrogen, and total nitrogen was in the blades of potassium deficient plants than in normal plants, whereas in stems the opposite was true. Janssen and Bartholomew (1932) also reported the percentage of total nitrogen and protein nitrogen was high in low potassium plants. Amino nitrogen was as high in potassium deficient plants as it was in normal plants. Roberts and Olsen (1944) found that potassium deficient soybean plants were higher in percentage of nitrogen and lower in soluble nitrogen than normal plants. They pointed out that this difference might be explained by assuming potassium to have some role in the synthesis and mobilization of carbohydrates. Griffith et al. (1960) reported that with high nitrogen - low potassium fertilization, amide nitrogen (mainly asparagine) accumulated, which indicated abnormal nitrogen metabolism.



Coleman and Richards (1956) associated potassium deficiencies with production of putrescine, a diamine which is not found in appreciable amounts in normal plants. They did find, however, considerable quantities in potassium deficient plants. They induced potassium deficiency symptoms on normal plants by administering putrescine.

Effect of potassium on enzymes: The potassium status of the plant influences the activity of several enzyme systems.

Doby and Hibbard (1927) found that potassium deficient plants contain more amylose and saccharase than do normal plants.

Amylose was strongly activated by the chloride ion and weakly activated by the  $K^+$ ,  $NO_3^-$ , and  $F^-$  ions. Saccharase was activated by the nitrate ion and slightly activated by the potassium ion, but was paralyzed by the chloride ion.

Eddy and Hinshelwood (1951) found that potassium and rubidium ions tended to compensate for the drop in glucose dehydrogenase activity due to lowering of the pH. Englis and

Lunt (1925) found that the diastase activity of nasturtium plants was greatest with medium applications of potassium.

In every case diastase activity was directly related to yield and vigor. They suggested that there was a correlation of diastase activity with favorable growing conditions in general rather than with the presence or absence of any one or more element. Hartt (1934) observed that potassium deficient plants had reduced invertase and increased amylase

activities. Thomas et al. (1959) found that evidently potassium was involved in the formation of one of the two CO<sub>2</sub> fixing enzymes phosphoenolpyruvate carboxylase or phosphoenolpyruvic carboxy kinase. Latzko (1959) found that the utilization of phosphorus during aerobic phosphorylation is markedly increased by the specific action of potassium. He thinks that the role of potassium in photosynthetic phosphorylation is similar to that of magnesium.

Potassium as a salt in glycolysis: Roberts et al. (1949) studied potassium uptake using several different metabolites as substrates. They concluded that potassium was involved in the formation of potassium salts of glucose and fructose phosphates during glycolysis.

Effect of potassium on winter injury: Jung and Smith (1959) found that increasing potassium applications up to 200 pounds per acre increased survival of alfalfa plants if sufficient phosphorus were available. The ratio of soil potassium to phosphorus was more important to winter survival than potassium per se. A ratio of five to two was recommended. Brake and Colby (1955) found that winter injury of alfalfa and clovers is related to low root reserves in the fall. Potassium in the cell sap is required for translocation and storage of sugars and starches in the plant, thus an abundance of potassium in the cell sap throughout the

growing season and especially in September improves root reserves and helps to insure winter survival. Wang et al. (1953) reached the same conclusion two years earlier.

Effect of potassium on translocation: Hartt (1934) found that potassium deficient sugar cane plants accumulated iron at the nodes which moved up into the blades when potassium was added. They concluded that potassium is important in relieving the toxic effects of iron and that the toxicity of iron is due to unequal distribution rather than its total concentration. Iron was deposited at the nodes and in the vessels; therefore, the leaves probably suffered from iron deficiencies. Drake and Colby (1955) also mentioned that potassium was necessary for movement and storage of sugars and starch. Anisimov (1959) found that both low nitrogen and potassium retarded translocation of  $C^{14}O_2$ .

Other effects of potassium: Gregory and Richards (1929) found potassium deficient plants had a lower assimilation rate and higher respiration rate than normal plants. Nitrogen deficient plants, on the other hand, had a lower respiration rate. They suggested that potassium might be required for the chloroplasts to take up  $CO_2$ . Richards (1932) also reported an increased respiration rate under potassium stress.

The work of Janssen and Bartholomew (1932) with sugar beets showed that low potassium caused thicker cell walls,

greater development of the schlerenchyma cells and mechanical tissue of the vascular system, smaller development of the number and size of the cortex cells, and reduced pericycle activity.

Sullivan and Wilkins (1948) reported that in South Africa, potassium applied monthly on forages increased the carotene content 6.2 percent. They pointed out that excessive amounts of fertilizers might upset the mineral balance in forage for animals. For example, too much potassium may lower the calcium and magnesium levels in the blood of animals to a dangerously low level. Grass tetany is believed to be a disease caused by such an unbalance.

Kennelly (1959) summarized the role of potassium in the plant as follows: "Potassium is important in the general health of the plant, particularly in developing sturdiness and disease resistance. It helps to promote the growth of woody tissues and usually improves texture, color, and quality."

For a more detailed review on the role of potassium in plants the reader is referred to the section on potassium in plant nutrition by Lawton and Cook (1954).

#### Factors Affecting Ion Uptake

Temperature: Ulrich (1941) found with excised barley roots that the  $Q_{10}$  of both ion acculation and respiration was about two. A  $Q_{10}$  of this magnitude suggests that ion

accumulation is of a physical-chemical nature. Broyer (1951) suggests that there might be a close relationship between respiration and ion uptake, since the  $Q_{10}$  of both varies from two to three at low temperatures to 1.5 at high temperatures.

Broyer (1950), working with excised barley roots, found that practically all the bromine from a potassium bromide solution was taken up in two hours at 20°C., but it took nine and a half hours at 0.5°C. Hoagland and Broyer (1936) found that increasing the temperature from 6°C. to 30°C. increased ion uptake. Similar results were obtained by Roberts et al. (1949). Jacobson et al. (1950) found that loss of  $K^+$  as well as uptake of  $H^+$  was much greater at 26°C. than at 0°C. Jacobson et al. (1957) concluded that a temperature of 25 to 35°C. was the optimum temperature for potassium and bromine absorption by barley roots.

Broyer (1951) pointed out that temperature, aside from its effect on permeability of the cell, might modify the rates of diffusion and exchange. Effects of this sort would be manifested through increase of kinetic energy of mobile substances in solution. Since the energy intensity for migration of a solute would be proportional to the absolute temperature, this influence would be relatively small. Broyer and Overstreet (1940) found that simple diffusion and exchange of cations amounted to about ten

percent of the absorbed cations and was not influenced by temperature. They concluded that apart from diffusion, there are two modes of ion movement into plants: ionic exchange which is independent of metabolism, and an accumulation mechanism which is directly related to metabolic activity.

Jones and Maderski (1960) studied the influence of heating the soil to a minimum temperature of 80°F. on corn. They found that heating hastened emergence and shortened the period of time from emergence to silking. Heating resulted in a greater assimilation of phosphorus and potassium and a depression of calcium early in growth.

Neilson et al. (1960) studied the effect of four nutrient treatments on corn, bromegrass, and potatoes grown under greenhouse conditions in soil held at 41°, 54°, 67°, and 80°F. Low soil temperature affected the supply of soil phosphorus most adversely, nitrogen next, and potassium least. Maximum yields of bromegrass tops and roots were obtained at 80 and 67°F., respectively. As temperature increased, nitrogen, phosphorus, and calcium decreased in the tissues while potassium increased to at least 67°F. The yield of corn tops and roots increased with temperature up to 80°F., while nitrogen, phosphorus, and potassium remained unchanged or decreased as temperature increased.

Concentration of the rooting medium: Broyer (1951) and Ulrich (1942) and many others have shown that increasing the concentration of a salt solution, whether in the soil or in solution culture, increases the rate of accumulation. There is usually a corresponding, but not necessarily proportional, increase in respiration.

Length of absorption period: Butler and Epstein found that when roots are placed into a salt solution there is an initial rapid uptake followed by a less rapid rate (Butler, 1953; Epstein, 1955). They attributed the first phase to equilibration of the outer space of the root with the ambient solution. The second phase was active uptake.

The work of Broyer (1951) showed a rapid uptake of radioactive KCl for about twenty minutes followed by a less rapid rate if the roots are under metabolic conditions, i. e., at 25°C, in the presence of oxygen and in the absence of respiratory inhibitors. When the roots were at a low temperature or under N<sub>2</sub> gas, maximum absorption was reached within one hour. Overstreet and Jacobson (1946) found this initial rapid uptake period to be about five minutes long for radioactive Rb, Sr, PO<sub>4</sub>, and I. Broyer and Overstreet (1940) showed a steady rapid potassium uptake by barley roots for three hours.

Brooks (1932) found that valonia cells had a maximum absorption rate for rubidium the first day with small

additional increases in absorption up to the ninth day.

Hoagland and Broyer (1936) found that nine week old excised barley roots reached maximum absorption of potassium in 24 hours. Conversely, Butler (1953) found that wheat roots attained maximum potassium absorption in two to three hours.

Hydrogen ion concentration: Broyer (1951) pointed out that moderate changes in the external pH are counteracted within the protoplasm by direct buffer action of constituent compounds and possibly by similarly effective modification in the rates of some metabolic reactions. Thus the pH in cells is maintained within rather narrow limits.

Previous history of the plant: Plants having high levels of salt within the tissues do not absorb additional salts as rapidly as plants with low salt levels. In fact there is often a loss of salts from plants with high salt content (Broyer, 1950; Hoagland and Broyer, 1936).

Broyer (1951) pointed out that respiration is a requirement for metabolic salt uptake, and sugar is a requirement for respiration; therefore, plants must have adequate metabolizable substrate to actively take up salts.

The age or stage of growth of the plant is important in the study of ion uptake. Burd (1923) reported that during the first eight to nine weeks of growth barley plants increased in potassium and nitrogen. These elements



diminished during the next six weeks. Hoagland and Broyer (1936) mentioned that young roots must be used in absorption studies. They used three to nine week old barley roots. Machlis (1944) used four day old barley plants.

Genetic differences between plant species and varieties of the same species should always be considered.

McCollum (1960) noted five-fold differences in the uptake of chlorine by three varieties of soybeans. Collander (1941) studied the variability of ion uptake by different species. The differences were very great in the case of sodium and manganese with the maximum uptake being 20 to 60 times greater than the minimum. Maximum uptake of silicon, magnesium, calcium, and strontium was three to five times greater than the minimum, and the maximum uptake for potassium, rubidium, and cesium was only two to three times greater than the minimum.

Drake and Searseth (1933) found that of twelve grass species bluegrass was able to grow best on soils low in potassium and responded least to additions of potassium. Lewis and Einsenmenger (1948) found that plants in lower stages of evolution were better able to obtain potassium from difficultly available forms than plants in the higher stages of development. Drake et al. (1951), McLean (1955), and many others have proposed that the cation exchange

capacity of plant roots contributes greatly to ion uptake. They propose that plants with roots of low cation exchange capacity such as grasses absorb more monovalent cations than plants with roots of high cation exchange capacity, whereas the inverse relationship occurs with polyvalent cations.

Other effects on ion uptake: Studies with excised barley, oats, and wheat roots have shown clearly the necessity of oxygen for the accumulation of salt in these organs. When the oxygen falls below three to five percent, ion uptake is reduced (Broyer, 1951; and many others).

Polyvalent cations such as calcium, magnesium, strontium, barium, and aluminum increase the potassium absorption. The calcium:potassium molecular ratio of 15:1 produces the largest absorption of potassium. The effect of polyvalent cations in the presence of potassium bromide apparently increases the rate of respiration, the loss of sugar, and the rate and total capacity for salt accumulation. Such effects may be evidence that these cations are modifying the oxidative mechanism providing the energy for accumulation (Viets, 1944). Similar results were obtained by Fawzy et al. (1954). Evidently potassium uptake is not influenced by light. There was no difference in potassium uptake by sugar cane in the day or night (Hartt, 1934).

### Mechanism Involved in Ion Uptake

There apparently are four principal means of ion movement into root cells. They are simple diffusion, Donnan diffusion, exchange absorption, and metabolic accumulation (Broyer, 1951). In simple diffusion the concentration of a particular ion tends to equalize itself between the root cell and the outside solution. Movement by this method is very slow across a differentially permeable membrane; therefore, it does not account for much diffusion. Donnan diffusion is a phenomenon which occurs when one of the ion pairs of a compound in solution does not readily penetrate a differentially permeable membrane between two aqueous solutions. The equilibrium condition imposed for this type of diffusion is that the product of the molar concentration of the cation and anion pairs in the one medium equal the same product in the solution on the opposing side of the limiting surface, i. e.,  $(C)_i \times (A^-)_i = (C)_e \times (A^-)_e$ . Although this phenomenon is valid in many cases, it is seldom realized in living plant roots. Exchange absorption is simply cation exchange by which movement can occur through solution exchange, surface migration, contact exchange, or diffusion in gels. Active or metabolic accumulation is a uni-directional movement involving the expenditure of energy.

Early workers attributed most ion absorption by plants

to the first three methods. Briggs (1932) suggested that salt absorption by mature plant cells from weak solutions consisted of an exchange of anions between solution and cell sap and of cations between the solution and cytoplasm and perhaps the cell wall. Jacobson and Overstreet (1947) pointed out that ion exchange occurs, but the rate of exchange is quite different between live and dead roots. Exchange of radioactive for non-radioactive ions was almost immediate for dead roots but was very gradual for live roots. This suggests a much more complicated mechanism.

McLean (1955) summarized root cation exchange capacity as follows: "Plant roots generate hydrogen ions in their internal growth processes. These ions may be exchanged or swapped to the soil for nutrient cations." He found large differences between the cation exchange capacity of different species.

Lundegardh, from work done in 1933, put forth a widely known theory on the mechanism of ion uptake. Briefly the theory is as follows: Tracks or bridges of cytochromes are formed across the cytoplasm. At the outside the ferri-cytochrome picks up an anion, and carries it to a second cytochrome where it picks up an electron and is changed to the ferro-cytochrome, while at the same time it loses the anion. The anion is passed through several cytochrome

systems until it reaches the vacuole. Metal cations are adsorbed by the cytochrome in exchange for  $H^+$  and are swept inward to the vacuole where they combine with the anion to form compounds. These compounds would cause the cation concentration to be reduced and more would be swept inward. Electrons keep moving outward where the ferrous ion is oxidized to the ferric ion, and  $O_2$  takes up the electron which then combines with  $H^+$  ions to form  $H_2O$  (Burstrom, 1951; Lundegardh, 1954).

Robertson (1951) proposed essentially the same theory as Lundegardh's except that Robertson does not postulate a successive exchange of anions along a cytochrome bridge and against an electron wave. He assumed that the cytochrome circulates within the cytoplasm between the outside and inside of the cell. When it reaches the outside it is oxidized and picks up an anion. The cytochrome then moves around to the inside of the cell where it is reduced by an electron and the anion is lost to the vacuole. Both theories assume that respiratory energy or "salt respiration" is involved in the uptake of anions. They assume that salt respiration is activated by an anion and that excess anions are balanced by  $H^+$  and excess cations are balanced by excess organic anions, such as malate.

The anion uptake requirement for salt respiration set forth in Lundegardh's theory was upset by Epstein (1954).

Epstein was able to get the same boost in respiration by using a cation exchange resin as the other workers obtained by using salts. Evidently the anion is not required after all. This experiment gives support to the latest theory put forth by Epstein.

Briefly Epstein's theory is as follows: A barrier occurs in the root cell which acts as a differentially permeable membrane. In this membrane a carrier mechanism is present involving a metabolically produced substance which combines with the free ion, carries it across the barrier, and discharges it in the inner space. (Epstein, 1956). This carrier is highly selective as to which ions are permitted to pass. Different carriers are used by different ions. Potassium, rubidium, and cesium are taken up at the same site; therefore, they are competitive to each other. Calcium and strontium are taken up at another site, and the anions bromine and chlorine are taken up at still another site (Epstein, 1953; Epstein and Hagen, 1952; and others).

The barrier divides the root cells into two distinct portions: the inner space or the interior of the barrier and the outer space or apparent free space on the outside of the barrier. In the outer space, ions and water are freely diffusible and apparently are in equilibrium with

the ambient solution. Cation exchange occurs between the ambient solution and the root colloids of the outer space. When the root is transferred to a new solution, equilibrium is attained in the outer space within 60 minutes. There is no competition of ions for the space, and there is no pH effect. Active absorption has as its substrate the ions in the outer space (Epstein, 1955). Epstein found that absorption had not reached an equilibrium after four hours, even after the roots had been removed from the medium.

Many people have attempted to calculate the size of the outer space in comparison to the remainder of the cell (Epstein, 1954; Butler, 1953). Figures obtained have been 22 to 34 percent (Conway and Downy, 1950), 23 percent (Epstein, 1955), and 13 percent (Hope and Stevens, 1952).

## METHODS AND MATERIALS

### General

The field studies involved responses of plant species with levels of potassium and nitrogen. The laboratory experiments were concerned with potassium uptake by different species of plants when temperature, potassium concentration, and duration for uptake were studied.

The data for each of the experiments were analyzed statistically and, unless otherwise stated, only differences which exceed the 95 percent level of probability are considered real. Most of the data were tested by Duncan's Multiple Range Test. In many instances values will be superscribed by small letters. These values superscribed by the same letter are within similar populations according to the test.

Methods and materials for each laboratory experiment will be discussed separately.

### Field Experiment

A field experiment was initiated on August 29, 1958, on the Kipps Farm, Blacksburg, Virginia on a Groseclose silt loam. There were six seeding variables: orchardgrass (Dactylis glomerata), Kentucky 31 fescue (Festuca arundinacea), and Kentucky bluegrass (Poa pratensis), seeded alone and in combination with each other. Fertilizer



treatments were superimposed on each of these seeding variables to form a split-split plot design with seeding variables being whole plots, nitrogen applications being sub-plots, and potassium applications being sub-sub-plots. The treatments were replicated in three blocks and were as follows.

<u>Species (seeding rates)</u>	<u>N Rates (lbs/a)</u>	<u>K<sub>2</sub>O Rates (lbs/a)</u>
Orchardgrass (12 lbs/a)	100	0
Kentucky 31 fescue (16 lbs/a)	300	100
Kentucky bluegrass (20 lbs/a)	500	200
Orchardgrass (6 lbs/a) - Kentucky 31 fescue (8 lbs/a)		300
Orchardgrass (6 lbs/a) - Kentucky bluegrass (10 lbs/a)		
Kentucky 31 fescue (8 lbs/a) - Kentucky bluegrass (10 lbs/a)		

6 seedings x 3 N x 4 K<sub>2</sub>O x 3 replications = 216 plots

The area was prepared for seeding by disking thoroughly the top three inches of soil until well pulverized, then a uniform treatment of two and one-half tons of dolomitic limestone, 200 pounds P<sub>2</sub>O<sub>5</sub>, and 20 pounds nitrogen per acre was applied. The lime was applied and disked into the soil, then the P<sub>2</sub>O<sub>5</sub> and nitrogen were applied and worked in with a section harrow. Plots were staked out, seeded by hand, then cultipacked. A period of unseasonably dry weather persisted throughout the remainder of the fall;

hence, there was a stand failure. The area was plowed and reseeded in late March of 1959.

Fertilizer treatments were to have been divided into four equal applications during the year: the first application in February and the others after each of the first three harvests. Since the area had to be reseeded in the spring, the February application was omitted the first year, and as a result only three-fourths of the annual rate was applied. The two higher rates of nitrogen were applied in two applications in the spring to prevent seedling damage. In 1960 the applications were made as planned. Fertilizer applications were made on the following dates in 1959: April 9, May 28, July 17, and September 16. In 1960 the application dates were: April 1, June 2, July 21, and October 21. The May 28, 1959 application was the second split of the spring application of nitrogen. A uniform application of 200 pounds  $P_2O_5$  and two tons lime per acre was applied on July 22, 1960.

Seedling stand counts were made during May 6 to 19, 1959. Stand was estimated by counting the number of seedlings in four 4" by 18" quadrats for each plot.

During the summer of 1959 three cuttings were made as the growth of forage permitted. All grasses except pure bluegrass were cut back to two inches; bluegrass was mowed to a height of one inch.

Broad leafed weeds were prevalent in the spring and summer of 1959. The percentages of cress (Lepidium campestre), lambsquarters (Chenopodium album), and ragweed (Ambrosia artemisiifolia) were determined for the first cutting in 1959 only. Samples of orchardgrass, tall fescue, and each of the above three weeds were hand picked from the field for chemical analyses.

Subsequent to the first harvest in 1959 the broad leafed weeds were controlled by spraying 2,4-D amine. Sprayings were made on August 1 and September 21, 1959 and on June 2, 1960. During the second year quackgrass (Agropyron repens) made up over 90 percent of the weedy growth in the sod.

Mixtures were cut at the boot stage and thereafter at a height of about 8 to 12 inches for three additional cuts in 1960. These harvests were made on April 30, May 30, July 4, and October 11. The pure grass stands were cut at the medium to late bloom stage to get maximum yield, then at heights of about 8 to 12 inches for two additional cuts. The cutting dates for pure grass stands were May 18, July 4, and October 11.

Harvests were made with a Gravely cutter-bar type mower. A 15-inch strip was removed at each end of the plots to eliminate border effects. Yields were taken by mowing

a 30-inch strip down the center of the plot. Ten to twelve hand grabs were taken from the yield strip and frozen for botanical and chemical analyses. The frozen samples were hand separated into the various species, then percentages and pounds per acre of dry matter for each species were calculated. Visual estimates for the percentages of each species were determined from the standing forage prior to each cutting. The percentage of ground cover was taken prior to each harvest in 1959 and following each harvest in 1960.

On the October 11, 1960 harvest the percent water was obtained by subtracting the weight of the dry sample from the weight of the green sample. The data are presented on the basis of percent water in the green sample.

Soil samples were taken on April 8, 1959 prior to the application of any fertilizer and on July 15 and September 7, 1959. No samples were taken after the third cutting in 1959. Samples were taken on May 23, July 11, and October 17, 1960. Ten to twelve plugs were taken from the top two inches of soil from each plot. Soil analyses were made by the State Soil Testing Laboratory. Procedures used were those outlined by Rich (1955).

Fertilizer applications referred to as pounds in the text, unless otherwise stated, will mean pounds per acre per year. Yield and soil chemical constituents referred to as pounds will mean pounds per acre.

## RESULTS

### Orchardgrass Botanical Composition

Seeding effects: Figure 1 shows the percentage of orchardgrass, calculated on a dry matter basis, in mixtures and pure seedings for the two growing seasons. During 1960 different cutting methods were used for the mixtures and pure seedings; therefore, comparisons between the two are confounded with cutting management. For this reason, comparisons may be made only within mixtures or within pure seedings.

Orchardgrass increased throughout the first year. The pure seeding of orchardgrass naturally produced a greater proportion of orchardgrass than mixtures containing one half as much orchardgrass seed. Plots not sown to orchardgrass had volunteer orchardgrass, but this amounted to less than 20 percent of the yield. The orchardgrass-bluegrass mixtures had more orchardgrass than orchardgrass-fescue mixtures during the second year; the differences were significant at all harvests.

On April 30, 1960, the percentages of orchardgrass were 80<sup>a</sup> and 95<sup>b</sup> for orchardgrass-fescue and orchardgrass-bluegrass mixtures, respectively. The drop in the percentage of orchardgrass in mixtures at the May 30 harvest was probably due to its early heading (Figure 1). Fescue and

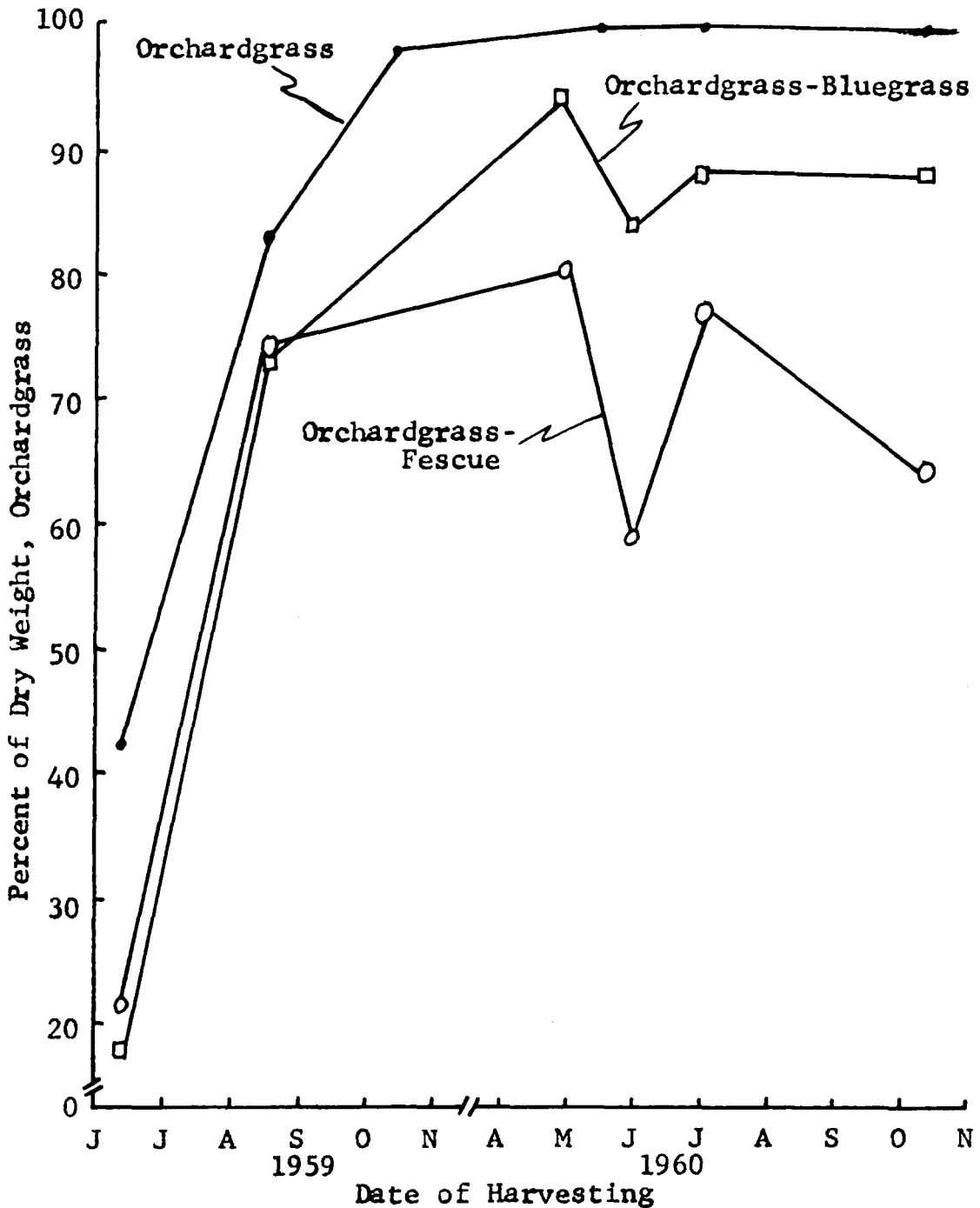


Figure 1. Seasonal changes in the percentage of orchardgrass in pure seedings and mixtures of grasses. Each point is an average of three nitrogen rates, four  $K_2O$  rates, and three replications.

bluegrass had many seedheads at this date; the orchardgrass seedheads were cut in the previous harvest.

Bluegrass offered very little competition to the orchardgrass throughout the two year period. The vigorous seedling growth of orchardgrass enabled it to form a quick sod cover, thus shading out the slower growing bluegrass seedlings.

Fescue in the orchardgrass-fescue mixture also was a slow starter. It offered very little competition to the orchardgrass for the first two harvests, but by October 16, 1959, it had become well established. By October 11, 1960, the fescue reduced the percentage of orchardgrass from 80 to 64. Fescue became more aggressive in this mixture as the season progressed. The orchardgrass was damaged by leaf diseases and it did not grow as well as fescue at low temperatures; hence, fescue became aggressive.

Nitrogen effects: The most apparent effect of nitrogen was the increase in orchardgrass with increasing rates of nitrogen in the orchardgrass-fescue mixture. For example, the percentages of orchardgrass in this mixture on May 30, 1960, were 42, 63, and 71 for 100, 300, and 500 pounds of nitrogen per acre per year, respectively. The respective percentages on July 4 were 72, 80, and 79. Similar trends occurred for orchardgrass-bluegrass mixtures, but the differences were smaller since most of the bluegrass had

been crowded out. Visual estimates also verified these trends.

At low nitrogen rates orchardgrass made less growth than at high nitrogen rates; hence, it did not shade out the fescue of the mixture. The fescue withstood the nitrogen stress much better and tended to crowd the orchardgrass.

Potassium effects: Visual estimates showed overall increases in the percentage of orchardgrass in mixtures of from one to three percent if at least 100 pounds per acre of  $K_2O$  was applied. The hand separates showed about the same increase, but it was not significant.

Without potassium there was an overall average of almost five percent less orchardgrass than for 300 pounds per acre of  $K_2O$  on August 18, 1959. The percentage of orchardgrass in the orchardgrass-bluegrass plots was reduced more by the potassium deficit than it was in the other mixtures. These percentages of the yield made up of orchardgrass were 68, 72, 75, and 77 for 0, 100, 200, and 300 pounds of  $K_2O$  per acre per year, respectively.

Another apparent effect of potassium occurred in the mixtures on October 11, 1960. The potassium by nitrogen interaction at this date showed that low potash and high nitrogen reduced the percentage of orchardgrass



more than for other treatments. The percentage of orchardgrass at the 0 potassium level was ten points lower than that of the 200 pounds per acre per year level. The high nitrogen levels increased orchardgrass growth and thus caused a more rapid depletion of the available potassium in the soil. Since orchardgrass is more sensitive to potassium deficiencies than the other grasses, other species encroach with  $K_2O$  stress. It is anticipated that orchardgrass will gradually die out, as the soil becomes more and more depleted of potassium, unless additions of potassium are made.

#### Fescue Botanical Composition

Seeding effects: Fescue had poor seedling vigor; hence, the June 12 and August 18 harvests in 1959 were weedy. Fescue made up less than six percent of the yield on June 12 (Figure 2). By August 18 of the same year, fescue made up 27<sup>a</sup>, 22<sup>a,b</sup>, and 9<sup>b,c</sup> percent of the yield for pure fescue, fescue-bluegrass, and fescue-orchardgrass, respectively. By October 16, 1959, fescue was well established, making up 85 percent of the growth in the pure fescue seedings. Except for the July 4, 1960 harvest, the pure fescue plots maintained this high botanical composition. The percentage of fescue in the mixtures increased steadily, reaching a peak on May 30 and a second

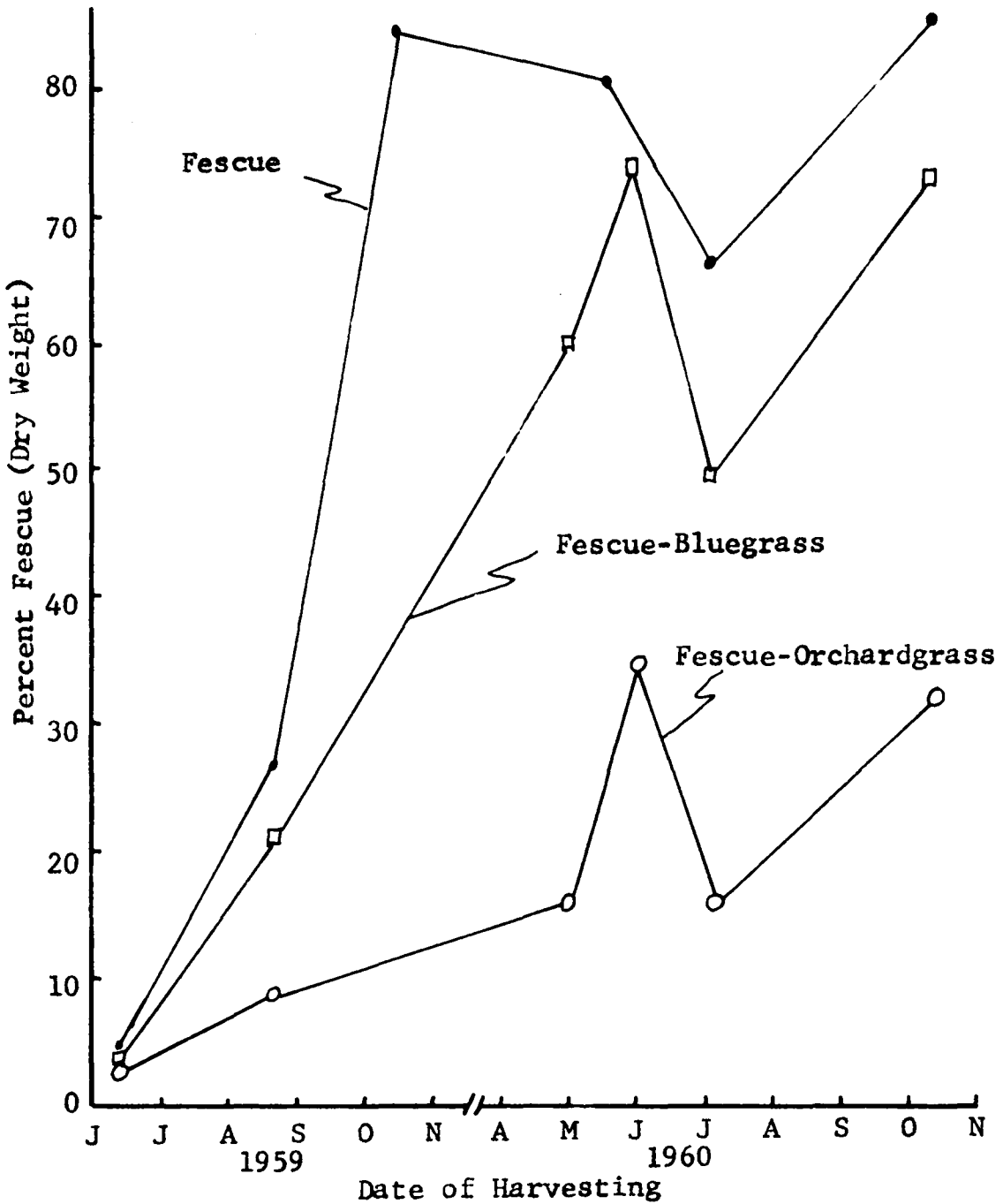


Figure 2. Seasonal changes in the percentage of fescue in pure seedings and mixtures of grasses. Each point is an average of three nitrogen rates, four  $K_2O$  rates, and three replications.

peak on October 11, 1960. Hand separations were not made on October 16, 1959, but visual estimates showed that the percentage of fescue for both fescue-bluegrass and fescue-orchardgrass mixtures was higher then than on May 30, 1960. Since the percentages increased again on October 11, 1960, there is good evidence that fescue is very aggressive during the fall months but is less aggressive during the spring and summer. The percentages of fescue on April 30, 1960 were 60<sup>a</sup> and 16<sup>b</sup> for fescue-bluegrass and fescue-orchardgrass, respectively. The respective percentages were increased to 73 and 32 by October 11, 1960.

The high percentage of fescue shown on May 30 was due to its heavy seedhead production as compared with the other species. The low percentage of fescue on July 4 is attributed in part to quackgrass which was heading on this date. Some volunteer fescue plants were present in the plots not seeded to fescue. Bluegrass was less competitive than orchardgrass; hence, more volunteer fescue was present in the bluegrass plots.

Nitrogen effects: The overall effect of nitrogen on the percentage of fescue was very small. During 1959, increased nitrogen fertilization did not improve fescue composition. On June 12 the 500 pound rate of nitrogen increased the percent fescue only one percentage point over the 100 pound

rate. During the second year nitrogen reduced fescue composition when nitrogen rates were 300 pounds or more per acre. On May 18 the percent fescue in the fescue seedings was 85, 88, and 69, respectively, for 100, 300, and 500 pounds of nitrogen per acre. The respective percentages were 58, 78, and 62 on July 4.

Each increment of nitrogen reduced the percentage of fescue in the mixtures during the second year. The data indicate that nitrogen reduced the botanical component fescue more in fescue-orchardgrass mixtures than in fescue-bluegrass mixtures, but the nitrogen by mixture interaction was not significant. The percentage of fescue in the fescue-orchardgrass mixture for each nitrogen rate and each harvest during 1960 is presented below.

	N <sub>100</sub>	N <sub>300</sub>	N <sub>500</sub>
April 30	18	14	14
May 30	51	29	22
July 4	21	14	14
October 11	38	29	30

At the low rate of nitrogen, orchardgrass produced comparatively less than at high rates of nitrogen; hence, orchardgrass tended to be more competitive toward fescue at the high nitrogen rates. The total dry weight produced by the 100 pound nitrogen rate was low, but a larger portion of it was composed of fescue than for the higher nitrogen rates.

**Potassium effects:** Potassium fertilization tended to improve fescue stands during the first year, even though the soil potassium content was quite high (Figure 3). For example, on August 18 fescue increased from 10 percent for 0 K<sub>2</sub>O to over 13 percent for 300 pounds K<sub>2</sub>O. This linear trend occurred for the pure seedings for the remainder of the season, except October 16 when differences were not significant. Visual estimates showed similar trends.

A potassium by mixture interaction was significant on April 30, May 30, and October 11, 1960. Potassium reduced the percentage of fescue in the fescue-orchardgrass plots while the reverse occurred for the fescue-bluegrass plots. The percentage of fescue for the two fescue mixtures for each of the three cuts is presented below.

K <sub>2</sub> O rates lbs/A/yr	<u>Fescue-Orchardgrass</u>			<u>Fescue-Bluegrass</u>		
	Apr. 30	May 30	Oct. 11	Apr. 30	May 30	Oct. 11
0	18	38	37	51	70	68
100	14	34	32	67	75	72
200	14	31	27	60	77	77
300	16	33	33	61	74	77

The orchardgrass probably was becoming deficient in potassium in the no K<sub>2</sub>O plots; hence, the stand was reduced. Fescue survived on lower soil potassium than did orchardgrass; therefore, it was aggressive under low K<sub>2</sub>O fertilization. Similarly, fescue in the fescue-bluegrass

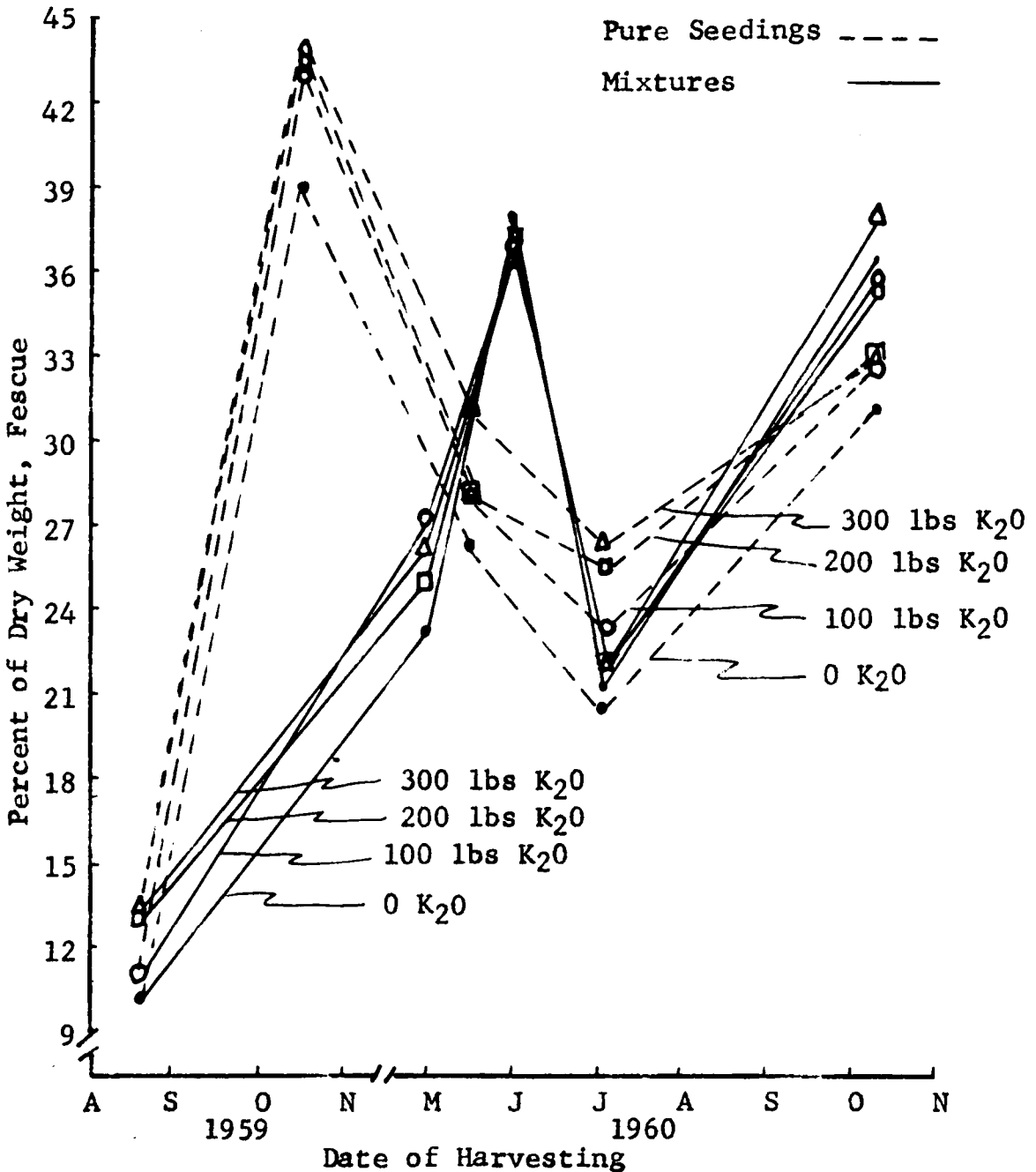


Figure 3. Seasonal changes in percentage of fescue as affected by  $K_2O$ . Points are means of three nitrogen rates, three seedings, and three replications. (Points on August 18 and October 16, 1959 are means of five and two seedings, respectively.)

plots probably was becoming more deficient in potassium on the no potash plots than bluegrass. Thus, bluegrass was more aggressive than fescue under low  $K_2O$  fertilization. Evidently the potassium requirement for bluegrass is much lower than that for fescue, and the fescue requirement is lower than that for orchardgrass.

### Bluegrass Botanical Composition

Seeding effects: Data on botanical composition by hand separation were not collected on bluegrass during the first year because of its limited growth. Visual estimates on August 18 showed that pure bluegrass seedings and bluegrass-fescue mixtures had more bluegrass than the bluegrass-orchardgrass mixtures. By October 16, 1959, the fescue of the fescue-bluegrass mixture, being very aggressive during the fall, had only one percent bluegrass. Pure bluegrass seedings had 11 percent bluegrass on this date.

The pure bluegrass seedings had over 50 percent bluegrass for the first two harvests in 1960, but the percentage dropped at the last harvest on October 11 due to a severe infestation of quackgrass (Figure 4). The bluegrass-fescue mixture had more bluegrass at all times than the bluegrass-orchardgrass mixture, except for the October 11, 1960 harvest. Bluegrass-orchardgrass seedings contained about two to four percent bluegrass, while the values for the

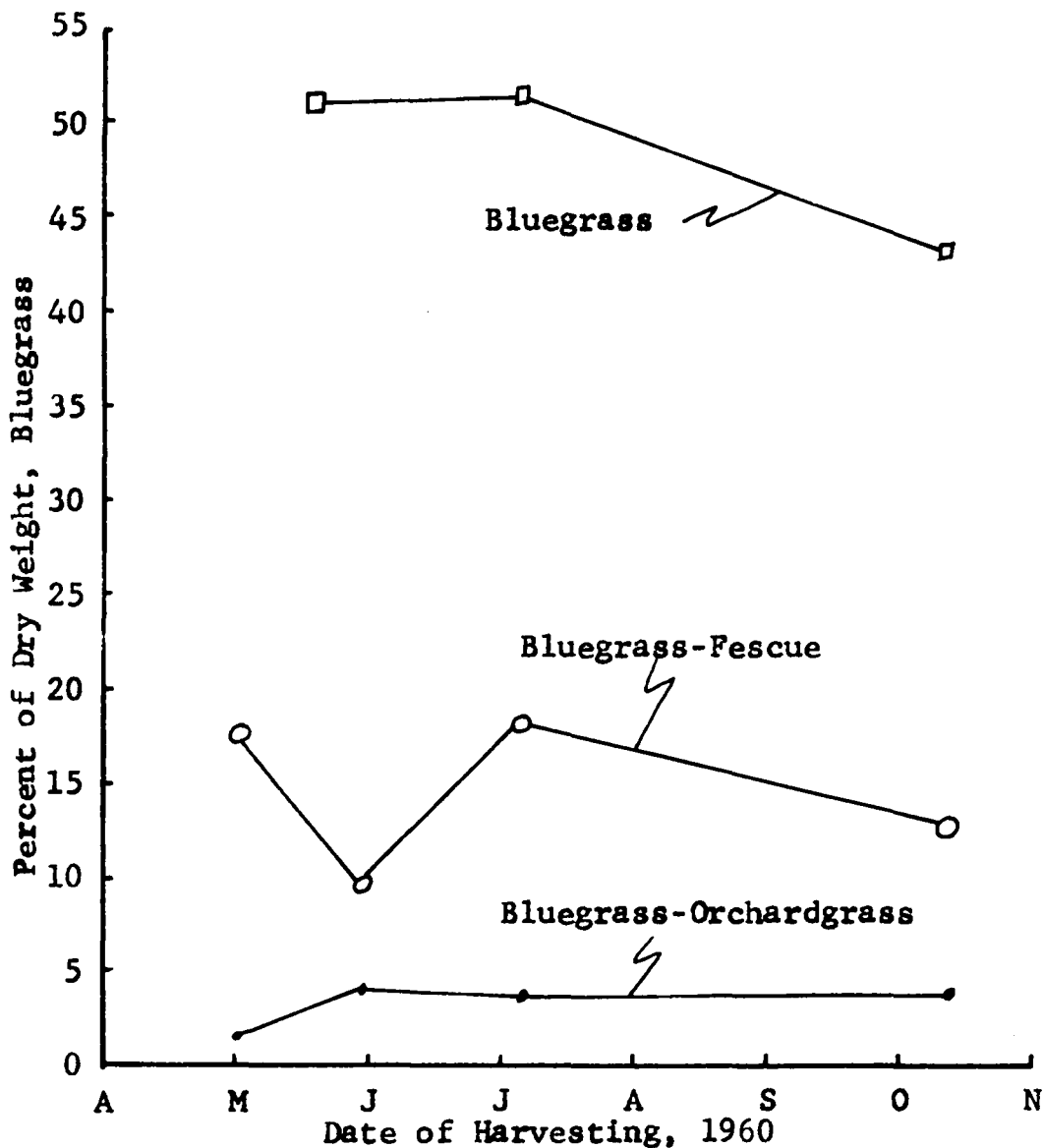


Figure 4. Seasonal changes in the percentage of bluegrass in pure seedlings and mixtures of grasses. Each point is an average of three nitrogen rates, four  $K_2O$  rates, and three replications.



bluegrass-fescue seedlings ranged from 9 to 18 percent. Orchardgrass, due to its vigorous seedling growth, was more aggressive than fescue.

Nitrogen effects: Nitrogen fertilization did not influence the percentage composition of bluegrass significantly.

Visual estimates, however, indicated that heavier nitrogen rates gave small increases in the percentage of bluegrass for the early spring cuttings.

Potassium effects: The percentage composition of bluegrass generally decreased as rate of  $K_2O$  increased (Figure 5).

On May 18, the pure bluegrass seedlings had 57, 54, 50, and 44 percent bluegrass for 0, 100, 200, and 300 pounds of  $K_2O$  per acre, respectively.

At every harvest in 1960 mixtures contained more bluegrass at the low rates of potassium; these differences were significant, except for the April 30 harvest. Although there was no nitrogen by potassium interaction, potassium seemed to decrease the percentage of bluegrass more for the high than for the low rates of nitrogen when bluegrass was seeded with fescue. The same effect was apparent when bluegrass was seeded with orchardgrass, but the values were much smaller. Table 1 shows these trends at the last harvest on October 11, 1960.

There was a difference in the soil potassium level between the replications. On the third replication, which

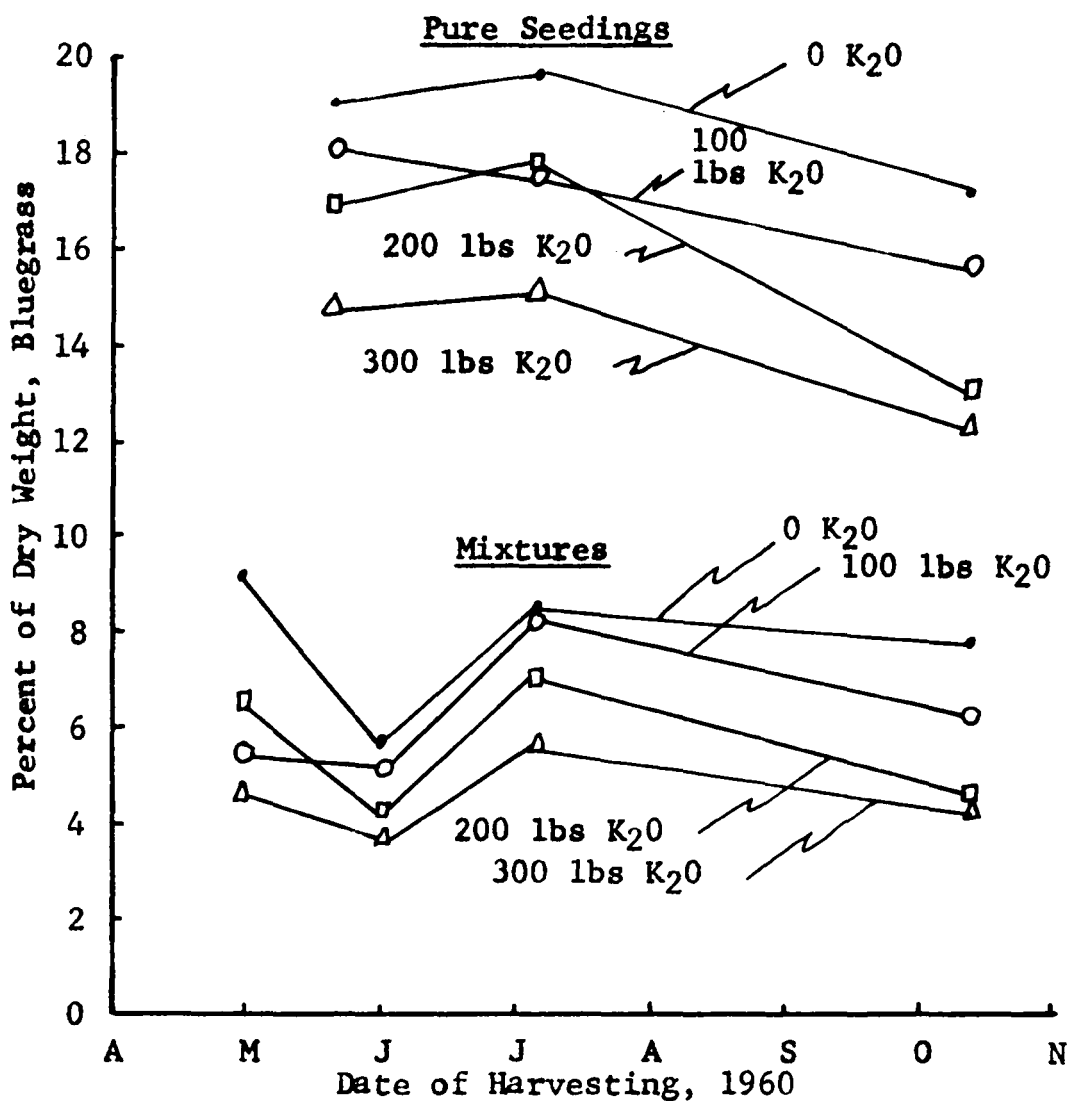


Figure 5. Seasonal changes in percentage of bluegrass as affected by K<sub>2</sub>O. Points are means of three nitrogen rates, three seedings, and three replications.

**Table 1. Bluegrass composition in percent of total yield as influenced by nitrogen and potassium fertilization of two mixtures.**

(Mean of three replications)

<b>N rate lbs/a/yr</b>	<b>100</b>	<b>300</b>	<b>500</b>	<b>Mean</b>
<b><u>K<sub>2</sub>O rate lbs/a/yr</u></b>	<b><u>Orchardgrass-Bluegrass</u></b>			
0	2.33	6.00	8.00	5.44
100	3.67	4.00	4.67	4.11
200	3.00	1.67	5.00	3.22
300	1.33	1.33	4.00	2.22
<b>Mean</b>	<b>2.58</b>	<b>3.25</b>	<b>5.42</b>	<b>3.75</b>
	<b><u>Fescue-Bluegrass</u></b>			
0	9.00	22.00	21.33	17.44
100	12.00	14.00	16.33	14.11
200	9.33	9.67	11.67	10.22
300	9.67	9.67	10.00	9.78
<b>Mean</b>	<b>10.00</b>	<b>13.83</b>	<b>14.83</b>	<b>12.89</b>

was lowest in soil  $K_2O$ , the 500 pound rate of nitrogen with no  $K_2O$  for the bluegrass-fescue mixture contained over 45 percent bluegrass. The 300 pound nitrogen rate for the same mixture contained 43 percent bluegrass. The available soil  $K_2O$  levels were only 66 and 125 pounds of  $K_2O$  per acre, respectively, for the 500 and 300 pounds nitrogen per acre rates. The 66 pounds available  $K_2O$  was the lowest  $K_2O$  level of any of the plots. Figure 6 is a photograph of sod samples from adjacent plots fertilized with 300 pounds nitrogen and different levels of  $K_2O$ .

At the low  $K_2O$  rates the companion grasses and weeds are not as vigorous as they are at the high  $K_2O$  rates; hence, bluegrass composition usually increases. Kentucky bluegrass apparently survives on low soil  $K_2O$  better than some other grasses, either because its requirement for potassium is lower or because it extracts potassium from the soil better than the other grasses. The reader will see later that bluegrass did not deplete the soil of potassium nearly as fast as orchardgrass or fescue (Figure 18) and that even at high soil  $K_2O$  levels bluegrass did not take up as much potassium as some other species. It thus appears that bluegrass has a lower potassium requirement than the other grasses used in this study.



Figure 6. Sod samples taken at random from two adjacent plots of a two-year old fescue-bluegrass mixture. Left,- no potassium; right,- 300 pounds  $K_2O$  per acre yearly. Both plots received 300 pounds nitrogen per acre yearly.

### Weed Botanical Composition

Seeding effects: All plots were weedy on June 12, 1959.

The rapid seedling growth of orchardgrass, however, enabled this species to compete with the weeds much better than fescue or bluegrass; therefore, seedings with orchardgrass had less weeds than those with fescue and bluegrass (Figure 7). Cress, lambsquarters, and ragweed were the most prevalent weeds in the sod.

On August 18, 1959, any seedings with orchardgrass had less weeds than seedings with other grasses. The percentages of weeds were 69, 67, 25, and 16 for fescue-bluegrass, fescue, orchardgrass-bluegrass, orchardgrass-fescue, and orchardgrass, respectively. Hand separations of bluegrass seedings were not made, but estimates showed 83 percent weeds in pure bluegrass seedings.

Only the pure orchardgrass and pure fescue plots were hand separated on October 16. These separations showed that pure fescue contained about 12 percent weeds, and pure orchardgrass contained only one percent weeds. Estimates showed that pure bluegrass seedings had 74 percent weeds as compared with 14 percent for the fescue-bluegrass mixture. Weeds were nil in the other treatments which had orchardgrass.

Weeds were reduced considerably in all plots during the second growing season. There were no differences in

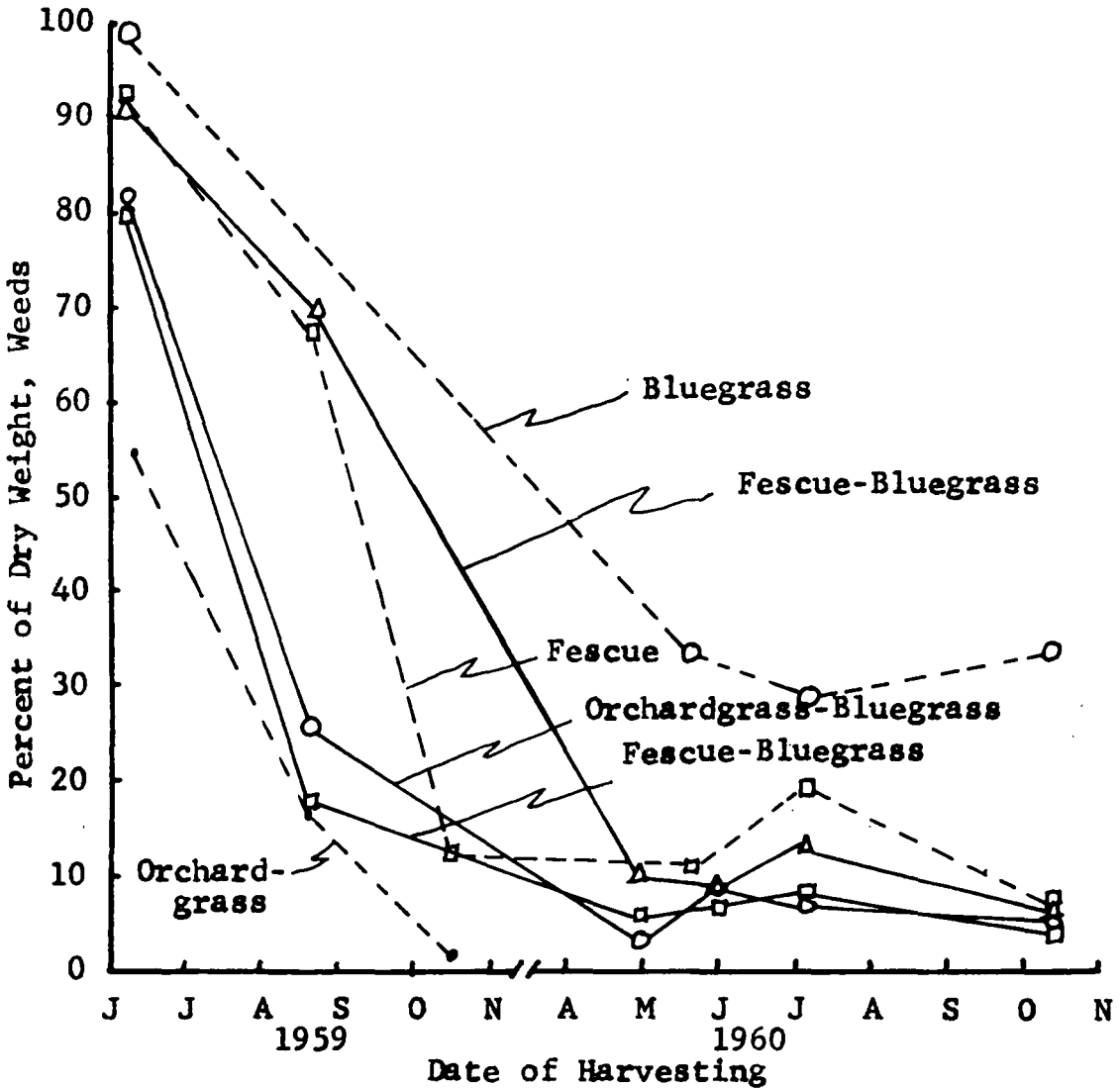


Figure 7. Seasonal changes in the percentage of weeds in pure seedings and mixtures of grasses. Each point is the mean of three nitrogen rates, four  $K_2O$  rates, and three replications.

weediness of the mixtures. However, weediness differed for the pure seedings; bluegrass always contained more weeds than pure fescue or pure orchardgrass. Some volunteer orchardgrass and fescue were always present in pure bluegrass seedings. The pure orchardgrass seedings contained such small amounts of weeds that no hand separations were made on the July 4 and October 11, 1960, cuts. The heading of quackgrass on July 4 increased the percentage of weeds in the fescue plots. Quackgrass was prevalent in the pure bluegrass seedings on October 11.

Nitrogen effects: The only effect of nitrogen on the three species of weeds separated on June 12, 1959, was a reduction in percent lambsquarters from 18 for 75 pounds of nitrogen to 8 percent for 125 pounds of nitrogen per acre. These two nitrogen rates correspond to the 300 and 500 pounds per acre per year rates, but only one-fourth of the year's allotment had been applied. Visual estimates, however, indicated that high rates of nitrogen increased the percentage of cress and ragweed.

The data indicate that the high rates of nitrogen tended to decrease the proportion of weeds in the sod during the second year. On May 18 nitrogen decreased the percentage of weeds from 35 for 100 pounds nitrogen to 29 for 500 pounds nitrogen for pure bluegrass seedings. A



similar reduction due to nitrogen was observed for all seedings on July 4. For example, the percentage of weeds in the fescue-bluegrass plots was 20, 10, and 8 for 100, 300, and 500 pounds nitrogen per acre per year, respectively.

Visual estimates also showed evidence that high nitrogen rates reduced the percentage of weeds. Evidently the high rates of nitrogen stimulated grasses more than weeds.

Potassium effects: On August 18, 1959, the effect of potassium on the percentage of weeds was linear with the increasing rates of  $K_2O$  reducing the proportion of weeds in the sod. This relationship held for the October 16, 1959, harvest, but only the 0  $K_2O$  rate was statistically different from the other three rates. At this date the percentages of weeds in pure fescue seedings were 18, 10, 8, and 10 for 0, 100, 200, and 300 pounds per acre of  $K_2O$ , respectively.

The reduction in weeds in pure fescue seedings due to high  $K_2O$  rates occurred again on July 4, 1960. The percentages of weeds were 29, 20, 14, and 14 for 0, 100, 200, and 300 pounds per acre of  $K_2O$ , respectively. On this date quackgrass was the prevalent weed. The low potassium plots could be detected in the field by the numerous quackgrass seedheads present. Visual estimates

also showed the same reduction in the percentage of weeds with increasing rates of K<sub>2</sub>O on August 18, 1959, and July 2, 1960.

### Ground Cover

Seeding effects: Estimates of ground cover were made before clipping for all dates through May 30, 1960. After May 30 estimates were made as soon as possible after clipping.

Although the statistical analysis did not show significant differences on June 12, 1959, averages for species showed an apparent higher ground cover for pure orchardgrass than for the other species. Pure orchardgrass seedings maintained the best ground cover of the six seedings on August 18, 1959. The percentages were 88<sup>d</sup>, 74<sup>a,b</sup>, 66<sup>b,c</sup>, 66<sup>b,c</sup>, 52<sup>c,d</sup>, and 44<sup>d</sup> for orchardgrass, orchardgrass-fescue, fescue, orchardgrass-bluegrass, fescue-bluegrass, and bluegrass, respectively. Bluegrass made the poorest sod cover; orchardgrass, having vigorous seedling growth, covered the ground more rapidly than the other species. Weeds comprised much of the vegetative ground cover on pure fescue and pure bluegrass seedings. All species, except bluegrass, had an excellent ground cover (over 94 percent) on October 16, 1959. Bluegrass had not spread sufficiently to cover more than 64 percent of the ground nor had it produced sufficient growth for harvesting. On April 30, 1960, there was little

difference in sod cover among species; all species covered 80 to 90 percent of the ground. Only the orchardgrass-fescue and orchardgrass-bluegrass plots ranked lower than the other four seedings. On May 19, May 24, and June 2, only those treatments containing orchardgrass were lower than the others. There was no difference between species or mixtures on July 6 or October 13, 1960.

Nitrogen effects: Nitrogen exerted very little effect on the percentage of ground cover over the two year period. On April 30, 1960, and 100 pound nitrogen rate gave less cover than 300 or 500 pounds of nitrogen. This observation was made prior to cutting. In subsequent ground cover estimates, when the observations were made following the harvest, the 100 pounds nitrogen rate gave the best cover for pure grass seedings. This rate also gave the best cover for mixtures after the final cutting.

Potassium effects: The differences in ground cover due to the rates of  $K_2O$  were very small, never being more than seven percentage points.

#### Total Dry Weight Production

Seeding effects: The yield of each seeding treatment at each of the cuttings over the two growing seasons is shown

in Figure 8. The variances over the several cuttings were highly heterogeneous; therefore, a combined analysis for yields was not made.

Pure orchardgrass seedings produced more forage than the other plots on the June 12th and August 18th cuttings in 1959, but the differences were not significant on June 12. On August 18 the yields were 1276<sup>a</sup>, 899<sup>b</sup>, 821<sup>b,c</sup>, 743<sup>b,c</sup> and 524<sup>c</sup> pounds for orchardgrass, orchardgrass-tall fescue, tall fescue, orchardgrass-bluegrass, and fescue-bluegrass seedings, respectively. On October 16 Kentucky bluegrass produced only 383 pounds of forage and the fescue-bluegrass mixture produced only 791 pounds. The other species produced over one-half ton of forage per acre.

The yields for the three pure grass seedings differed during the second growing season. On May 18, orchardgrass and bluegrass produced over one and one-half tons of forage per acre while pure fescue produced 2670 pounds per acre. There was no difference between the amount of forage produced by either of the three species by July 4. The vigorous growth of fescue during the fall enabled it to produce over 50 percent more forage than orchardgrass or bluegrass at the October 11 harvest.

The relative yield of the three mixtures fluctuated throughout the second growing season. There was no difference in yields on April 30, but on May 30 the

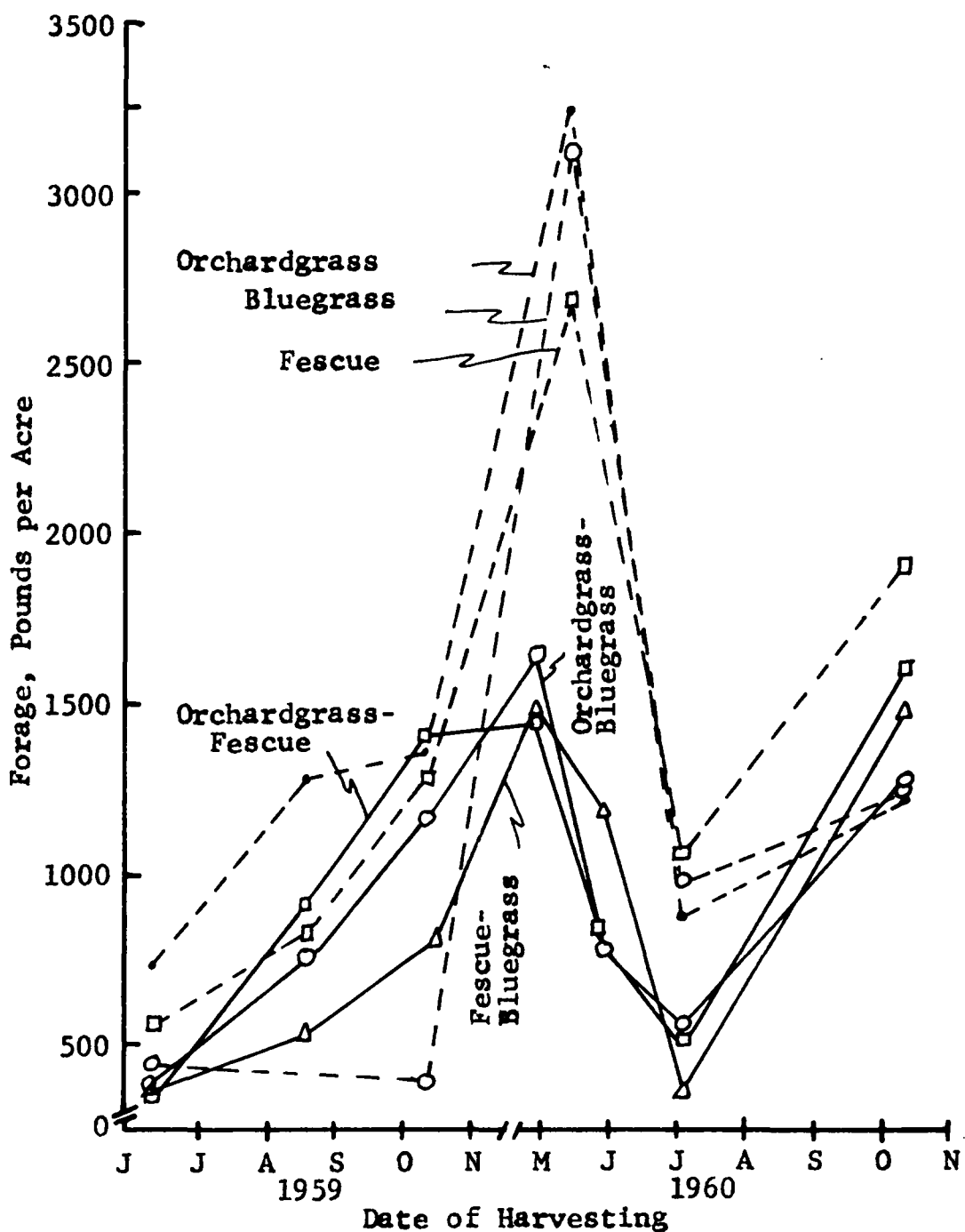


Figure 8. Seasonal production of grasses grown alone and in mixtures. Each point is an average of three nitrogen rates, four  $K_2O$  rates, and three replications.

fescue-bluegrass plots produced over 300 pounds more dry matter than other mixtures. This high yield was attributed to the seedheads of the fescue. The fescue-bluegrass plots produced about 150 pounds per acre less than the orchardgrass-fescue and orchardgrass-bluegrass plots on July 4. The orchardgrass-bluegrass plots produced over 200 pounds per acre less forage than orchardgrass-fescue or fescue-bluegrass on October 11.

Nitrogen effects: Nitrogen, up to 300 pounds, was beneficial at all cuttings except on August 18, 1959 (Figure 9). Additional nitrogen increased the yields very little. Only the pure grass seedings on May 18 and the mixtures on May 30, 1960, showed significant increases due to the additional 200 pounds of nitrogen. It is apparent that nitrogen is more efficiently utilized in the early spring and fall (Figure 9).

The yield of dry matter for each mixture as influenced by nitrogen rates is presented below for the May 30, 1960 harvest.

<u>N rates (lbs/a/yr):</u>	<u>100</u>	<u>300</u>	<u>500</u>	<u>Average</u>
Orchardgrass-fescue	523	875	1132	843
Orchardgrass-bluegrass	390	832	1084	769
Fescue-bluegrass	1025	1227	1282	1178

Nitrogen at the rate of 500 pounds per acre per year more

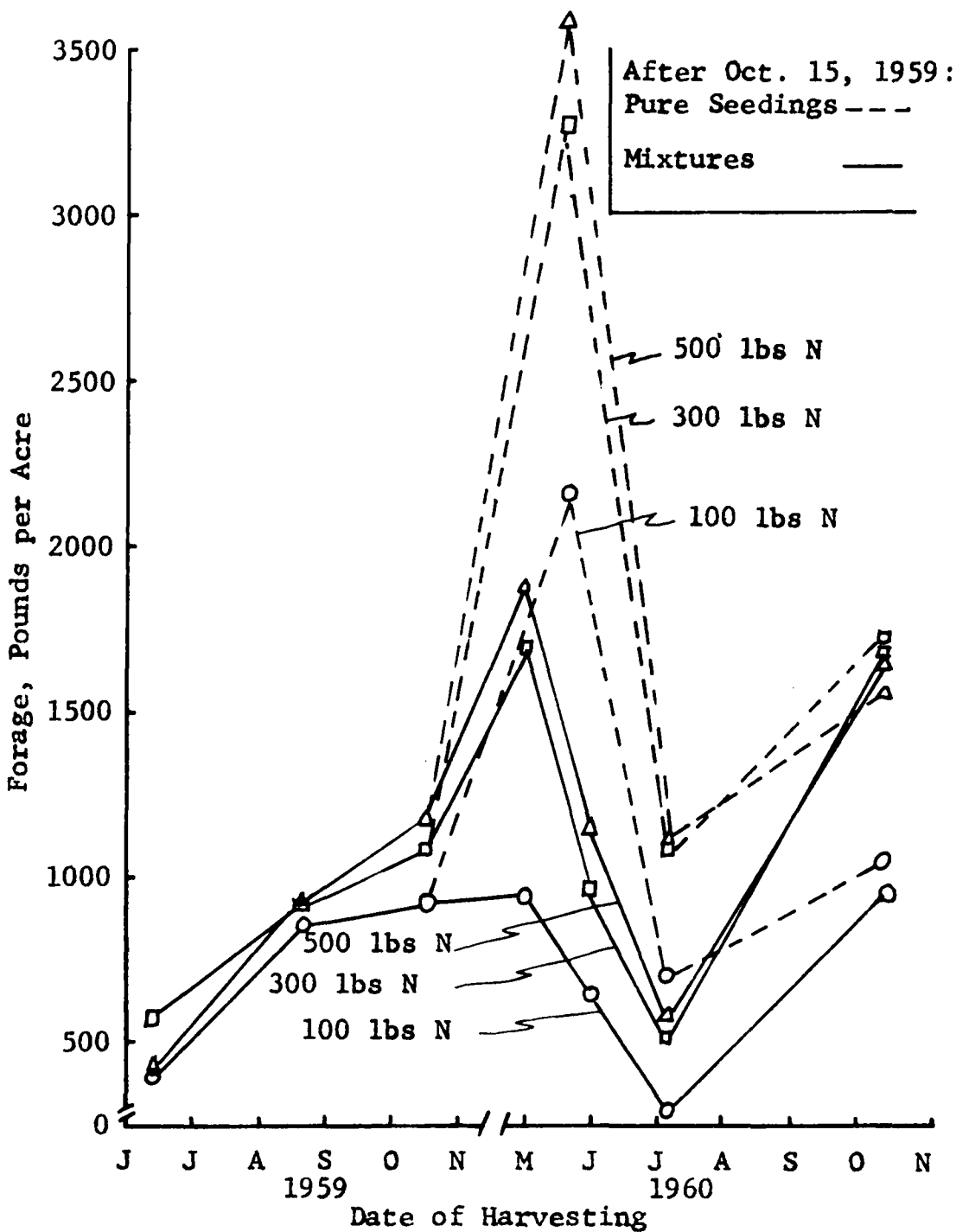


Figure 9. Seasonal production of forage as affected by rate of nitrogen. Curves in 1960 are means of four  $K_2O$  rates and three seedings. Curves in 1959 are same as above, except points on June 12, August 18, and October 16 are means of six, five, and two seedings, respectively.

than doubled the yield of the orchardgrass-fescue and the orchardgrass-bluegrass mixtures, but it increased the fescue-bluegrass yields very little. This interaction between mixtures and nitrogen levels was not evident in any of the other cuts.

Potassium effects: Potassium additions improved the yield at every cutting; however, these yield increases for mixtures on May 30 and pure grass seedings on July 4, 1960 were not significant (Figure 10). The first 100 pounds of  $K_2O$  increased the yield of most harvests by about 100 pounds of forage per acre during the first year.

The benefit from increasing the rate of  $K_2O$  was variable for the mixtures during the second growing season. On April 30, forage yields were higher for 200 pounds than for 100 pounds of  $K_2O$ , but the yield differences were small. Similar results were obtained on July 4, but the differences were less than 100 pounds per acre. By October 11 each addition of  $K_2O$  increased the yield. These yield increases from  $K_2O$  were more pronounced for 300 and 500 pounds than for 100 pounds nitrogen. For example, on October 11 the yields were 1386, 1626, 1669, and 1904 pounds of forage for 0, 100, 200, and 300 pounds of  $K_2O$ , respectively, when 500 pounds of nitrogen was used with all treatments.

The pure grass seedings showed potassium responses on



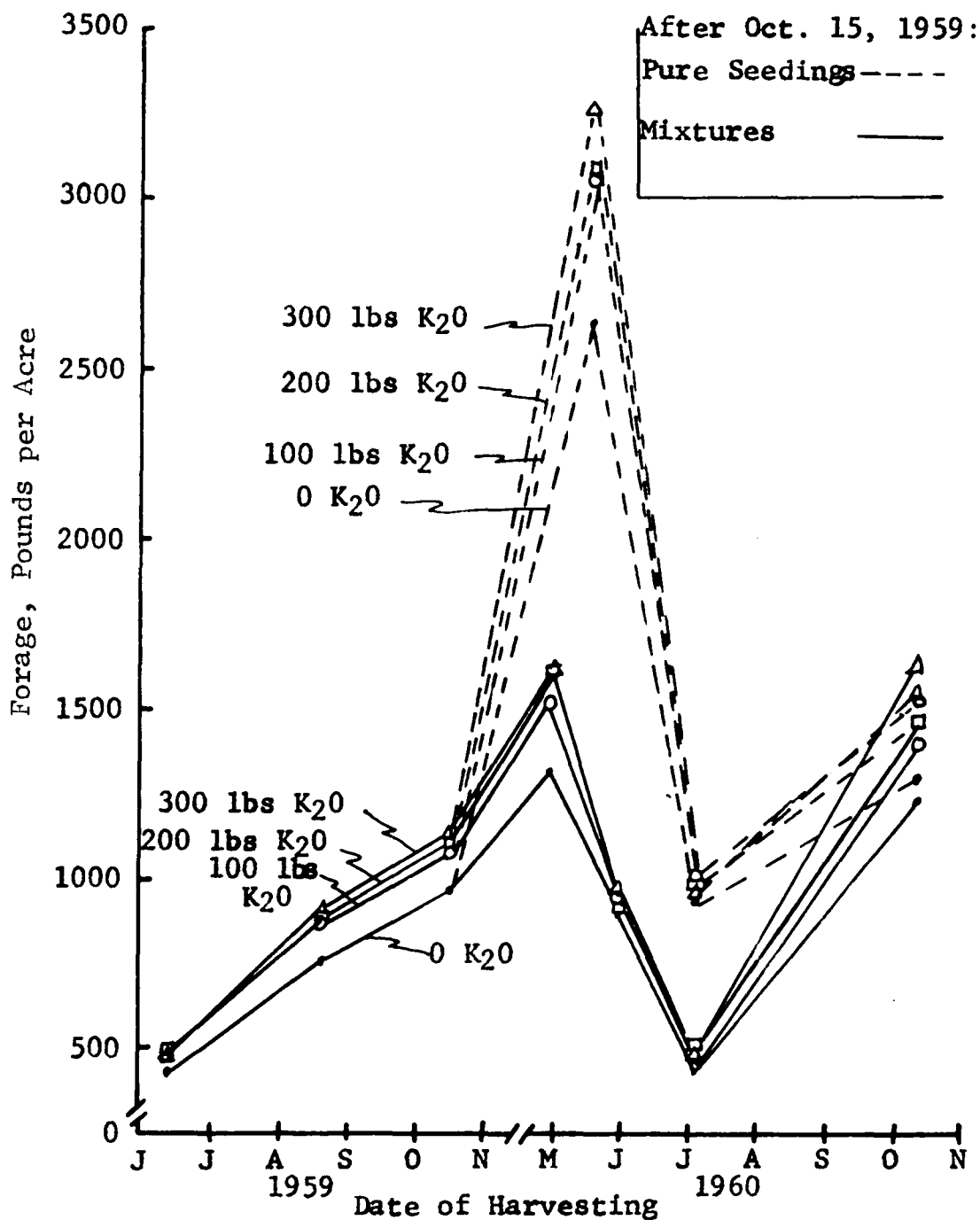


Figure 10. Seasonal production of forage as affected by rate of K<sub>2</sub>O. Curves in 1960 are means of three nitrogen rates and three seedings. Curves in 1959 are same as above, except points on June 12, August 18, and October 16 are means of six, five, and two seedings, respectively.

the May 18 and October 11 cuttings during 1960. On May 18 the yields of all three grasses increased with additional increments of  $K_2O$ , but orchardgrass was the most responsive. Average yields of orchardgrass for all nitrogen treatments were 2660, 3308, 3448, and 3559 for 0, 100, 200, and 300 pounds of  $K_2O$ , respectively. The yield of orchardgrass for 300 pounds of  $K_2O$  and 500 pounds of nitrogen was over two tons of dry matter at this cutting. Responses from potassium for pure seedings on October 11 were much less spectacular; only the 100 pounds  $K_2O$  rate gave increases over the 0 rate.

Potassium, like nitrogen, appears more beneficial in early spring and early fall. The low growth responses during summer may be attributed to other limiting growth factors, such as drought.

#### Yield of the Orchardgrass Component

Seeding effects: Orchardgrass seeded alone produced more orchardgrass than when seeded with fescue or bluegrass. Yield from pure seedings was very low (309 pounds) at the first cutting, but yields were over one-half ton at each of the succeeding harvests in 1959 (Figure 11). The highest yield (3244 pounds) occurred on May 18, 1960, when orchardgrass was heading. Drought and disease limited the yield of orchardgrass from pure seedings to about

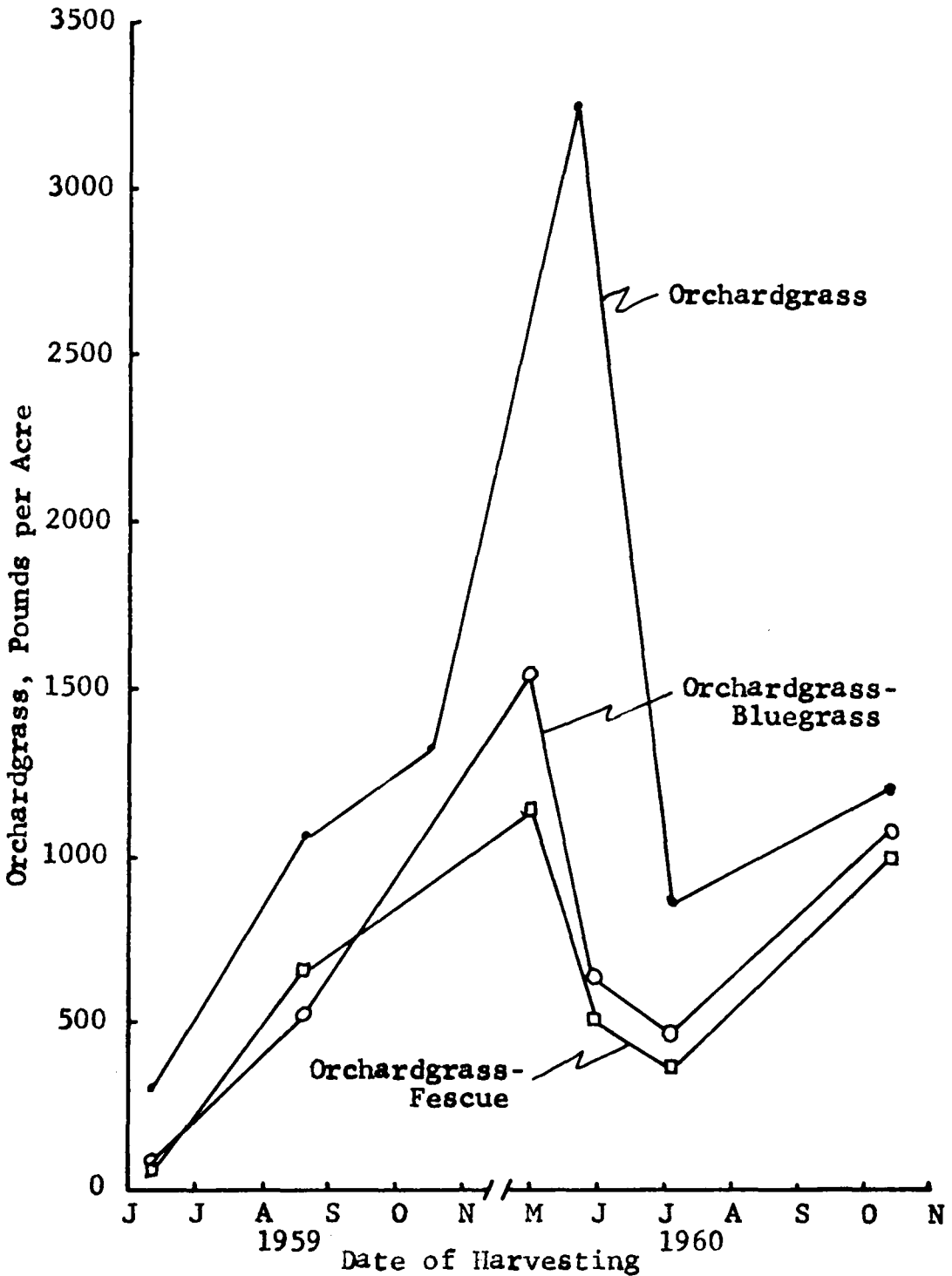


Figure 11. Seasonal production of the orchardgrass component of pure seedings and mixtures of orchardgrass. Each point is an average of three nitrogen rates, four  $K_2O$  rates, and three replications.

one-half ton per acre for both the remaining harvests in 1960.

The yield of the orchardgrass component of orchardgrass-bluegrass mixtures was higher than that of orchardgrass-fescue mixtures during the second year, but the differences were significant only on April 30 (Figure 11). The respective yields at this date were 1551 and 1155 pounds. Bluegrass was not as competitive to the orchardgrass as was fescue.

Nitrogen effects: Nitrogen applications of more than 100 pounds increased the yield very little during the seedling year, but at the spring harvest in 1960 large increases resulted from applications of 300 pounds of nitrogen (Figure 12). The average yields of the orchardgrass component in mixtures on April 30, 1960, were 864, 1562, and 1635 for 100, 300, and 500 pounds of nitrogen, respectively. The respective yields for pure seedings of orchardgrass on May 18 were 2440, 3471, and 3821 pounds. Nitrogen applications of up to 300 pounds gave small, but statistically significant, increases in yield of all seedings at the remaining harvests in 1960; significant increases in yield resulted from applications of an additional 200 pounds of nitrogen to pure seedings on May 18 and July 4 and to mixtures on May 30.

Potassium effects: Significant increases in yield of

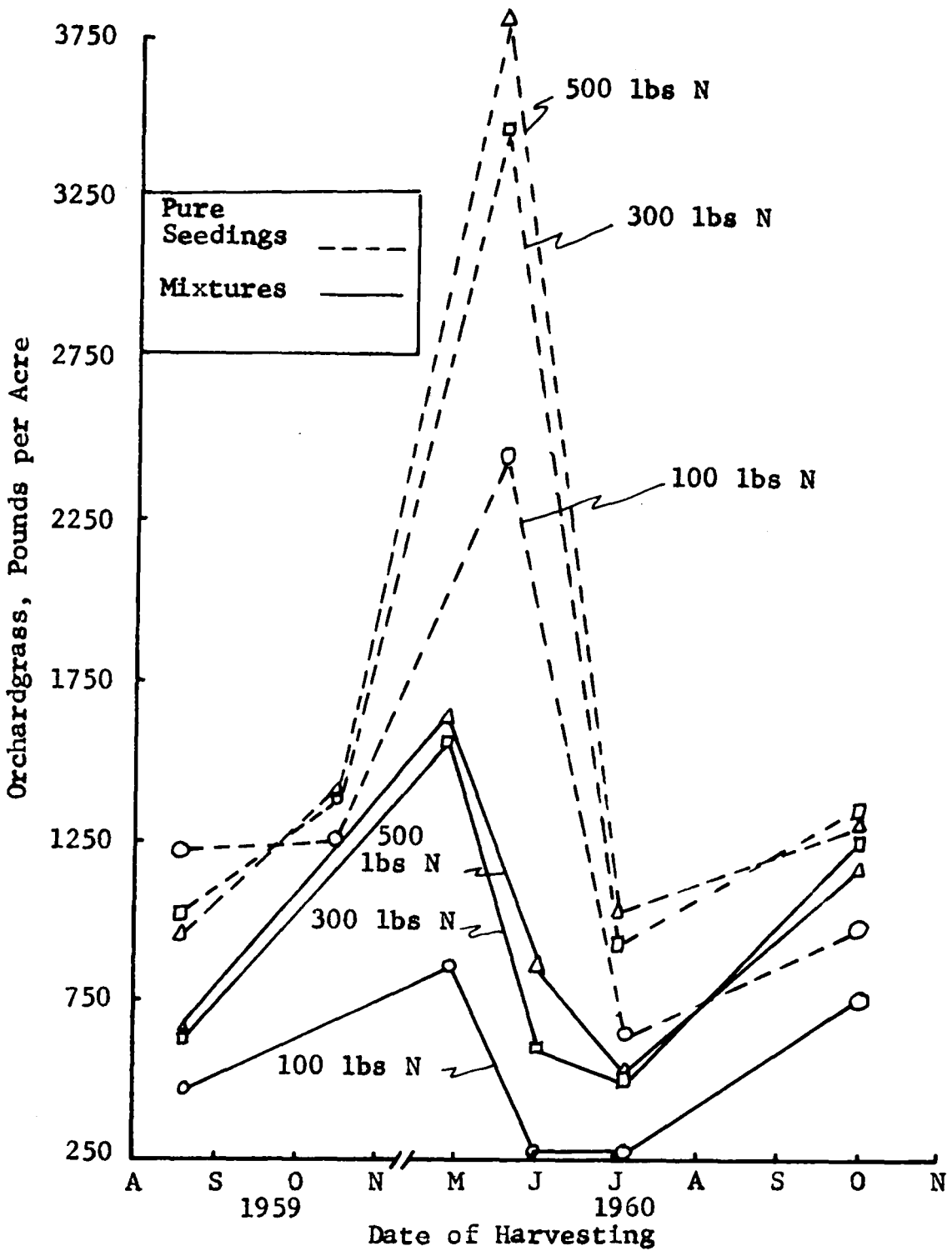


Figure 12. Seasonal production of the orchardgrass component of pure seedings and of mixtures of orchardgrass as affected by rate of nitrogen. (Mixtures were orchardgrass-fescue and orchardgrass-bluegrass).

orchardgrass occurred from  $K_2O$  applications of at least 100 pounds on pure seedings of orchardgrass at all harvests except on October 16, 1959, and July 4, 1960 (Figure 13). Largest yield increases from  $K_2O$  occurred at the May 18, 1960 harvest; yields were 2660, 3308, 3448, and 3559 for 0, 100, 200, and 300 pounds of  $K_2O$ , respectively. Significant orchardgrass yield increases from at least 100 pounds of  $K_2O$  occurred for orchardgrass mixtures on August 18, 1959, and July 4 and October 11, 1960. The average yield increase of the orchardgrass component of mixtures due to the highest level of  $K_2O$  was never more than 325 pounds.

A potassium by nitrogen interaction for mixtures on May 30, 1960, showed that the greatest responses from potassium occurred at the 500 pounds rate of nitrogen. Yields of orchardgrass from the orchardgrass-bluegrass mixture were 803, 959, 972, and 1018 for 0, 100, 200, and 300 pounds of  $K_2O$ , respectively, when 500 pounds of nitrogen was applied; the respective yields were 348, 298, 302, and 299 when 100 pounds of nitrogen was applied. A similar interaction for pure orchardgrass seedings on October 11, 1960, showed an increase of over 500 pounds of dry matter due to 100 pounds of  $K_2O$  with applications of 500 pounds of nitrogen and no increase when the same amount of  $K_2O$  was applied with 100 pounds of nitrogen. Heavy

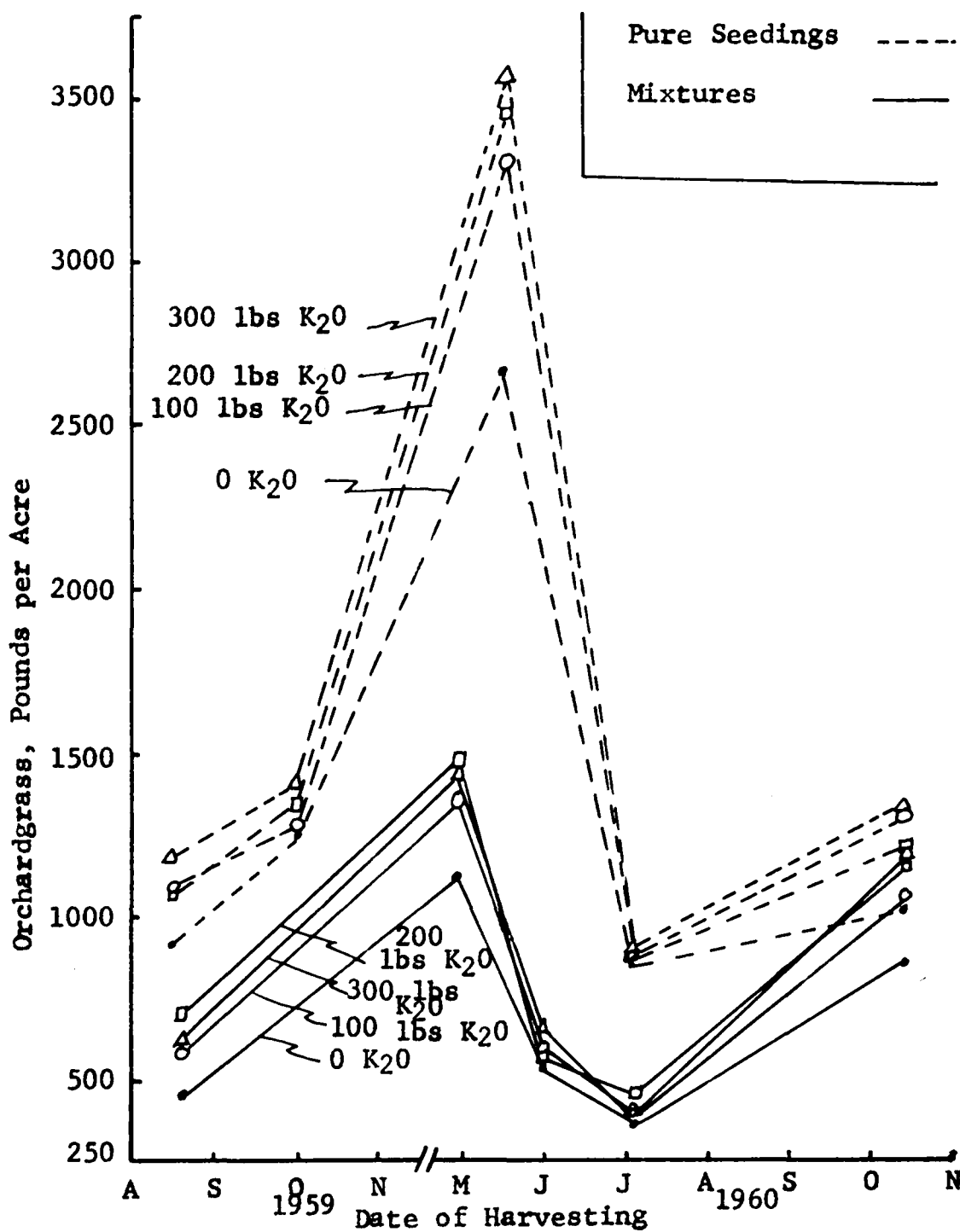


Figure 13. Seasonal production of the orchardgrass component from pure seedings and mixtures of orchardgrass as affected by rate of K<sub>2</sub>O. (Mixtures were orchardgrass-fescue and orchardgrass-bluegrass.)

nitrogen applications cause more rapid growth of herbage; hence, there is a more rapid removal of available  $K_2O$  than when low rates of nitrogen are applied. Ammonium ions tend to block the release of fixed potassium; thus the replenishment of the available form is hindered.

#### Yield of the Fescue Component

Seeding effects: The yields of the botanical component, fescue, when seeded alone and in two mixtures are given in Figure 14.

Fescue seeded alone produced more fescue throughout the two seasons than fescue-orchardgrass or fescue-bluegrass mixtures. During the first season the growth of fescue in all plots was very slow. On August 18, 1959, the yields were 219<sup>a</sup>, 83<sup>b</sup>, and 69<sup>b</sup> pounds for fescue, fescue-orchardgrass, and fescue-bluegrass, respectively. On October 16, fescue seeded alone produced 1104 pounds; yields in mixtures were not determined on this date. The largest yields of fescue from pure seedings of fescue were 2141 pounds on May 18 and 1617 pounds on October 11, 1960. Fescue-bluegrass mixtures produced more fescue than fescue-orchardgrass mixtures during the second year, because the aggressiveness of orchardgrass retarded fescue more than bluegrass. For example, on May 30 the yields were 870 and 258 pounds, respectively, for fescue-bluegrass



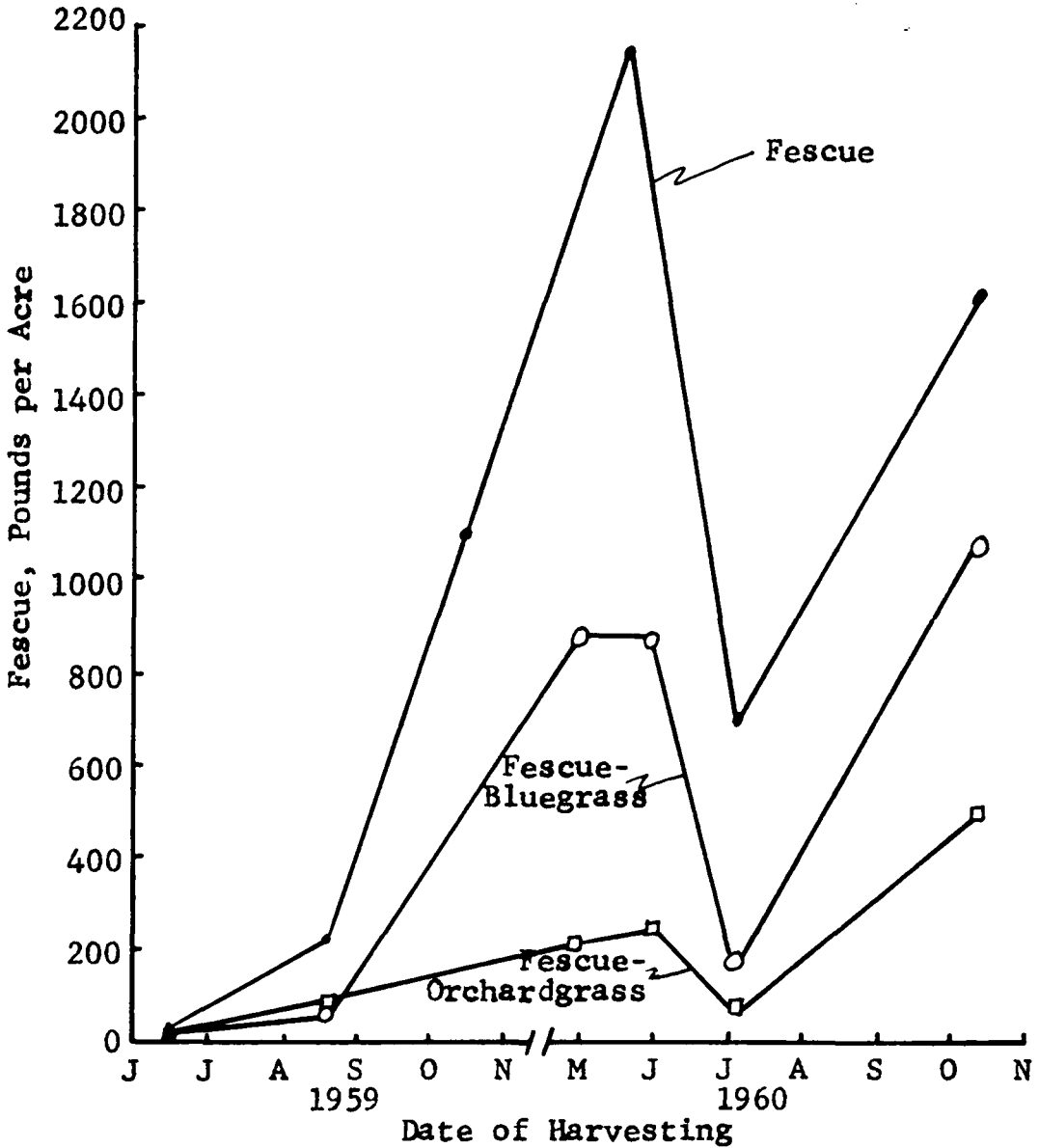


Figure 14. Seasonal production of the fescue component of pure seedings and mixtures of fescue. Each point is an average of three nitrogen rates, four  $K_2O$  rates, and three replications.

and fescue-orchardgrass. Fescue was productive in fall as shown by the yield of over one-half ton of fescue in the fescue-bluegrass seedings on October 11, 1960.

Fescue in the fescue-orchardgrass mixture yielded about 500 pounds on the same date.

Nitrogen effects: Fescue yields increased at a diminishing rate with increase in nitrogen fertilization for the June 12, August 18, and October 16, 1959, cuttings; but the increase was very small for the first two cuts of that year (Figure 15). Three hundred pounds of nitrogen increased the yield more than the 100 pound rate for both mixtures and pure stands for all cuttings, except May 30, during the second year. The 500 pound rate of nitrogen did not increase yield more than the 300 pound rate. Yield increases from nitrogen were higher for the pure fescue seedings and fescue-bluegrass mixtures than for fescue-orchardgrass mixtures. These yields are tabulated below for each cut during 1960.

<u>Date</u>		<u>N rate (lbs/A/yr)</u>		
		<u>100</u>	<u>200</u>	<u>500</u>
	<u>Pure Fescue</u>			
May 18		1643	2563	2217
July 4		431	940	748
October 11		1056	2161	1634
	<u>Fescue-Bluegrass</u>			
April 30		536	1002	883
May 30		813	895	902
July 4		65	219	263
October 11		626	1375	1255

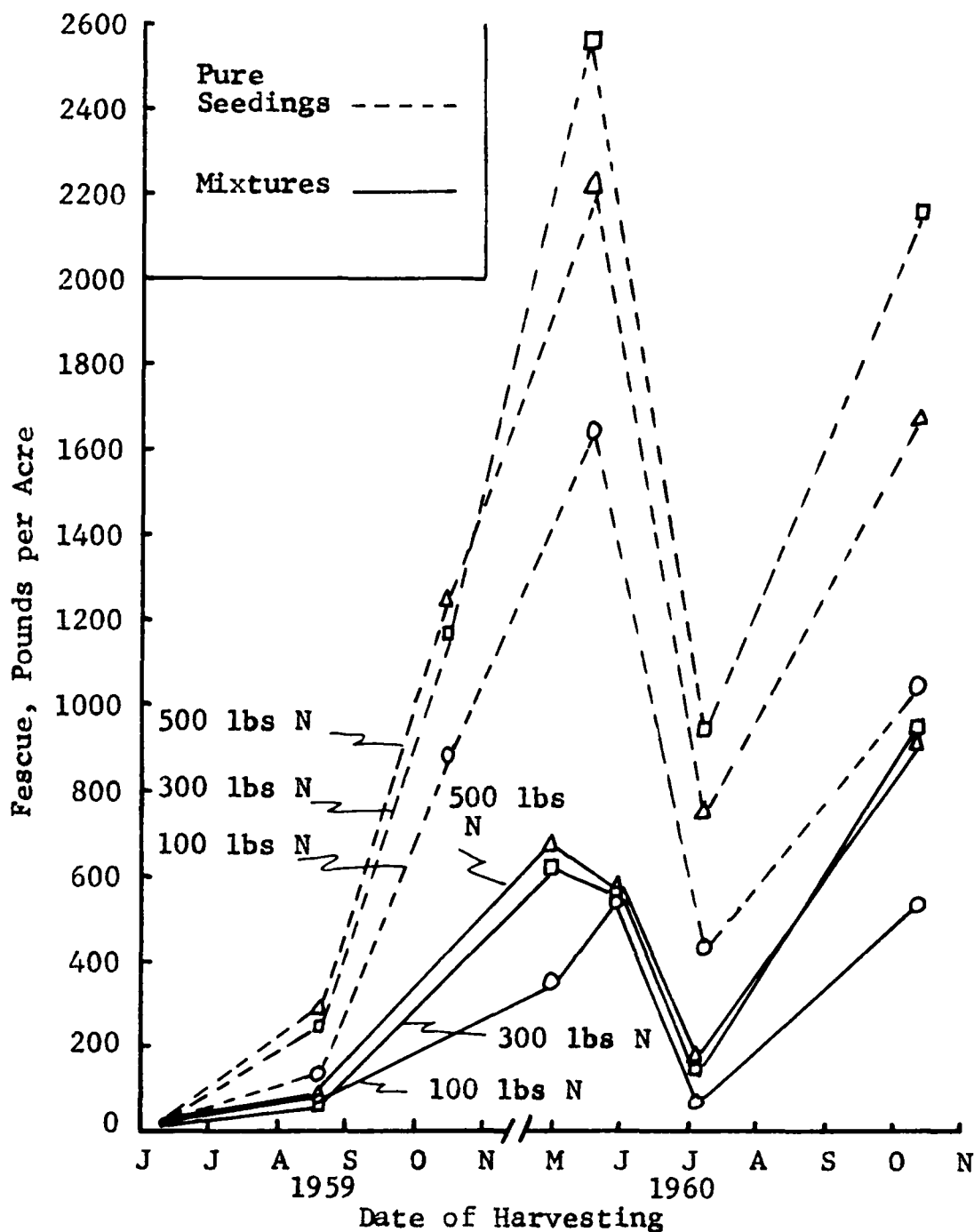


Figure 15. Seasonal production of the fescue component from pure seedlings and mixtures of fescue as affected by rate of nitrogen. (Mixtures were fescue-orchardgrass and fescue-bluegrass.)

Potassium effects: All the cuttings showed increases in yield of fescue as a result of potassium fertilization (Figure 16); however, the increases were not significant for any seedings on June 12, 1959, and for the pure fescue seedings on July 4, 1960. On August 18, 1959, the yield of fescue in fescue seedings was increased 69 percent by adding 150 pounds of  $K_2O$ . Similar increases for pure fescue occurred on October 16, 1959, and for fescue-bluegrass mixtures on April 30, 1960. The yields of pure fescue were 1740, 2158, 2138, and 2527 for 0, 100, 200, and 300 pounds of  $K_2O$ , respectively, on May 18, 1960. Even the volunteer fescue in the pure bluegrass seedings increased from 100 pounds to 300 pounds per acre by the addition of 300 pounds of  $K_2O$ . Yield of the fescue component of fescue-bluegrass mixtures on May 30, 1960, was increased by about 200 pounds with applications of up to 200 pounds of  $K_2O$ ; but there was no increase in the fescue component of fescue-orchardgrass mixtures due to  $K_2O$ . Similar results occurred on July 4. Fescue, when seeded alone, produced highest yields with 100 pounds of  $K_2O$  on October 11, 1960. The fescue-bluegrass mixtures showed increases in yield of fescue with each additional increment of  $K_2O$  on October 11. This increase was even more pronounced at the higher rates of nitrogen. For example,

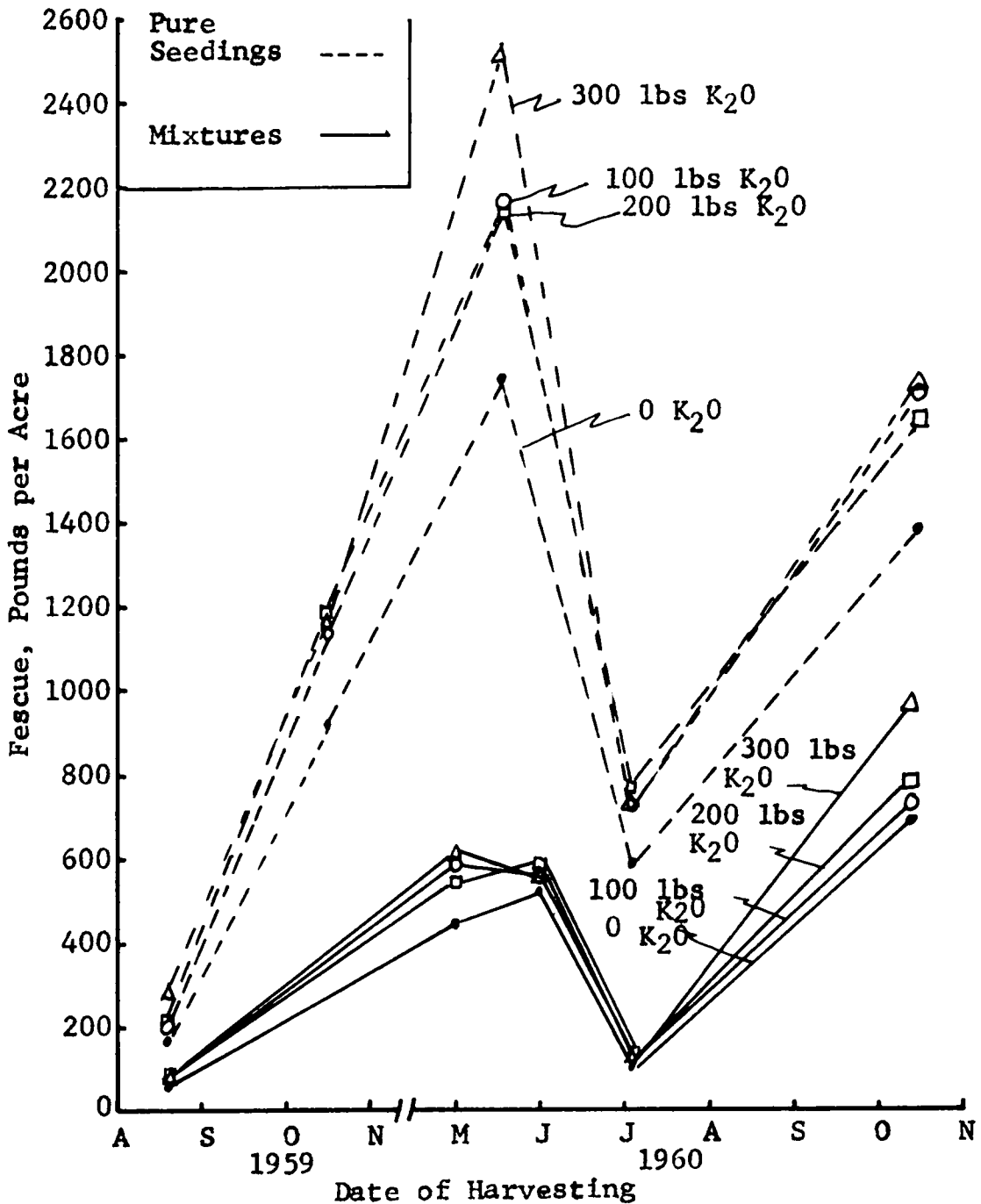


Figure 16. Seasonal production of the fescue component from pure seedlings and mixtures of fescue as affected by K<sub>2</sub>O. (Mixtures were fescue-orchardgrass and fescue-bluegrass.)

the yield of fescue with 300 pounds of nitrogen was 1040, 1191, 1556, and 1714 pounds for 0, 100, 200, and 300 pound rates of  $K_2O$ , respectively. There was no yield increase with increasing rates of  $K_2O$  with 500 pounds of nitrogen on the fescue-orchardgrass mixtures, but small increases did occur with 100 pounds of nitrogen. Orchardgrass was not as aggressive to fescue at the low nitrogen rates as at the high rates; hence, fescue responded at the low rates.

#### Yield of the Bluegrass Component

Seeding effects: The bluegrass component of the forage was not determined the first growing season because of poor growth; only the pure bluegrass and the bluegrass-fescue seedings produced significant yields of bluegrass during the second season. The vigorous seedling growth of orchardgrass shaded out most of the bluegrass in bluegrass-orchardgrass mixtures. Average yields of the bluegrass component of pure bluegrass seedings were 1616, 503, and 528 pounds for harvests on May 18, July 4, and October 11, respectively. The yield of the bluegrass component of bluegrass-fescue mixtures was 254, 116, 63, and 178 pounds on April 30, May 30, July 4, and October 11, respectively. The respective yields for the bluegrass-orchardgrass mixture were 27, 31, 20, and 47 pounds.

Nitrogen and potassium effects: Bluegrass yields usually increased with increases in nitrogen fertilization. The greatest response from nitrogen by mixtures occurred on October 11, when yields of the bluegrass component were 80, 216, and 238 pounds, respectively, for 100, 300, and 500 pounds of nitrogen. The respective yields from pure seedings on May 18 were 937, 1804, and 2110 pounds.

Potassium fertilization did not increase the yield of the bluegrass component for any of the mixtures. Significant decreases in yield occurred on May 30; yields were 138, 122, 109, and 95 pounds for 0, 100, 200, and 300 pounds of  $K_2O$ , respectively. Bluegrass yields for pure seedings were never greater with 300 pounds of  $K_2O$  than they were without  $K_2O$ . Yields for pure seedings at the 300 pound rate of nitrogen were 837, 704, 722, and 423 pounds, respectively, for 0, 100, 200, and 300 pounds of  $K_2O$  at the October 11 harvest. Other species compete with bluegrass when liberal amounts of potassium are present; hence, bluegrass is crowded out. Growth of other species is less with low rates of  $K_2O$ , and the potassium requirement for bluegrass is less than most other species; therefore, yield of the bluegrass component is greater than other species at low rates of  $K_2O$ .

### Yield of the Weed Component

Seeding effects: The yield of weeds for each of the seeding variables at each cutting date for the two growing seasons is given in Figure 17. At the harvest on June 12, 1959, the different seedings did not affect the amount of cross, ragweed, or lambsquarters; however, the yield of all weeds was lower on the orchardgrass-fescue and fescue-bluegrass seedings than for the other four seeding treatments. There were 125 pounds more weeds per acre on fescue than for orchardgrass seedings on October 16, 1959. Pure orchardgrass seedings were almost free of weeds at this date, having only 13 pounds of weeds.

Bluegrass seeded alone was the most weedy of all seedings, having one half ton of weeds on May 18, 1960. Fescue seeded alone was next with 281 pounds of weeds per acre, and orchardgrass was free of weeds. This relationship of weedy contamination among the seedings was true for the October 11, 1960 harvest, but the yield of weeds was less than 300 pounds in both the July 4 and October 11 harvests. There was no difference in the amount of weeds produced by any of the three mixtures during the second year.

Nitrogen effects: Applications of 75 pounds of nitrogen produced more lambsquarters than either the 25 or 125 pound rate on June 12, 1959. The yields were 85, 161, and 39



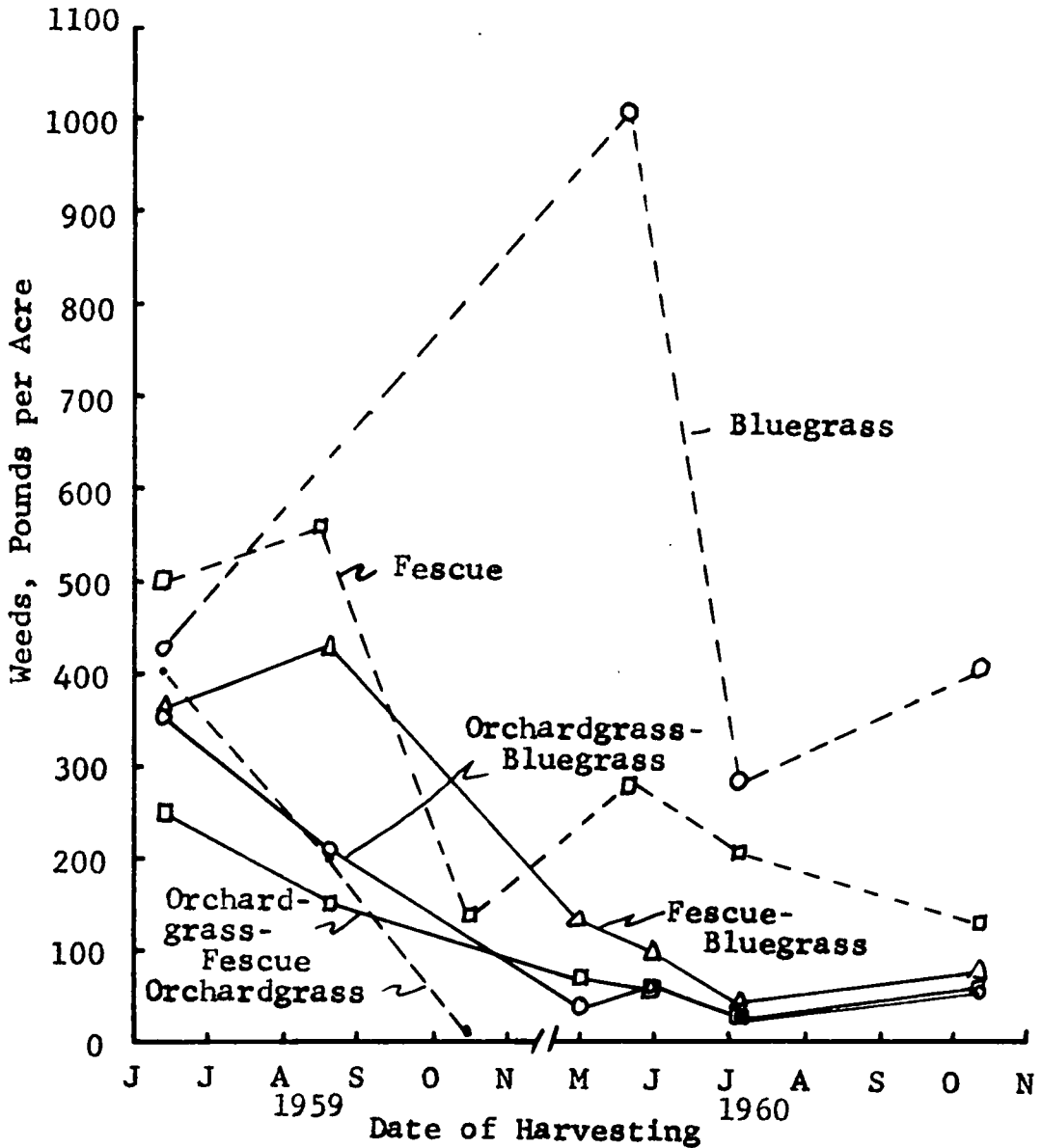


Figure 17. Weediness at various dates of three grasses seeded alone and in mixtures. Each point is the mean of three nitrogen, four K<sub>2</sub>O rates, and three replications.

pounds for 25, 75, and 125 pounds of nitrogen, respectively. Similar results were obtained for ragweed and weeds other than cress, lambsquarters, and ragweed. Both 75 and 125 pounds of nitrogen per acre increased the amount of cress produced.

During 1960 there were more weeds with 300 than with 100 pounds of nitrogen for all mixtures on April 30, May 30, and October 11. The average increase in weed yield was less than 200 pounds per acre for any one cutting.

Nitrogen fertilization also stimulated weeds in seedings with individual grasses on May 18 and October 11, 1960. Pure seedings of bluegrass yielded 738<sup>a</sup>, 1180<sup>b</sup>, and 1105<sup>b</sup> pounds of weeds for 100, 300, and 500 pounds of nitrogen, respectively, on May 18. Pure seedings of fescue made similar responses, but yields were smaller. Weed yields for the three grasses combined were 122<sup>a</sup>, 177<sup>a,b</sup>, and 239<sup>b</sup> pounds for 100, 300, and 500 pounds of nitrogen, respectively.

Potassium effects: The effect of potassium on the amount of weeds produced during the two growing seasons was very small and variable. High rates of K<sub>2</sub>O reduced the amount of weeds produced in the pure fescue seedings on July 4, 1960. The yields of weeds were 327, 230, 146, and 135 pounds per acre for 0, 100, 200, and 300 pounds of K<sub>2</sub>O,

respectively. Fescue was thinner in the low potassium plots; hence, this permitted weeds to encroach.

#### **Total Yields for the 1960 Growing Season**

Total yields for all seedings, nitrogen rates, and potassium rates for 1960 are presented in Table 2. Comparisons between pure stands and mixtures are confounded with cutting frequency, since mixtures were cut four times and pure stands were cut only two times. These differences in cutting treatments were the primary cause of the reduced yield of mixtures in comparison to pure stands. There were no differences in the yield of orchardgrass, fescue, or bluegrass when grown in pure stands. Neither were there any differences in yield of mixtures of any two of these species.

An increase in yield of 2105 pounds was obtained by increasing the nitrogen rate from 100 to 300 pounds (Table 2). An additional 200 pounds of nitrogen increased the yield an additional 277 pounds. It is apparent that 500 pounds of nitrogen is beyond the point of economical returns.

Each additional increment of potassium fertilizers increased the yield slightly (Table 2). An application of 300 pounds of potassium raised the yield 859 pounds over that of plots without potassium, but the first

Table 2. Total yield (lbs/A) of dry matter for three grasses seeded alone and in mixtures as affected by various nitrogen and potassium rates, 1960.

(Mean of three replications)

N rates lbs/A/yr	Species or Mixtures Seeded				Mean	Species or Mixtures Seeded				Mean		
	100	300	500	Mean		100	300	500	Mean			
	Orchardgrass					Tall Fescue						
0	3743	4794	5005	4514	3598	5709	5753	5020	3468	6033	5542	5014
100	4041	5841	6539	5480	3978	6775	6794	5849	3879	5977	6121	5325
200	4134	6015	6453	5534	4002	6341	6547	5630	4102	5887	6326	5438
300	4316	6336	6633	5762	3868	7283	6750	5967	3864	5979	6660	5501
Mean*	4059	5746	6163	5322 <sup>a</sup>	3861	6527	6461	5616 <sup>a</sup>	3828	5969	6162	5319 <sup>a</sup>
	Orchardgrass-Fescue					Orchardgrass-Bluegrass					Fescue-Bluegrass	
0	2586	4280	4850	3905	2476	4440	4236	3717	2707	4461	4770	3980
100	2879	4528	5011	4139	2905	4725	5158	4263	3011	4773	5441	4408
200	3168	5357	5570	4698	2835	5038	5306	4393	2753	5231	5753	4579
300	2982	5400	5901	4761	2809	4982	5407	4399	3200	5631	5912	4914
Mean*	2904	4891	5333	4376 <sup>b</sup>	2756	4796	5027	4193 <sup>b</sup>	2918	5024	5469	4470 <sup>b</sup>
	Mean of all Pure Seedings and Mixtures											
0	3096 4953 5026 4358 <sup>f</sup>											
100	3449 5436 5847 4910 <sup>g</sup>											
200	3499 5644 5992 5045 <sup>h</sup>											
300	3507 5935 6210 5217 <sup>i</sup>											
Mean*	3387 <sup>c</sup> 5492 <sup>d</sup> 5769 <sup>e</sup> 4883											

\* Means with the same letter are in the same yield category.

increment of 100 pounds produced the largest increment increase in yield of 552 pounds per acre. The application of 100 pounds of  $K_2O$  increased the dry matter yields of pure seedings of fescue and orchardgrass by as much as 829 pounds.

The statistical analysis revealed a potassium by species and a potassium by nitrogen interaction. Bluegrass plots produced more dry matter than orchardgrass and as much as fescue without  $K_2O$ , but the yields of bluegrass were lower than for the other species with  $K_2O$  applications. The potassium by nitrogen interaction was caused by the greater yield response to potassium when higher rates of nitrogen were used. The increase in yield of the plots receiving 300 pounds potassium over the no potassium plots was 411, 982, and 1184 pounds for applications of 0, 300, and 500 pounds of nitrogen per acre, respectively.

#### Available Soil $K_2O$

Seeding effects: There was no difference in the amount of available soil  $K_2O$  due to seedings in 1959; however, by May 23, 1960 the pure orchardgrass plots contained an average of 370 pounds  $K_2O$  as compared with higher values of 459 pounds for fescue and 607 pounds for bluegrass (Figure 18). The soil growing orchardgrass contained a

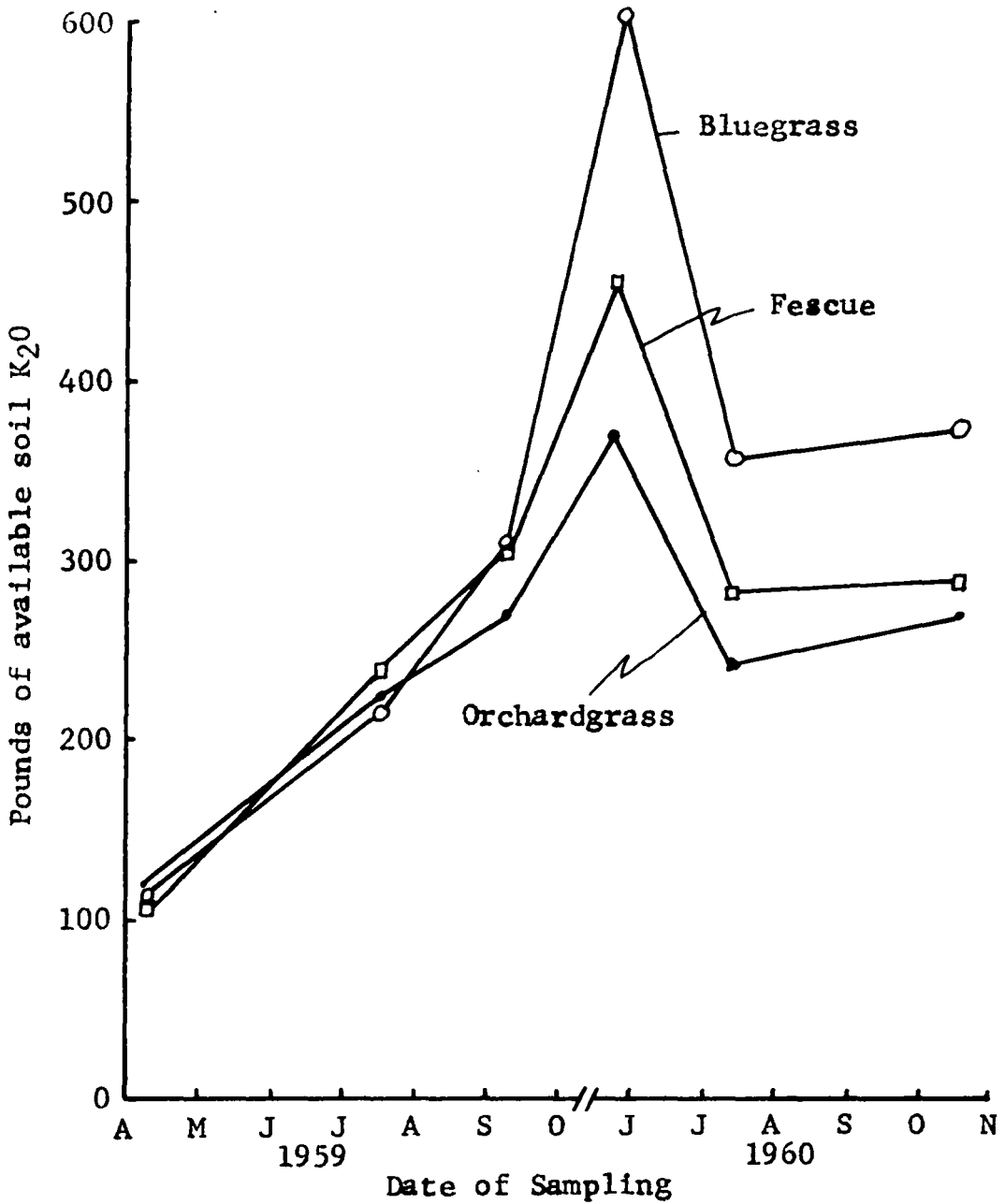


Figure 18. Seasonal changes in the available soil K<sub>2</sub>O as affected by growth of three grasses. Points are means of three nitrogen rates, four K<sub>2</sub>O rates, and three replications.

little over one-half as much  $K_2O$  as for bluegrass. Similar trends were evident for soil samplings on July 11 and October 17, but the differences were not as pronounced. The  $K_2O$  content of the soil from the mixtures was intermediate between these extremes and did not differ statistically.

Nitrogen effects: Increasing rates of nitrogen decreased the amount of available  $K_2O$  in the soil at every sampling, but the differences between the 300 and 500 pound nitrogen rates were not significant on May 23 and July 11, 1960 (Figure 19). Higher levels of nitrogen increased the yield, and thus more  $K_2O$  was removed in the forage than at low levels of nitrogen. The competition by the ammonium ion ( $NH_4NO_3$  fertilizer) with the potassium ion for exchange spots of the clay might also have accounted for some of the reduction in soil  $K_2O$ .

Potassium effects: Each increment of potassium increased the  $K_2O$  content of the soil at all sampling dates through May 23, 1960 (Figure 20). At this date soil fertilized with the 300 pound  $K_2O$  rate had over 750 pounds available  $K_2O$  per acre. Plots without additional potassium doubled in available soil  $K_2O$  content during this period, even though they produced over two tons of forage. This high potassium release of the soil explains why responses from potassium were generally low. The  $K_2O$

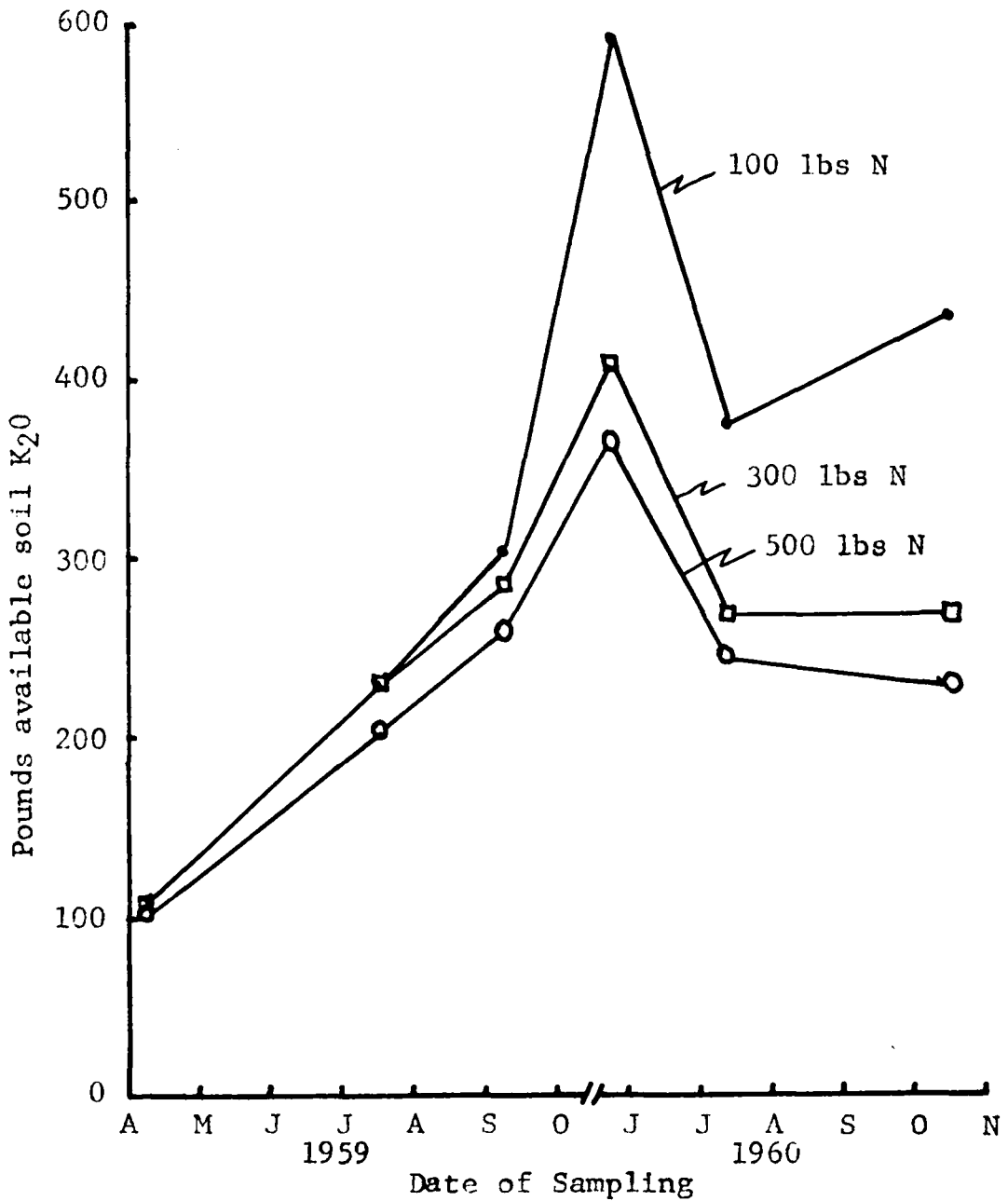


Figure 19. Seasonal changes in the available soil K<sub>2</sub>O as affected by nitrogen. Points through the May 23, 1960, sampling are means of six seedings, four K<sub>2</sub>O rates, and three replications. Remaining points are as above except means are for three pure grass seedings.



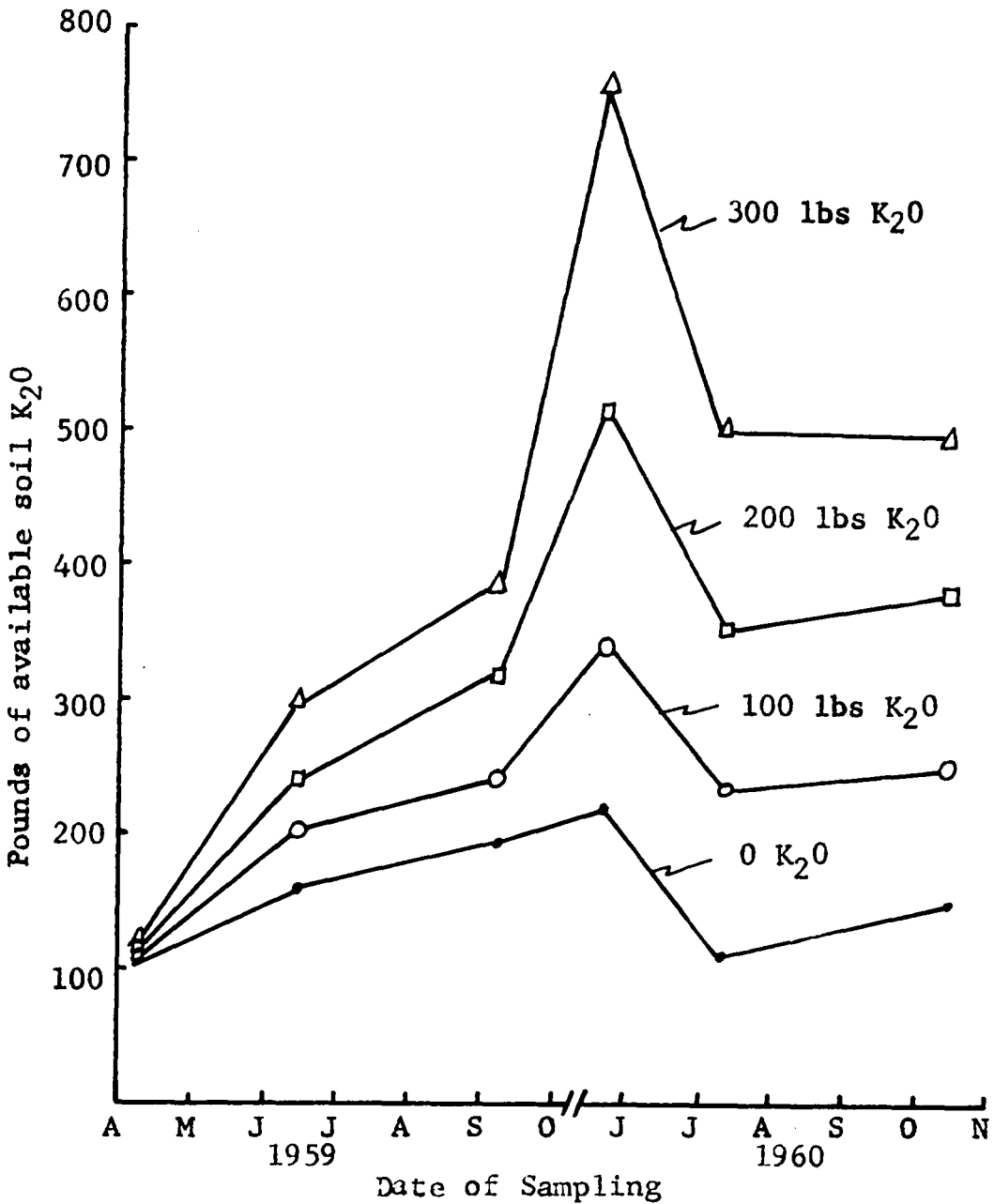


Figure 20. Seasonal changes in the available soil K<sub>2</sub>O as affected by K<sub>2</sub>O. Points through May 23, 1960, are means of six seedings and three nitrogen rates. Remaining points are as above except means are of three pure grass seedings.

level on the no potassium plots never fell below that of the original analysis. There was little change in the soil  $K_2O$  level between the final two samplings, indicating that the available  $K_2O$  in the soil might be reaching an equilibrium with rates of fertilization. The average  $K_2O$  content of the soil of mixtures at the last sampling on October 17 was 147, 257, 391, and 493 pounds for the 0, 100, 200, and 300 pound  $K_2O$  rates, respectively. Similar results were obtained from the pure stands.

#### Available Soil $CaO$ , $MgO$ , and $P_2O_5$

The seedings had no effect on available soil  $CaO$ ,  $MgO$ , and  $P_2O_5$ .

The available  $CaO$  and  $MgO$  in the soil was reduced with increased rates of nitrogen (Table 3). The reduction in available  $CaO$  was consistent at all soil sampling dates, except October 17, 1960. A two ton application of lime on July 22, 1960 increased the  $CaO$  content of all plots to around 4500 pounds. Nitrogen reduced the  $MgO$  content of the soil at all sampling dates in 1959 but did not at any of the sampling dates in 1960. Nitrogen during the second season was applied in the form of ANL, which contains seven percent  $MgO$  due to the dolomite filler. Greater yields due to high nitrogen causes greater removal of calcium and magnesium ions from the

Table 3. Seasonal changes in the available soil CaO and MgO as affected by nitrogen and potassium fertilization. All values are means of three replications; values for nitrogen are means of potassium rates; values for potassium are means of nitrogen rates. (1959 and 1960)

N rates lbs/A/yr	Composite of all Seedings						Pure Seeding		Mean			
	Apr. 8*		July 15		Sept. 7		May 23	July 11		July 11	Oct. 17	Oct. 17
	Pounds CaO											
100	2523	971	2081	1807	1190	1569	4500	4500	2393			
300	2613	926	1306	778	573	560	4500	4500	1970			
500	2613	805	831	271	372	488	4500	4500	1798			
K <sub>2</sub> O rates lbs/A/yr	Pounds MgO											
0	2576	929	1374	1058	775	852	4500	4500	2071			
100	2580	887	1490	859	722	1126	4500	4500	2083			
200	2754	904	1471	1017	700	727	4500	4500	2072			
300	2418	880	1286	872	650	785	4500	4500	1986			
N rates lbs/A/yr	Pounds MgO											
100	286	169	236	190	275	275	341	340	264			
300	289	163	199	182	278	266	325	328	254			
500	285	147	147	156	292	276	338	351	249			
K <sub>2</sub> O rates lbs/A/yr	Pounds MgO											
0	285	164	202	187	306	275	353	338	264			
100	289	162	202	181	288	281	343	344	261			
200	296	160	196	178	274	275	313	346	255			
300	277	154	176	159	258	257	329	331	243			

\* Soil test before fertilization.

soil than with low nitrogen. The ammonium ion replaces some of the calcium and magnesium on the exchange spots of the clay, thus making them more available for uptake by plants or leaching.

Potassium fertilization had little influence on the available CaO content of the soil, but higher rates reduced the MgO content at all sampling dates, except for mixtures on July 11 and October 17, 1960 (Table 3).

Seeding and fertilizer treatments had little effect on the available  $P_2O_5$  content of the soil. The only significant influences were a reduction in  $P_2O_5$  with increases in  $K_2O$  on July 15, 1959, and a similar reduction with increasing nitrogen on September 7, 1959.

#### Soil pH

High rates of nitrogen reduced the pH of the soil drastically at all sampling dates (Figure 21). Even though two tons of lime had been applied, 125 pounds of nitrogen in the form of  $NH_4NO_3$  reduced the pH from 6.6 to 5.9 by July 15, 1959. The pH continued to drop the second year, even though ANL was the nitrogen source. The application of limestone on July 11, 1960, increased the pH of all plots to above 6.0 by October 17.

The influence of potassium on pH was not consistent, but usually very small increases in pH occurred with

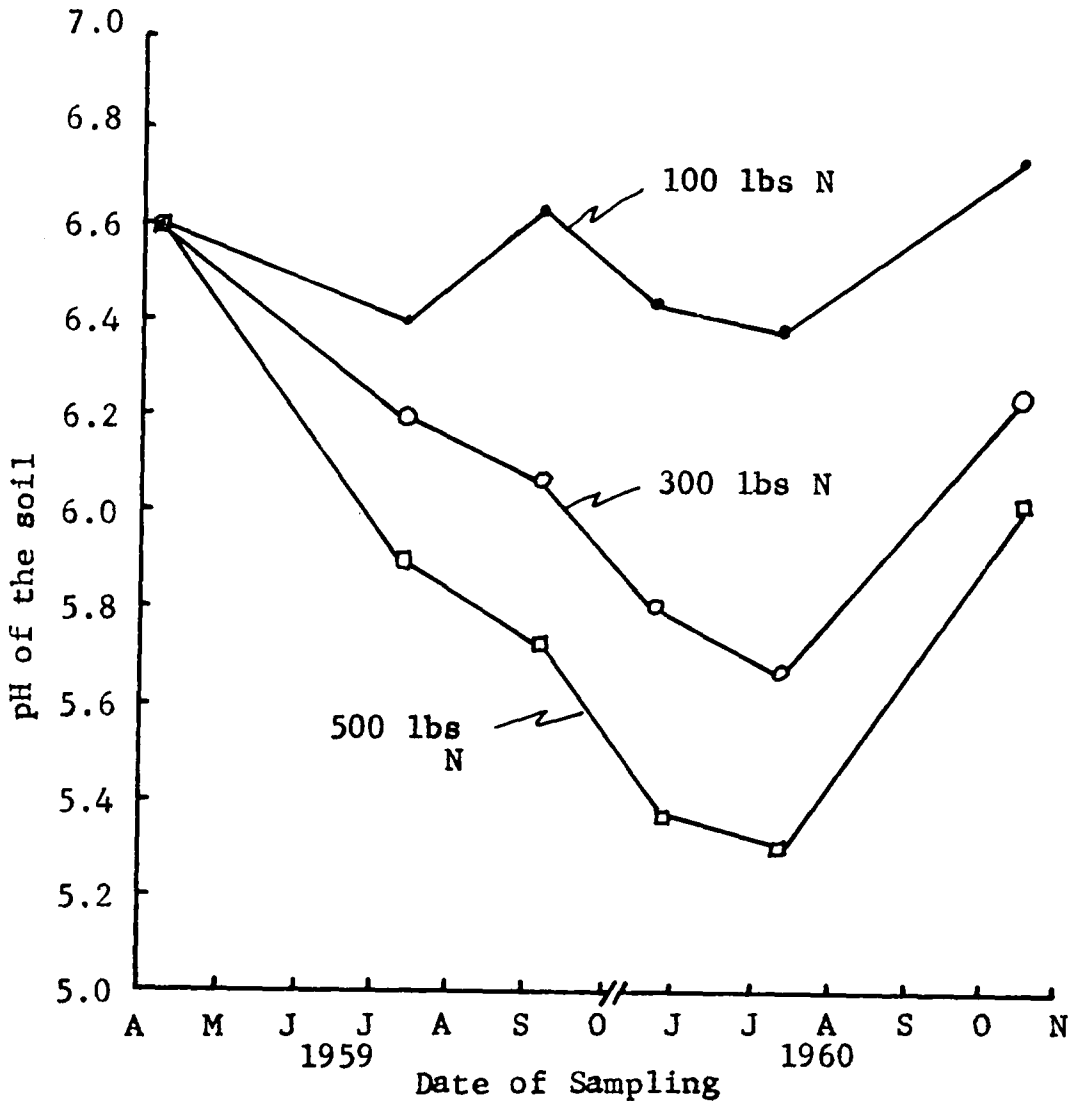


Figure 21. Seasonal changes in the pH of soil seeded to various species and mixtures of grasses as affected by nitrogen. Points through May 23, 1960 are means of three pure seedings and three mixtures. Points after May 23 are means of three pure seedings. All points are means of four  $K_2O$  rates.

increases in  $K_2O$ . The largest increases occurred on October 17, 1960, when the pH of the soil under mixtures was 6.38<sup>a</sup>, 6.47<sup>a</sup>, 6.49<sup>a,b</sup>, and 6.60<sup>b</sup> for 0, 100, 200, and 300 pounds of  $K_2O$ , respectively.

#### Color of Herbage

Arbitrary color values were made for the various grasses at each of the nitrogen and potassium rates (Table 4). Even though only one color estimation was made, there were apparent color differences throughout the remainder of the experiment.

The differences in color between the species is unimportant because orchardgrass is naturally paler green than fescue or bluegrass. The darker green color of grasses fertilized by heavy rates of nitrogen is also common. Color changes due to  $K_2O$  applications have not been widely reported by agricultural workers.

The plots of all three grasses which did not receive  $K_2O$  were greener in color than those fertilized with  $K_2O$ . Increasing rates of  $K_2O$  made the grasses progressively paler green.

It was first thought that this color change was due to changes in the chlorophyll content. In September, 1960, a pilot study was made to determine whether or not chlorophyll was causing the color changes. The chloro-

Table 4. Color reading of grasses grown alone and in mixtures when fertilized with nitrogen and potassium, November 19, 1959.\*

N rates lbs/A/yr		100	300	500	Mean	100	300	500	Mean	100	300	500	Mean
K <sub>2</sub> O rates lbs/A/yr		<u>Species or Mixtures Seeded</u>											
		Orchardgrass				Tall Fescue				Kentucky Bluegrass			
0		4.33	5.99	6.66	5.66	6.66	7.99	7.99	7.55	6.99	7.99	7.99	7.66
100		4.33	5.00	5.33	4.88	6.99	7.33	7.66	7.33	6.33	7.33	8.33	7.33
200		3.66	4.33	5.33	4.44	6.66	7.66	7.99	7.44	6.66	7.66	7.33	7.22
300		4.00	4.33	5.00	4.44	6.33	7.33	7.66	7.10	5.99	6.99	7.33	6.77
Mean**		4.08	4.91	5.58	4.86 <sup>a</sup>	6.66	7.58	7.83	7.36 <sup>b</sup>	6.50	7.50	7.75	7.25 <sup>b</sup>
0		5.00	5.66	6.33	5.66	5.33	5.66	7.33	6.11	6.66	8.33	7.99	7.66
100		4.33	4.66	5.33	4.77	4.33	5.66	5.99	5.33	5.99	7.66	7.66	7.10
200		4.33	5.00	5.33	4.88	4.33	5.33	5.66	5.11	5.66	7.33	8.33	7.10
300		4.33	4.66	5.00	4.66	4.00	5.33	5.66	5.00	5.66	6.99	7.66	6.77
Mean**		4.50	5.00	5.50	5.00 <sup>a</sup>	4.50	5.50	6.16	5.39 <sup>a</sup>	6.00	7.58	7.91	7.17 <sup>b</sup>
Mean of all Seedings**													
0		5.83	6.94	7.39	6.72 <sup>h</sup>								
100		5.39	6.28	6.72	6.13 <sup>g</sup>								
200		5.22	6.22	6.67	6.04 <sup>g</sup>								
300		5.06	5.94	6.39	5.80 <sup>f</sup>								
Mean		5.38 <sup>c</sup>	6.35 <sup>d</sup>	6.79 <sup>e</sup>	6.17								

\* A color reading of 1 is light yellowish green; 10 is dark green.

\*\* Means with the same letter have similar color characteristics.

phyll analysis developed by Comar and Zscheile (1942). was used. Samples were taken from each of the potassium treatments and analyzed for chlorophyll, but no difference could be detected between the chlorophyll content for the potassium treatments.

#### Stand Count

A great deal of research has been reported on fertilizer injury to seedlings. Nitrogen, in particular, has been very damaging and potassium has been suspected of causing damage. The two highest rates of nitrogen were applied in two applications in the spring of 1959 to prevent seedling injury. The first application of 25, 50, and 75 pounds of nitrogen was applied on April 9 for the respective treatments of 100, 300, and 500 pounds of nitrogen per acre per year. Seedling stand counts were made May 6 to May 19 prior to the second application of nitrogen.

The bluegrass seedlings showed damage due to nitrogen. The average number of plants per square foot was 151<sup>a</sup>, 130<sup>b</sup>, and 121<sup>d</sup> for 25, 50, and 75 pounds of nitrogen, respectively. Even with the reduction in stand due to nitrogen, there were still plenty of plants left for adequate stand.

Potassium did not show any detrimental effect on any



of the three grasses. In fact, the statistical analysis showed an increase in the number of fescue and orchardgrass seedlings due to  $K_2O$ .

#### Potassium Content of Orchardgrass

Seeding effects: The potassium content of orchardgrass was similar when grown in pure stands or in mixtures. The amount of bluegrass in the orchardgrass-bluegrass mixtures was small; hence, chemical analyses of orchardgrass from this mixture were discontinued after May 30, 1960.

Nitrogen effects: Orchardgrass harvested on July 4, 1960, was significantly reduced in potassium content due to additions of nitrogen. The percentages of potassium were 2.59<sup>a</sup>, 2.41<sup>a</sup>, and 2.20<sup>b</sup> for 100, 300, and 500 pounds of nitrogen, respectively.

Potassium effects: Increasing rates of potassium increased the potassium content of orchardgrass in all harvests, except on October 16, 1959 (Figure 22). At the harvest on June 12, 1959, orchardgrass from the orchardgrass-fescue mixtures contained 2.68, 2.90, 3.07, and 3.37 percent potassium for applications of 0, 100, 200, and 300 pounds  $K_2O$ , respectively. These significant differences occurred even though only one-fourth of the yearly potassium allotment had been applied. Potassium content was very low by the last harvest in October, 1960, as compared to other harvests,

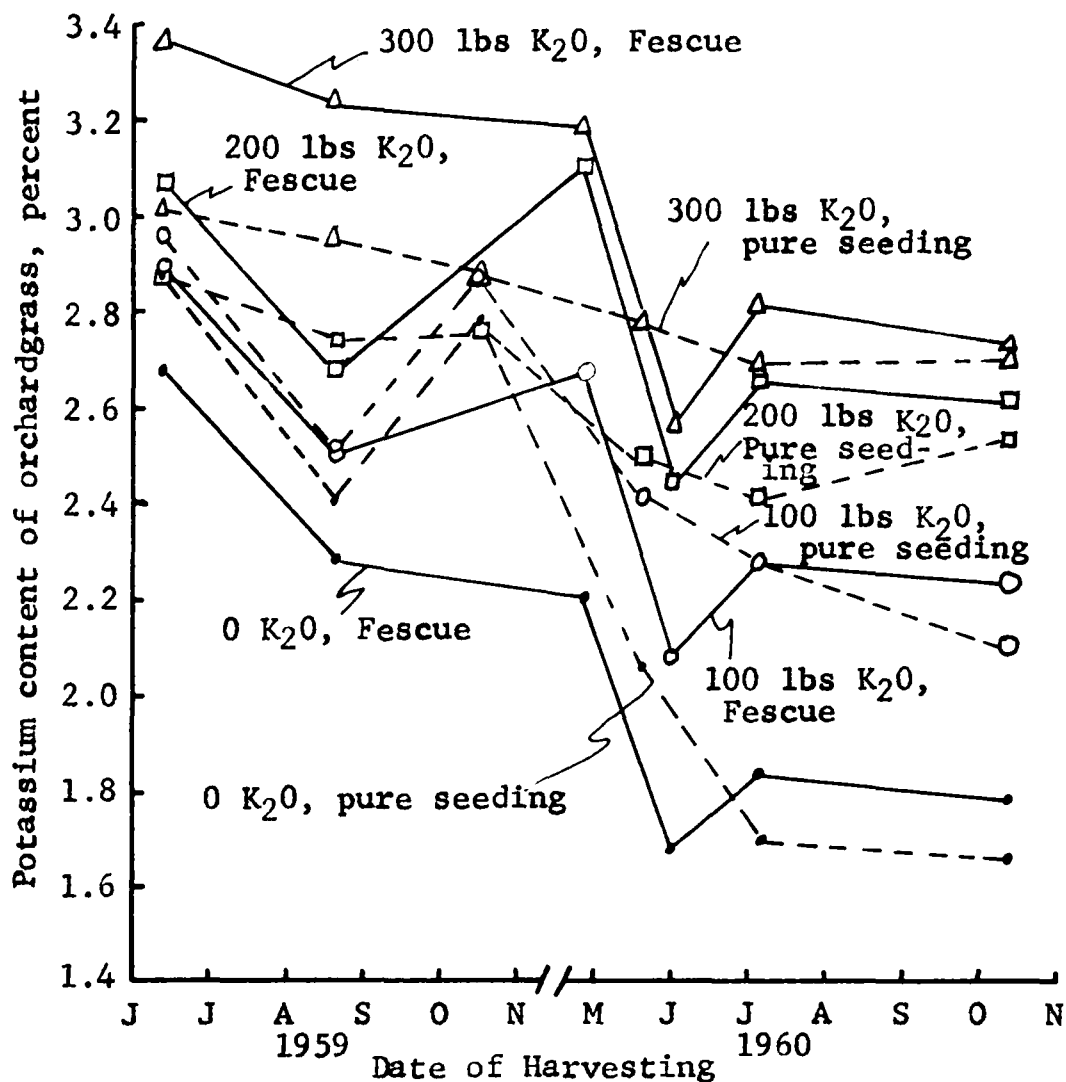


Figure 22. Seasonal changes in potassium content of orchardgrass from pure orchardgrass and orchardgrass-fescue seedings as affected by K<sub>2</sub>O. Points through May 30, 1960 are means of two nitrogen rates. The remaining points are means of three nitrogen rates.

even though more potassium had been applied. The potassium content for mixtures at this date was 1.79, 2.24, 2.60, and 2.73 percent for 0, 100, 200, and 300 pounds of  $K_2O$ , respectively.

There was very little difference between the potassium content of orchardgrass in orchardgrass-fescue mixtures receiving 200 and 300 pounds  $K_2O$  during the second season. This might indicate that the plants are reaching maximum luxury consumption at these levels. Orchardgrass with 100 pounds  $K_2O$  was up to 50 percent higher in potassium than unfertilized plants, and the differences for applications of 100 and 200 pounds of  $K_2O$  were also large.

A potassium by nitrogen interaction appeared for mixtures on May 30 and October 11, 1960. This interaction indicated that at low  $K_2O$  rates, heavy nitrogen rates reduced the potassium content in the plants but did not at high  $K_2O$  rates. For example, orchardgrass without  $K_2O$  and with 100 and 500 pounds of nitrogen contained 1.95 and 1.41 percent potassium, respectively, on May 30, 1960. The respective potassium contents were 2.48 and 2.63 percent when orchardgrass was fertilized with 300 pounds of  $K_2O$

#### Potassium Content of Fescue

The potassium content of fescue was similar when fescue

was grown alone or in mixtures with orchardgrass or bluegrass.

Nitrogen effects: The pure seedings of fescue on October 16, 1959, and fescue in mixtures on July 4 and October 11, 1960, varied in potassium content due to nitrogen fertilization; but these effects were contradictory. Increasing the nitrogen rate increased the potassium content in the October 16, 1959, cutting and decreased it in the other two cuttings. The average potassium content in fescue from pure seedings on October 16 was 2.94 and 3.16 percent for 100 and 500 pounds of nitrogen, respectively. Corresponding percentages for mixtures on October 11, 1960, were 2.61<sup>a</sup>, 2.30<sup>b</sup>, and 2.24<sup>b</sup> for 100, 300, and 500 pounds of nitrogen, respectively.

Potassium effects: Fescue from all harvests, except August 18, 1959, showed significant increases in potassium content resulting from additions of potassium fertilizer (Figure 23). The average potassium content of fescue without K<sub>2</sub>O was always over 1.8 percent which may be considered adequate by most workers. However, these plants had potassium deficiency symptoms.

Mixtures showed a potassium by nitrogen interaction on May 30 and October 11, 1960. High nitrogen rates decreased the potassium content of fescue with low potassium fertilization; but did not with high potassium

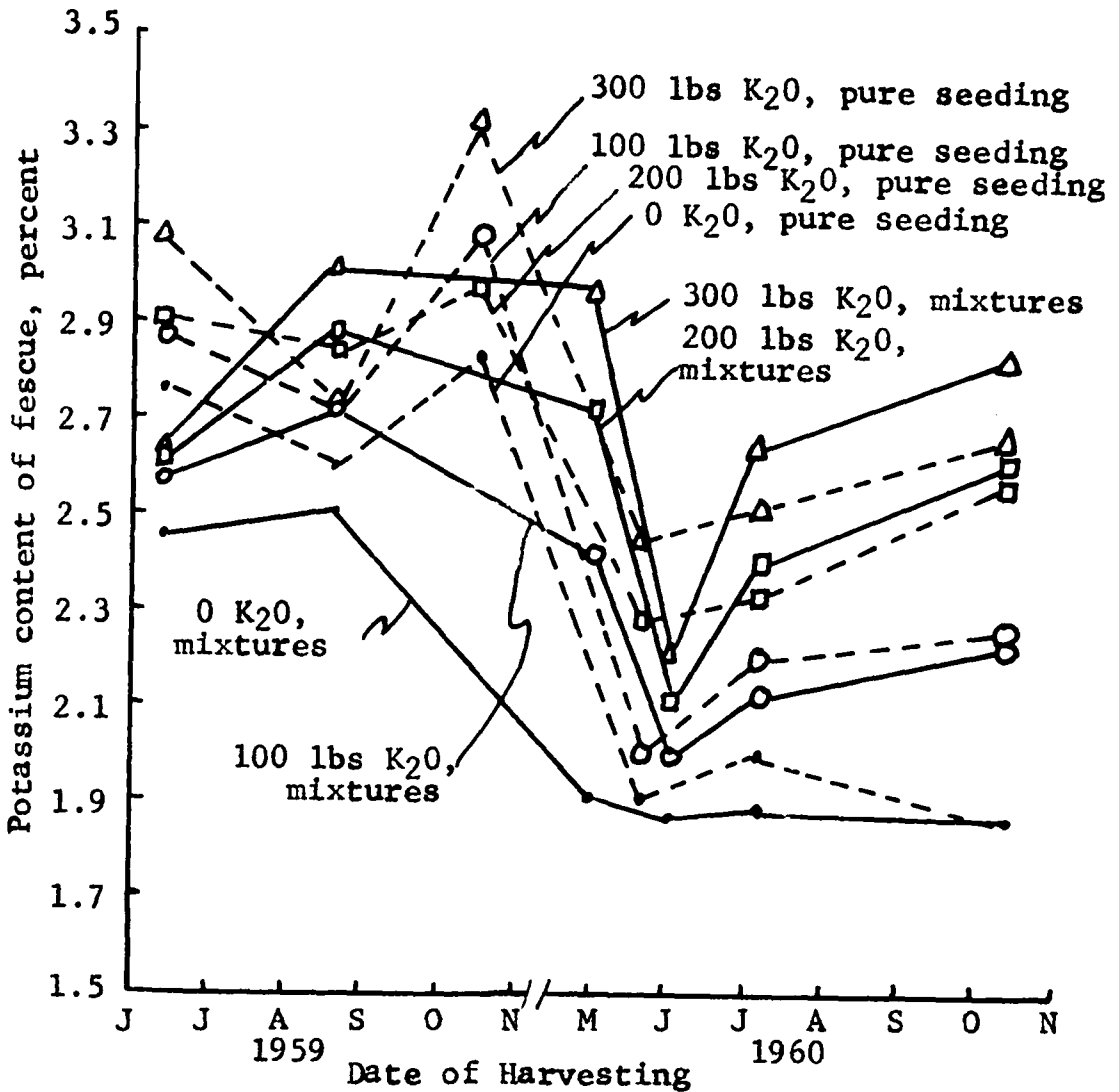


Figure 23. Seasonal changes in potassium content of fescue from pure fescue and the mean of fescue-orchardgrass and fescue-bluegrass seedings as affected by K<sub>2</sub>O. Points through October 16, 1959 and points on May 30, 1960 are means of two nitrogen rates. Remaining points are means of three nitrogen rates.

fertilization. For instance, the percentages of potassium were 1.91 and 1.83 for 100 and 500 pounds nitrogen, respectively, when no  $K_2O$  was added on May 30. With 300 pounds of  $K_2O$ , the respective percentages were 2.10 and 2.33. Nitrogen apparently reduces the potassium content of plants and soils when no  $K_2O$  is added. For example, fescue in the fescue-bluegrass mixtures without potassium fertilization, represented in Figures 6 and 31, analyzed 1.14 percent potassium and that with high potassium fertilization analyzed 2.70 percent potassium. These low potassium fescue plants were showing deficiency symptoms, and the plots were reverting to bluegrass.

There was a potassium by mixture interaction on May 30, 1960. The potassium content in fescue from orchardgrass-fescue mixtures was 1.70, 1.89, 2.13, and 2.17 percent for 0, 100, 200, and 300 pounds of  $K_2O$ , respectively. Corresponding percentages were 2.04, 2.11, 2.17, and 2.25 for fescue-bluegrass seedings. The orchardgrass growth was much greater than that of bluegrass on May 30; therefore, orchardgrass competed with fescue for potassium more strongly than bluegrass. This trend almost disappeared by the last cutting on October 11, 1960, when fescue was growing vigorously and orchardgrass was diseased. Bluegrass was also more competitive to the fescue in October than it was in May.

### Potassium Content of Bluegrass

Seeding effects: Comparisons were not made for potassium content of bluegrass in pure stands and mixtures because of different cutting treatments. Only the fescue-bluegrass mixture produced enough bluegrass for a chemical analysis; therefore, comparisons cannot be made for potassium content of bluegrass from orchardgrass-bluegrass mixtures.

Nitrogen effects: Bluegrass from pure seedings on October 11, 1960, showed significant increases in potassium content with increasing nitrogen. Potassium contents at this harvest were 1.97<sup>a</sup>, 2.13<sup>b</sup>, and 2.16<sup>b</sup> percent for 100, 300, and 500 pounds of nitrogen, respectively.

Potassium effects: The potassium content of bluegrass from both pure bluegrass and fescue-bluegrass seedings increased with increasing rates of K<sub>2</sub>O. Only the May 18 and May 30, 1960, harvests failed to be statistically significant (Figure 24). The potassium content was low during the summer and increased during the fall. The potassium content of bluegrass ranged from 1.44 percent without K<sub>2</sub>O on July 4 to 2.32 percent with 300 pounds of K<sub>2</sub>O on October 11, 1960.

### Potassium Content of Weeds

Ragweed, cress, and lambsquarters were analyzed for potassium for the June 12, 1959, cutting only. Lambsquarters showed a reduction in potassium with high

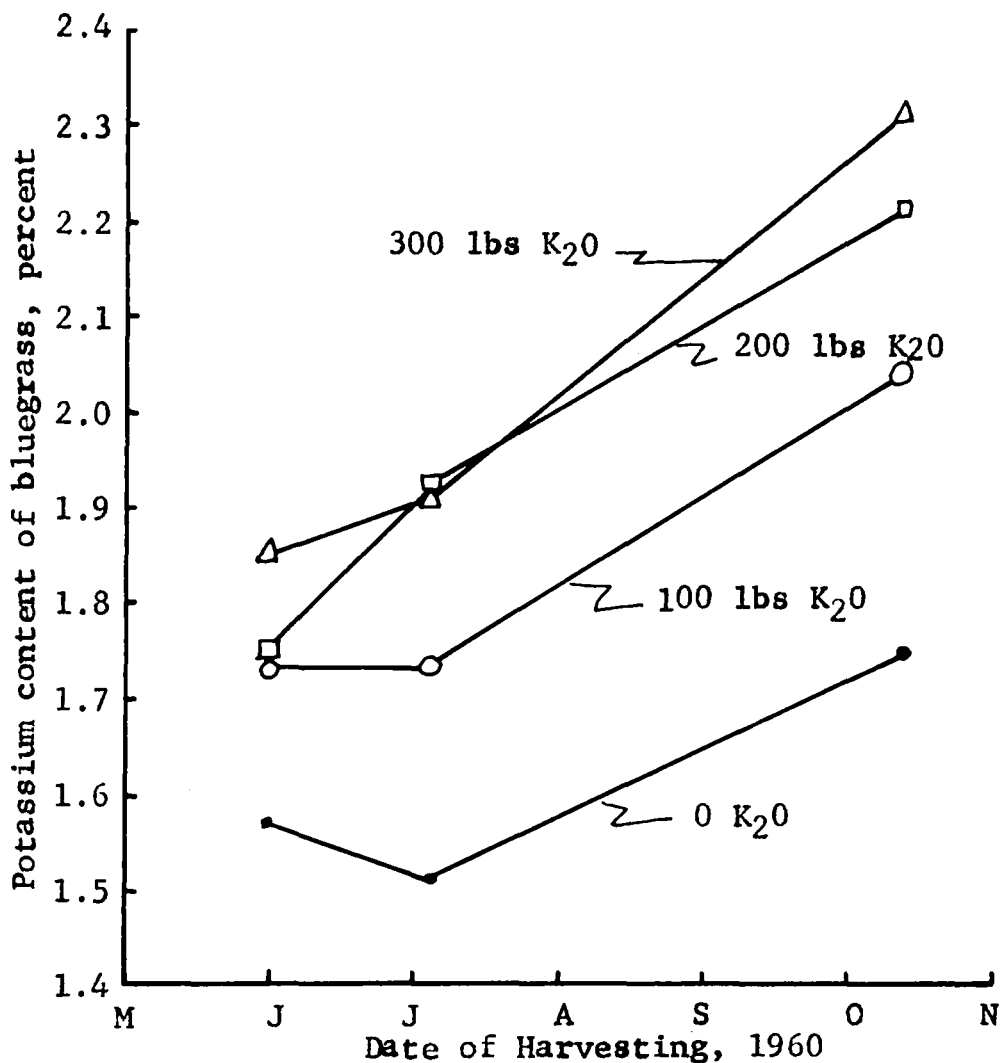


Figure 24. Seasonal changes in potassium content of bluegrass from bluegrass-fescue mixtures as affected by K<sub>2</sub>O. Points on May 18 and May 30 are means of two nitrogen rates. Remaining points are means of three nitrogen rates.



rates of nitrogen application, and cross showed a reduction in potassium due to nitrogen only at lower  $K_2O$  rates. All three weeds increased in potassium content with increasing  $K_2O$ , but the increase was not significant for lambsquarters. Lambsquarters was exceptionally high in potassium; the overall average was 4.42 percent, but some of the treatments had over 6 percent potassium.

#### Calcium Content of Orchardgrass

Seeding effects: Calcium content of orchardgrass from orchardgrass and orchardgrass-fescue seedings was similar on June 12 and August 18, 1959. Likewise, the calcium content of orchardgrass from orchardgrass-fescue and orchardgrass-bluegrass mixtures was similar on April 30 and May 30, 1960.

Nitrogen effects: There was a tendency for calcium content of orchardgrass to increase with nitrogen fertilization, but these differences were not large enough to be significant.

Potassium effects: Orchardgrass from mixtures and pure stands on June 12, 1959, mixtures on July 4, 1960, and mixtures and pure stands on October 11, 1960, showed significant decreases in calcium resulting from potassium fertilization. The calcium content for orchardgrass from orchardgrass-fescue mixtures on October 11 was  $0.65^a$ ,  $0.58^b$ ,  $0.56^b$ , and  $0.53^b$  for applications of 0, 100, 200, and 300

pounds of  $K_2O$ , respectively. The respective calcium content of orchardgrass from pure seedings on the same date was 0.67<sup>a</sup>, 0.60<sup>b</sup>, 0.57<sup>b</sup>, and 0.56<sup>b</sup> percent.

#### Calcium Content of Fescue

Seeding effects: There was no difference in the calcium content of fescue from orchardgrass-fescue and pure seedings of fescue on June 12 and August 18, 1959.

Fescue grown with bluegrass had more calcium than fescue grown with orchardgrass on October 11, 1960. The average calcium content in fescue was 0.63 and 0.77 percent for orchardgrass-fescue and fescue-bluegrass mixtures, respectively. The other three harvests in 1960 did not show this trend.

Nitrogen effects: Fescue from pure seedings on October 16, 1959, and pure seedings and mixtures on July 4, 1960, showed significant increases in calcium from increases in nitrogen (Figure 25). The calcium content of fescue from pure stands on July 4 was 0.59<sup>a</sup>, 0.71<sup>b</sup>, and 0.75<sup>b</sup> for 100, 300, and 500 pounds of nitrogen, respectively. Similar results occurred on October 16, 1959. Many of the other harvests showed similar trends, but they were not statistically significant.

Potassium effects: Potassium fertilization decreased the calcium content in fescue from mixtures on April 30,

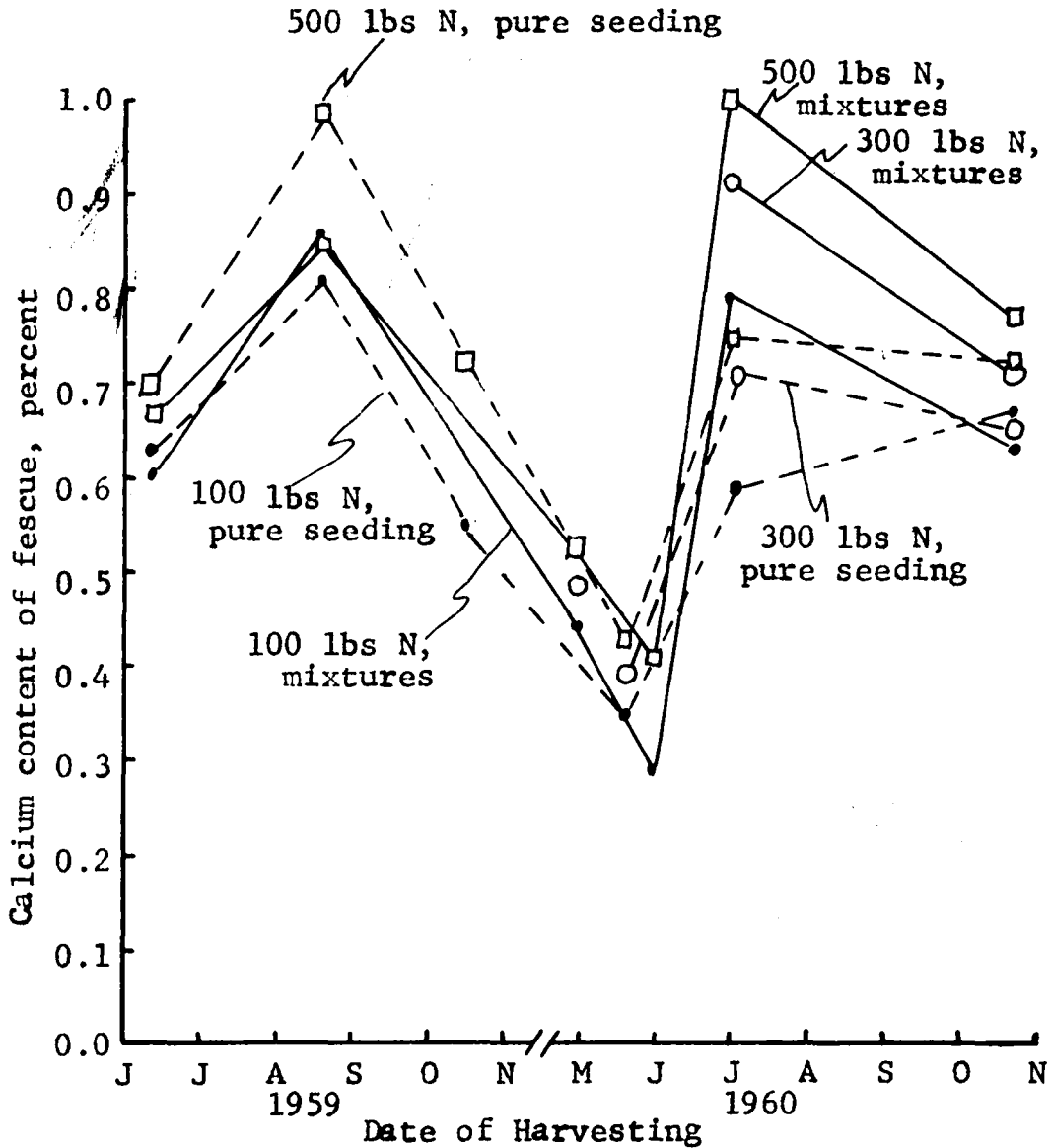


Figure 25. Seasonal changes in calcium content of fescue from pure fescue and the mean of fescue-orchardgrass and fescue-bluegrass seedings as affected by nitrogen. Curves are means of four  $K_2O$  rates.

July 4, and October 11 and from pure seedings of fescue on July 4 and October 11, 1960 (Figure 26). For example, calcium content in fescue from pure seedings of fescue on July 4 was 0.80<sup>a</sup>, 0.71<sup>a,b</sup>, 0.64<sup>b,c</sup>, and 0.60<sup>c</sup> for 0, 100, 200, and 300 pounds of K<sub>2</sub>O, respectively.

#### Calcium Content of Bluegrass

Nitrogen effects: The calcium content of bluegrass grown with fescue increased with high rates of nitrogen for the May 30 and July 4, 1960, harvests. For example, the calcium content was 0.42<sup>a</sup>, 0.48<sup>a,b</sup>, and 0.53<sup>b</sup> percent for 100, 300, and 500 pounds of nitrogen, respectively, on July 4. Bluegrass from many other harvests had small, but statistically insignificant, increases in calcium resulting from high rates of nitrogen.

Potassium effects: The percentage of calcium in bluegrass grown with fescue decreased with increasing rates of K<sub>2</sub>O for the July 4 and October 11, 1960, harvests (Figure 27). For example, the calcium content of bluegrass was 0.68<sup>a</sup>, 0.53<sup>b</sup>, 0.47<sup>b</sup>, and 0.46<sup>b</sup> for 0, 100, 200, and 300 pounds of K<sub>2</sub>O, respectively, on October 11. Bluegrass from most of the other harvests had small, but statistically insignificant, decreases in calcium content resulting from increased potassium rates.

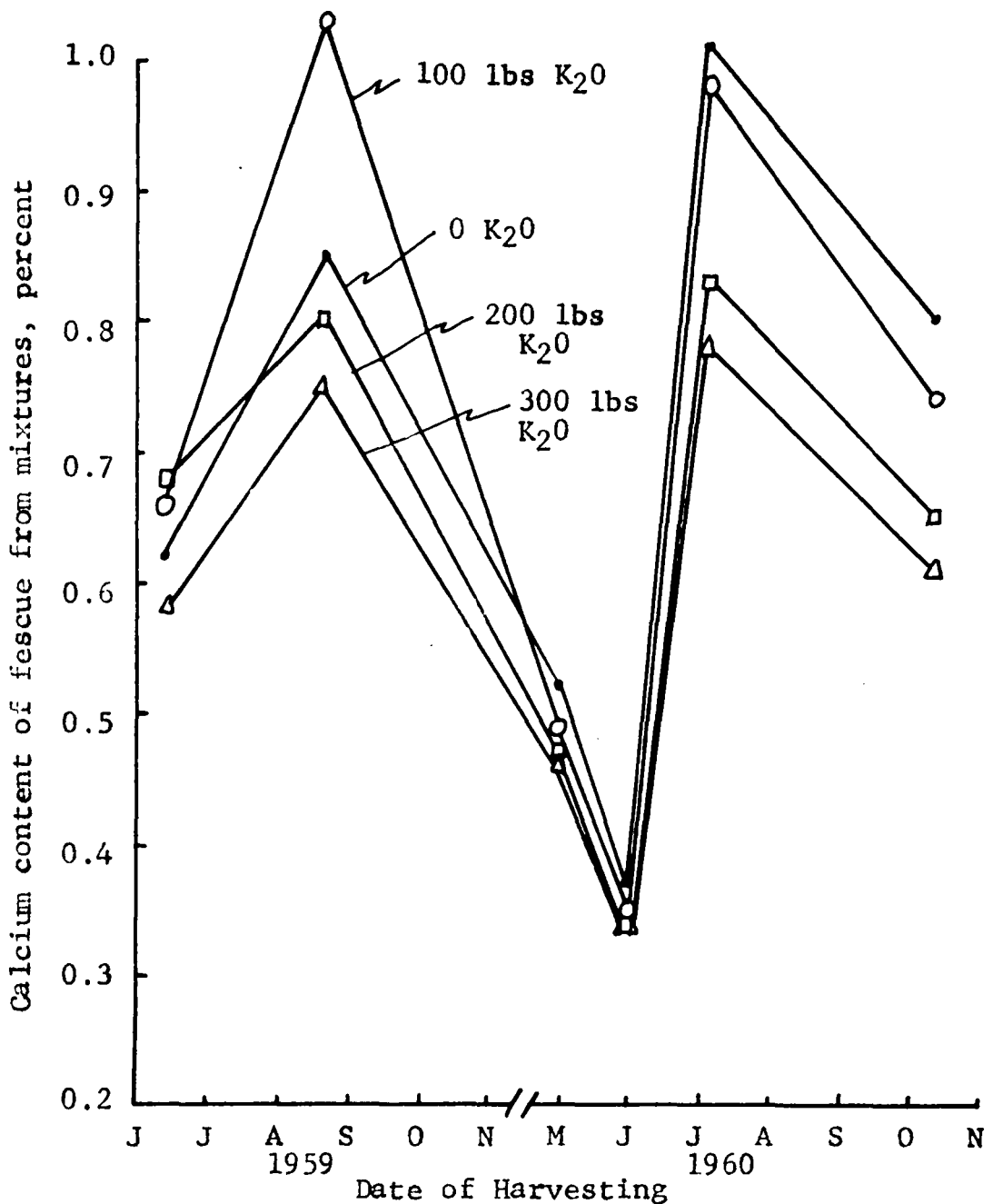


Figure 26. Seasonal changes in the calcium content of fescue from fescue-orchardgrass and fescue-bluegrass mixtures as affected by K<sub>2</sub>O. Points on June 12 and August 18, 1959 and May 30, 1960, are means of two nitrogen rates; remaining points are means of three nitrogen rates.

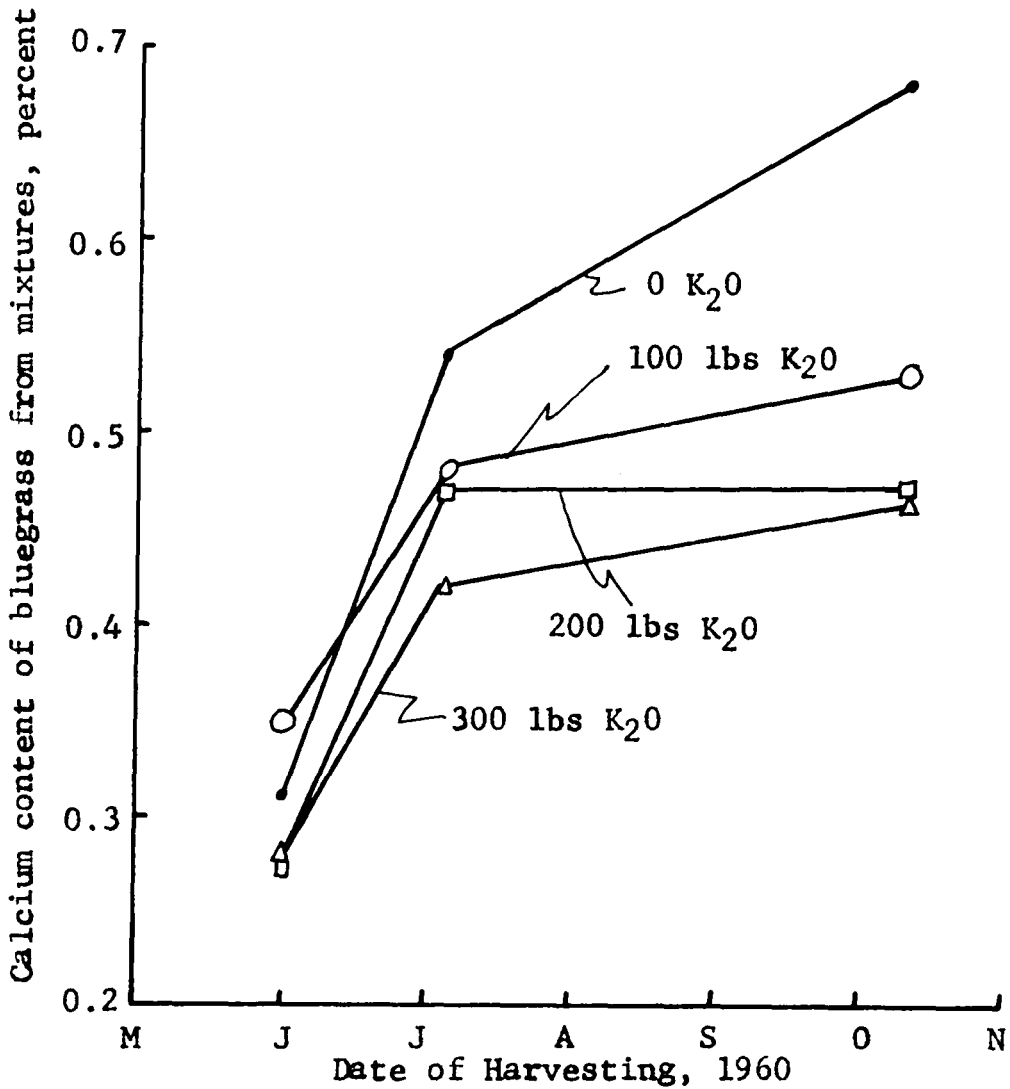


Figure 27. Seasonal changes in calcium content of bluegrass from bluegrass-fescue mixtures as affected by  $K_2O$ . The point on May 30 is the mean of two nitrogen rates; remaining points are means of three nitrogen rates.

### Calcium Content of Weeds

The only effect of treatments on the calcium content of the three weeds was an increase from 2.39 to 2.88 percent in cress when the nitrogen rate was raised from 100 to 500 pounds.

### Magnesium Content of Orchardgrass

The magnesium content of orchardgrass was similar when grown alone and with fescue.

Nitrogen effects: Significant increases in the magnesium content of orchardgrass occurred with increasing rates of nitrogen for harvests on June 12, 1959, and April 30 and May 30, 1960 (Figure 28). The magnesium content of orchardgrass grown with fescue was 0.23 and 0.30 percent, respectively, for 100 and 500 pounds nitrogen on May 30.

Potassium effects: Increasing rates of  $K_2O$  usually decreased the magnesium content of orchardgrass (Figure 29). Duncan's Multiple Range Test showed that the relative position of the treatments changed with harvests, but orchardgrass without  $K_2O$  was invariably higher in magnesium than when treated with 300 pounds of  $K_2O$ . The magnesium content of orchardgrass grown with fescue averaged 0.30, 0.28, 0.25, and 0.24 percent for 0, 100, 200, and 300 pounds of  $K_2O$ , respectively, on May 30, 1960.

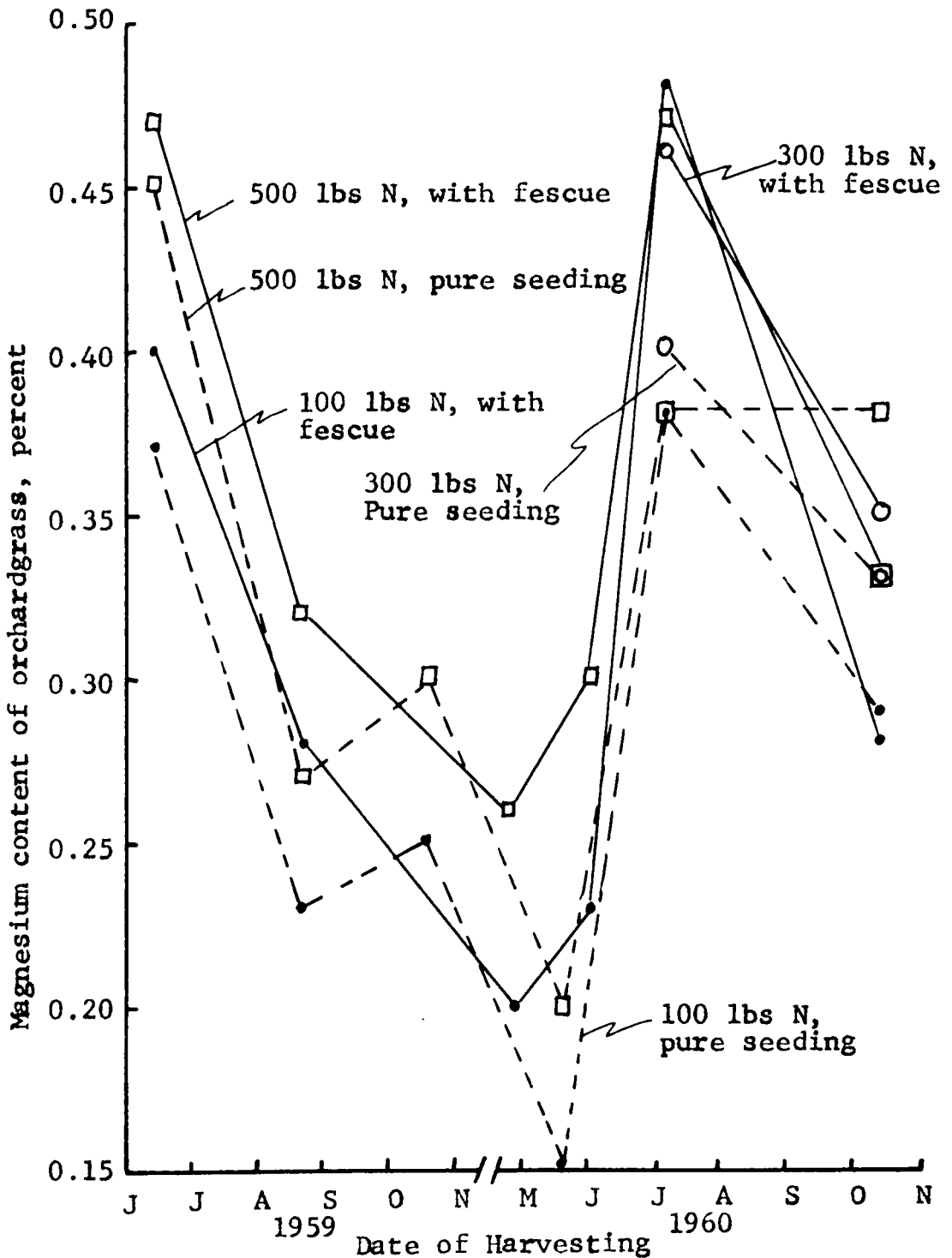


Figure 28. Seasonal changes in magnesium content of orchardgrass from pure orchardgrass and orchardgrass-fescue seedings as affected by nitrogen. Curves are means of four  $K_2O$  rates.



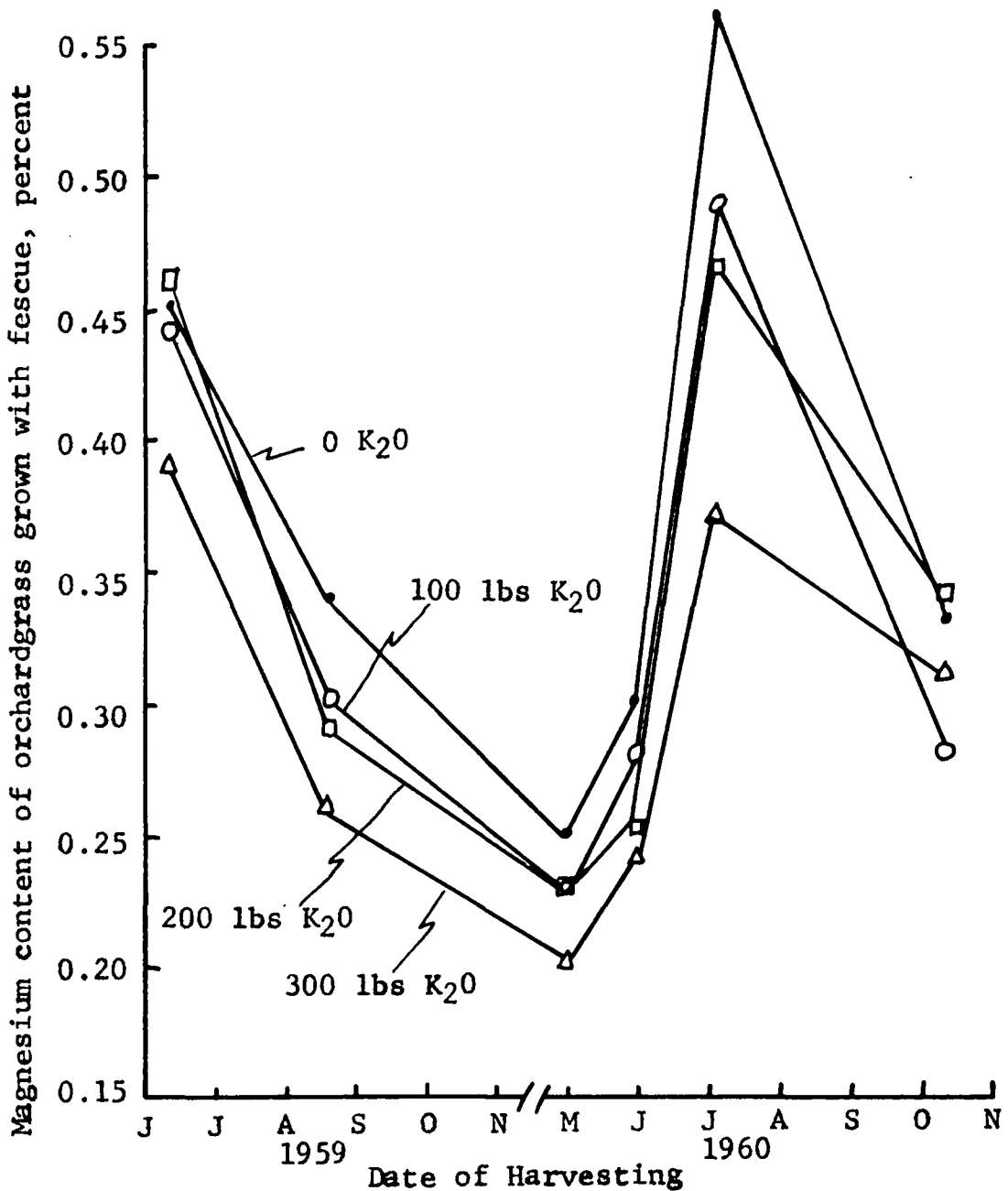


Figure 29. Seasonal changes in magnesium content of orchardgrass from orchardgrass-fescue mixtures as affected by K<sub>2</sub>O. Points on July 4 and October 11, 1960, are means of three nitrogen rates; remaining points are means of two nitrogen rates.

### Magnesium Content of Fescue

There was no difference in the magnesium content of fescue when grown alone or in mixtures.

Nitrogen effects: Fescue from all harvests, except the pure stand on October 11, 1960, showed increases in magnesium content due to increased nitrogen applications, but the degrees of freedom for the error term of the statistical analysis was so small that the increases were not significant.

Potassium effects: The relative rank of the means (Duncan's Multiple Range Test) varied for the various harvests, but the fescue from the no K<sub>2</sub>O plots was always higher in magnesium than fescue from plots receiving 300 pounds of K<sub>2</sub>O, except for pure fescue on October 11, 1960 (Figure 30). The magnesium content of fescue grown with orchardgrass and bluegrass was 0.44<sup>a</sup>, 0.39<sup>b</sup>, 0.36<sup>c</sup>, and 0.33<sup>d</sup> percent for 0, 100, 200, and 300 pounds K<sub>2</sub>O, respectively, on July 4, 1960.

A potassium by nitrogen interaction appeared for both pure stands and mixtures on June 12, 1959, and for mixtures on October 11, 1960. These interactions indicated that nitrogen increased the magnesium content of fescue with no or small amounts of K<sub>2</sub>O but did not with 300 pounds of K<sub>2</sub>O. For instance, on October 11 the percentages of magnesium in fescue without K<sub>2</sub>O were 0.37, 0.41, and 0.46 for

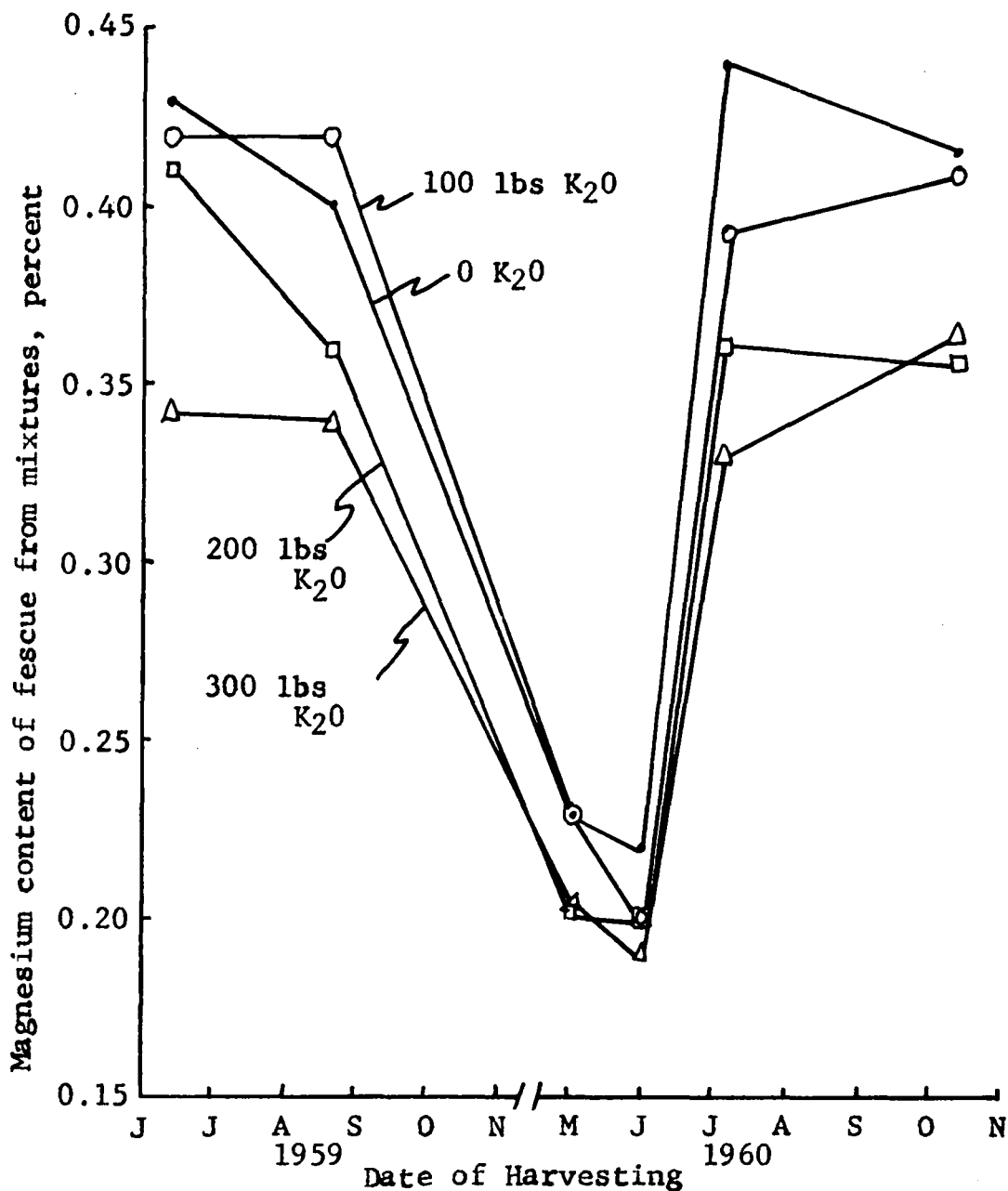


Figure 30. Seasonal changes in magnesium content of fescue from fescue-orchardgrass and fescue-bluegrass mixtures as affected by K<sub>2</sub>O. Points on June 12 and August 18, 1959 and May 30, 1960, are means of two nitrogen rates; remaining points are means of three nitrogen rates.

applications of 100, 300, and 500 pounds of nitrogen; the corresponding percentages with 300 pounds of  $K_2O$  were 0.41, 0.30, and 0.34. Plants take up potassium more readily than magnesium, and when high rates of potassium are applied, uptake of magnesium is depressed. The ammonium ion in nitrogen fertilizers blocks the release of "fixed" potassium; hence, there is less potassium available for competition with magnesium at low rates of potassium and high rates of nitrogen.

#### Magnesium Content of Bluegrass

Nitrogen effects: Bluegrass increased in magnesium content with increasing rates of nitrogen at all harvests, except mixtures on October 11, but the degree of freedom was so small that only the bluegrass-fescue mixtures on May 30 and July 4, 1960, and pure seedings on July 4 showed significant differences. For instance, the 500 pound rate of nitrogen increased the content of magnesium in bluegrass of the bluegrass-fescue mixture from 0.14 to 0.18 percent on July 4.

Potassium effects: Increasing potassium rates decreased the magnesium content of bluegrass at every harvest, but the differences were statistically significant only on mixtures and pure seedings on July 4, 1960 (Figure 31).

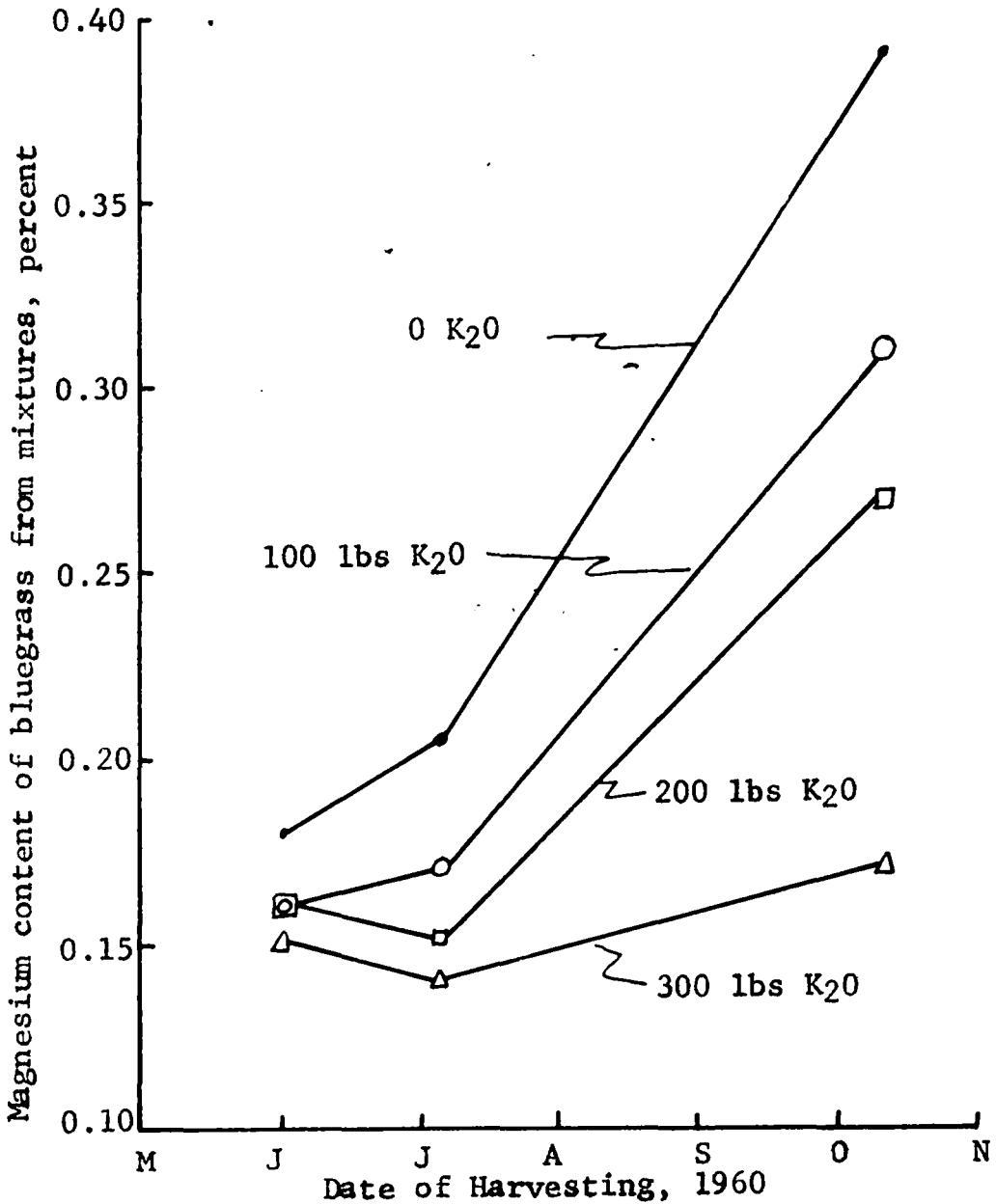


Figure 31. Seasonal changes in magnesium content of bluegrass from bluegrass-fescue mixtures as affected by K<sub>2</sub>O. The point on May 30 is the mean of two nitrogen rates; remaining points are means of three nitrogen rates.

### Magnesium Content of Weeds

Cress, lambsquarters, and ragweed showed slight increases in magnesium content due to nitrogen, but the differences were significant only for cress. Potassium fertilization decreased the magnesium content of lambsquarters and ragweed. There was a slight increase from 0.31 to 0.34 percent magnesium in cress when either 100 or 200 pounds of  $K_2O$  was applied. Lambsquarters was very high in magnesium compared to the other two weeds. The average magnesium content was 1.02, 0.68, and 0.32 percent for lambsquarters, ragweed, and cress, respectively.

### Water Content of Grasses

Although all herbage harvests were dried, wet weights for moisture determinations were obtained on October 11, 1960 (Tables 5 and 6).

Seeding effects: Fescue had 68 percent water, as compared with average values of 65 percent for bluegrass and 59 percent for orchardgrass. Disease killed about half of the orchardgrass leaves which may account for the low water content.

Nitrogen effects: Nitrogen at 300 pounds increased the average water content from five to six percent for both the pure and mixed seedings. An additional 200 pounds of nitrogen increased the water content slightly; the increase

Table 5. Percentage of water in the green forage of various grasses on October 11, 1960, as affected by nitrogen and potassium fertilization.

(Mean of three replications)

N rates lbs/A/Yr	Mean					Mean	Mean					
	100	300	500	100	300		500	100	300	500	Mean	
<u>Species Seeded</u>												
Orchardgrass						Kentucky Bluegrass						
0	55.0	58.3	59.0	57.4	61.0	68.0	67.0	65.3	61.0	64.0	65.7	63.6
100	55.7	59.7	63.0	59.4	64.3	69.7	69.7	67.9	63.0	66.3	67.0	65.4
200	55.0	61.3	62.0	59.4	65.3	70.3	71.3	69.0	62.7	66.3	68.0	65.7
300	55.7	63.3	64.3	61.1	65.0	71.7	71.7	69.4	64.7	67.7	69.0	67.1
Mean*	55.3	60.7	62.1	59.4 <sup>a</sup>	63.9	69.9	69.9	65.4 <sup>b</sup>	62.8	66.1	67.4	67.9 <sup>c</sup>
Mean of all Species*												
0	59.0	63.4	63.9	62.1 <sup>f</sup>								
100	61.0	65.2	66.6	64.3 <sup>g</sup>								
200	61.0	66.0	67.1	64.7 <sup>h</sup>								
300	61.8	67.6	68.3	65.9 <sup>h</sup>								
Mean	60.7 <sup>d</sup>	65.6 <sup>e</sup>	66.5 <sup>e</sup>									

\* Means with the same letter have similar moisture contents.

Table 6, Percentage of water in the green forage of various grass mixtures on October 11, 1960, as affected by nitrogen and potassium fertilization.

(Mean of three replications)

N rates lbs/A/Yr	Mean				Mixtures Seeded							
	100	300	500	Mean	100	300	500	Mean				
					<u>Mixtures Seeded</u>							
	Orchardgrass-Fescue				Orchardgrass-Bluegrass				Fescue-Bluegrass			
0	58.7	62.7	65.0	62.1	54.7	58.7	57.7	57.0	58.7	64.3	65.7	62.9
100	61.7	64.3	66.0	64.0	54.7	61.3	62.3	59.4	61.3	67.3	68.7	65.8
200	62.3	66.3	66.7	65.1	57.3	62.3	62.7	60.8	61.7	69.7	69.3	66.9
300	61.7	68.3	68.3	66.1	56.7	65.0	64.3	62.0	63.0	70.0	70.0	67.7
Mean*	61.1	65.4	66.5	64.3 <sup>a</sup>	55.8	61.8	61.8	59.8 <sup>b</sup>	61.2	67.8	68.4	65.8 <sup>a</sup>
	Mean of all Mixtures*											
0	57.3	61.9	62.8	60.7 <sup>f</sup>								
100	59.2	64.3	65.7	63.1 <sup>g</sup>								
200	60.4	66.1	66.2	64.3 <sup>h</sup>								
300	60.4	67.8 <sup>d</sup>	67.6	65.3 <sup>i</sup>								
Mean	59.4 <sup>c</sup>	65.0 <sup>d</sup>	65.6 <sup>e</sup>	63.3								

\* Means with the same letter have similar moisture contents.



was significant only for the mixtures.

Potassium effects: Potassium, like nitrogen, increased the water content of the green forage. The moisture in forage from the pure seedings was 62<sup>a</sup>, 64<sup>b</sup>, 65<sup>b</sup>, and 66<sup>c</sup> percent for 0, 100, 200, and 300 pounds of K<sub>2</sub>O, respectively. The corresponding percentages for the mixtures were 60<sup>a</sup>, 63<sup>b</sup>, 64<sup>c</sup>, and 65<sup>d</sup>. Figure 32 illustrates the difference in fescue tillers from adjacent plots receiving different K<sub>2</sub>O levels. Fescue from low K<sub>2</sub>O plots was stunted, and the leaves were rolled tightly into needlelike cylinders during dry periods. Fescue from the high K<sub>2</sub>O plots was still turgid and growing well.

#### Nitrogen Content of Forage and Weeds

Five species of plants taken from the June 12, 1959, harvest were analyzed for nitrogen for the 100 and 500 pounds of nitrogen treatments. The soil had received only one-fourth of the annual fertilizer at the time of this harvest. The nitrogen content for each species is presented below.

<u>Species</u>	<u>Nitrogen rate (Lbs/A/Yr)</u>	
	<u>100</u>	<u>500</u>
Cress	3.52	5.03
Lambsquarters	3.49	4.83
Orchardgrass	3.01	4.30
Ragweed	3.80	4.82
Tall Fescue	3.15	3.82



Figure 32. Tillers taken from two adjacent plots of a two-year old fescue-bluegrass mixture. Left, - no potassium; right, - 300 pounds  $K_2O$  per acre yearly. Both plots received 300 pounds nitrogen per acre yearly.

All species increased in nitrogen with the higher applications of nitrogen. Higher rates of  $K_2O$  tended to reduce the nitrogen content slightly. Since it is well known that increasing nitrogen rates increases the nitrogen content of the plant, no further nitrogen analyses were made.

## DISCUSSION OF FIELD STUDIES

### General

Data for the field experiment are compiled for only two years of growth. The first year was required to establish the grasses; therefore, differences from fertilizer are small. In essence, there are one year's data to really determine the effects of fertilization. This experiment will be continued by others to more fully establish grass-fertilizer interrelationships.

The initial potassium content of the soil was rather high, thus it will probably take more than one year for grasses and soil potassium to come to an equilibrium. Chamblee and Lovvorn (1953) found no fertilizer differences in a legume-grass association during the first year, but after two years differences due to potassium fertilization were obtained. Other workers have reported similar results. Differences due to potassium reported herein should reflect trends which will be more pronounced later as the soil potassium is depleted and as the potassium fertilized soils reach an equilibrium.

### Botanical Composition

Seeding effects: During the two years of growth the species composition of the sod differed. Pure orchardgrass seedings were practically free of other species by the second year,

while pure fescue and pure bluegrass both accumulated some weeds. The seedling vigor of orchardgrass forced out most grasses the seedling year. Fescue seedlings started slower than orchardgrass, but not as slow as bluegrass. Pure fescue, therefore, contained volunteer orchardgrass, quackgrass, and other grassy weeds in amounts from 15 to 30 percent during the second year. Pure bluegrass made such slow seedling growth that botanical separations were not made during the first year. During the second year bluegrass made up only about 50 percent of the stand.

The grasses behaved similarly in pure stands and mixtures. Orchardgrass was the dominant species when seeded alone or in mixtures. In the absence of orchardgrass, fescue was the dominant species. A trend was developing in the orchardgrass-fescue plots during the second season showing that orchardgrass was being gradually replaced by fescue. Tall fescue withstands more adverse soil and climatic conditions and also makes more vigorous growth in the fall than orchardgrass. Orchardgrass was also retarded by leaf diseases during the fall of 1960. Chamblee and Lovvorn (1953) also noticed that fescue was more aggressive to alfalfa than orchardgrass after two years.

Bluegrass was more prevalent in fescue-bluegrass

mixtures than in orchardgrass-bluegrass mixtures. This situation was caused by the greater seedling vigor of orchardgrass than for fescue. Blaser et al. (1956) observed such differences in seedling vigor. It is possible that bluegrass will be more prevalent in the orchardgrass-bluegrass plots than in the fescue-bluegrass plots, especially under low potassium fertilization.

Nitrogen effects: The overall effect of nitrogen was variable and inconsistent, but in general it followed the hypothesis of Blaser and Brady (1950) and Ward and Blaser (1957). These workers concluded that nitrogen causes a legume-grass mixture to revert to grass, because grasses respond to nitrogen while legumes do not. In this experiment the species that responded best to nitrogen tended to become dominant in the seed. The orchardgrass-fescue mixture brought this point out clearly. Orchardgrass became established earlier in the spring than fescue; therefore, it had first chance at all the growth factors. Nitrogen applications accelerated the growth of orchardgrass even more, causing an even greater suppression of the fescue which was not established sufficiently to utilize the nitrogen. Thus, there was more fescue and less orchardgrass on low nitrogen plots than on high nitrogen plots. The same analogy could account for the response from nitrogen by fescue plots on

July 4, 1960. The fescue was able to respond to nitrogen better than was quackgrass; therefore, nitrogen improved the stand of fescue.

Potassium effects: Two important trends were apparent with potassium fertilization: 1. Increases in potassium fertilization tended to improve the stand of orchardgrass and fescue. 2. The effect of potassium on bluegrass was just the opposite. These trends were apparent on pure seedings and mixtures. Drake and Colby (1949) also found that Kentucky bluegrass grew on low potassium soils better than orchardgrass or tall fescue. Their results indicated that orchardgrass grew on low potassium soils better than tall fescue. According to Drake, Vengris, and Colby (1951) the cation exchange capacity of the roots should cause bluegrass to be best on low potassium soils, orchardgrass next, and fescue next.

When either orchardgrass or fescue were grown with bluegrass, bluegrass stands were reduced with higher applications of  $K_2O$ , but there was more bluegrass grown in fescue than in orchardgrass mixtures. In the orchardgrass-fescue mixture, fescue also made up a greater percentage of the sward at low potassium than at high potassium levels. The cation exchange theory could be used to explain why bluegrass grows better at the lower potassium levels when grown with either orchardgrass or

fescue, but it does not explain the lower percentage of bluegrass in the orchardgrass as compared with fescue mixture. Likewise, it does not explain the increased portion of fescue at the low potassium rates in the fescue-orchardgrass mixture.

Orchardgrass in mixtures responded more to the higher levels of potassium than either fescue or bluegrass; this may be attributed to better initial stands of orchardgrass due to vigorous seedling growth. Orchardgrass growth was less without potassium fertilization than with potassium fertilization. Fescue and bluegrass survived on low potassium soils better than orchardgrass; therefore, they were more prevalent with low as compared with high soil potassium. Likewise, bluegrass, grown in association with fescue, survived on lower soil potassium than fescue. Under low potassium, the fescue stand and growth were reduced, thus permitting more light and encroachment of bluegrass.

Bluegrass was more prominent in the mixtures when liberal nitrogen was applied with no  $K_2O$ . Blasser and Brady (1950) found that grasses were more prominent in grass-legume mixtures when nitrogen was applied. Their conclusion was that the nitrogen stimulated yield which in turn depleted the soil of potassium. The grasses survived at lower soil potassium than the legumes,



causing the grass population to increase. A similar explanation may apply in this experiment. Nitrogen increased growth which in turn depleted the soil of potassium, thus causing a reduction in stand of those species more sensitive to low soil potassium.

The data in this experiment are in agreement with those of Doll (1957) with respect to the effect of potassium on the weed population. There was a reduction in the percentage of weeds and weedy grasses with increasing potassium rates. Blaser and Brady (1953) reported that broad leaf weeds removed more potassium than either grasses or legumes; hence, higher weed populations may be expected for low as compared with high soil potassium. Most of the weeds in this experiment after the first year were grassy weeds.

#### Ground Cover

Seeding effects: The degree of ground cover was associated with seedling vigor of the three grasses the first year. Orchardgrass was best, followed by fescue, with bluegrass being poorest. Very little difference was observed in ground cover during the second year, but plots seeded to orchardgrass had slightly less ground cover than the others on most dates. The bunch-type growth of orchardgrass permitted many bare spots between plants. These bare spots

were especially prominent in the mixtures, where a lower rate of seed was applied.

Nitrogen and potassium effects: Nitrogen stimulated growth which provided a dense cover prior to cutting. Foliage of vigorous plants retarded the shorter, less vigorous plants because of light competition. The root systems of plants with good seedling vigor were well nourished by photosynthetic products from the tops. These roots then spread rapidly, cutting off water and nutrients from the less vigorous species. After cutting there was a great deal of bare space between the bunch-type grasses. When the nitrogen rate was low, there was less competition between plants; therefore, there was a denser plant population after cutting, even though the yield was lower.

The grass stands without potassium had thinned slightly due to the potassium deficiency during both seasons. The experiment was not of sufficient duration to allow encroachment of other species to fill in these bare spots, but it is predicted that bluegrass and weeds will encroach within the next year or two. Gerwig and Ahlgren (1958) and many other workers have also reported stand reductions due to low potassium.

### Yield

Seeding effects: The relationship between the yield of

the grasses grown alone and in mixtures was too variable between cuttings to make any statement that would apply for all cutting dates. The yield of the first year, however, was a reflection of the seedling vigor of the plants; that is, orchardgrass best, followed by fescue, with bluegrass last.

During the second year the following observations were made:

1. Orchardgrass was a very prolific producer in the spring, but fall growth was inferior to fescue. It was very productive during spring and was damaged during the late summer by leaf diseases and drought.

2. Fescue did not produce as much forage at the spring harvest as orchardgrass, but the fall harvest was much larger. It was not damaged by diseases and could withstand drought. Seedheads emerged a little later in the spring than for orchardgrass.

3. Bluegrass produced less forage than either fescue or orchardgrass, but weeds raised the yield to about that of orchardgrass.

The above observations seemed to occur for the mixtures, also, but little differences in yield showed up because the high and low producing species tended to equalize each other. The delayed heading of fescue caused the fescue-bluegrass plots to yield more than the

other two mixtures on May 30. The author (1956) found that tall fescue produced seedheads about one to two weeks later than Virginia grown orchardgrass. Since both orchardgrass and bluegrass were poorer producers in the fall than fescue, the orchardgrass-bluegrass mixture yielded less forage than mixtures with fescue.

Nitrogen effects: Applications of 300 pounds of nitrogen were beneficial in practically all instances, but additional applications did not improve yield except in the spring harvest. The 300 pound rate produced about one ton more forage than the 100 pound rate. Griffith (1960) also reported large increases in yield of orchardgrass up to the 300 pound rate. Kresge and Yeunts (1960) found that 400 pounds of nitrogen produced maximum yields when adequate K<sub>2</sub>O was applied. In this experiment 500 pounds of nitrogen produced only 300 pounds more dry matter than the 300 pound rate; therefore, it would not be economical to apply 500 pounds of nitrogen.

The results obtained are in agreement with those of Drake and Colby (1958) in that the nitrogen responses were best in the spring. McNaught (1958) obtained greater efficiency in the summer in New Zealand, but the New Zealand summer is probably very similar to spring at Blacksburg.

Potassium effects: Potassium applications usually gave a small increase at each cutting, but as with nitrogen, the greatest responses were obtained in the spring and fall. These responses were a reflection of the seasonal growth. The summer was very dry; therefore, the benefit from summer fertilization was very small.

Responses to potassium were greater with 300 and 500 pounds than with 100 pounds of nitrogen. Griffith (1960) and Kresge and Yeunts (1960), Blaser and Brady (1950), and many others observed similar results. Nitrogen stimulates grass growth which removes more potassium from the soil; thus a deficiency results unless potassium is added. The poor yield at the high rates of nitrogen and low rates of potassium also might be explained by toxicity caused by the  $\text{NH}_4$  ion (Jackson, 1960).

It is difficult to specify an optimum potassium application. The cost of the fertilizer, the prices of the hay or pasture, residual potassium in soils, and the amount of rainfall would be important considerations. The author feels that approximately 75 pounds of nitrogen and 50 pounds of  $\text{K}_2\text{O}$  in early spring and the same amounts before the last cut would be beneficial. If rainfall were sufficient, summer applications would probably pay. Such a schedule would provide potassium and nitrogen for the periods of rapid growth when the plant could utilize

them and reduce the elements when the plant could not utilize them because of drought or other factors.

### Soil Chemical Analysis

Seeding effects: The grasses differed considerably in their capacity to extract potassium from the soil.

Orchardgrass depleted the soil of potassium most, fescue next, and bluegrass least. Since the dry matter removed from the soil by the three species was practically equal, it is evident that these soil differences were due to differential potassium uptake among the grasses.

Bluegrass extracted sufficient potassium on low potassium soils, and it took up less potassium than fescue and orchardgrass when adequate amounts were supplied. Chamblee and Lovvorn (1953) concluded that orchardgrass was less competitive for potassium than tall fescue when they were grown in association with alfalfa. They based their conclusions on plant analyses. Soil analyses in this experiment did not support this trend. Fescue did not extract as much potassium as orchardgrass at any sampling date. These results indicate that if potassium competition were the only factor considered, bluegrass would be the best species of the three to grow in association with legumes, and orchardgrass would be the poorest. This, of course, is not true because the

morphology and usage of the grasses must be considered. Gray et al. (1953) attributed the poor compatibility of bentgrass and Kentucky bluegrass when grown with ladino clover to the cation exchange capacity of roots. Bentgrass and bluegrass are both rhizomatous plants which would offer a great deal of above ground competition to ladino, regardless of the root cation exchange capacity.

Nitrogen effects: Increasing nitrogen rates decreased soil potassium, pH, magnesium, and calcium during the first season and all of these, except magnesium, the second season. Hileman (1959) also reported that nitrogen applications reduced the soil potassium content. The decrease in soil potassium caused by nitrogen corresponded very closely with the increase in yield. The decrease in the other ions was probably caused to a great extent by the increased yields, also.

Scott and Walsh (1959) found that ammonium fertilizers blocked the release of potassium from the fixed form. Ammonium nitrate was used in this experiment; therefore, the increased amount of ammonium ions in the soil might account for the lowering of the potassium content. The ammonium ion also acts as a cation which can replace any of the other cations on the exchange complex, thus freeing them for uptake by the plant root or leaching. It is well known that nitrogen fertilizers increase the

calcium and magnesium content of the plant (Blaser, 1955; McLean, 1955).

Ammonium nitrate is a highly soluble compound which freely dissociates in water to form  $\text{NH}_4\text{OH}$  and  $\text{HNO}_3$ . The  $\text{HNO}_3$  is a very strong acid, producing  $\text{H}^+$  ions which replace other cations on the clay. The  $\text{NH}_4\text{OH}$  is transferred to  $\text{HNO}_3$  by the soil microorganisms; therefore, it causes release of other cations, both as the  $\text{NH}_4$  ion and indirectly as the  $\text{H}^+$  ion. Since both the  $\text{NH}_4^+$  and the  $\text{NO}_3^-$  ion form acids in the soil, the pH is reduced.

Increased nitrogen rates did not reduce the MgO content of the soil during the second year. In the spring of 1960 the source of nitrogen was changed from ammonium nitrate to commercial ANL which is ammonium nitrate with dolomitic limestone added. This nitrogen source is seven percent MgO; therefore, increased additions of nitrogen are accompanied by additions of MgO and CaO. The ANL probably accounts for the rise in MgO during the second growing season.

Potassium effects: The frequent applications of potassium fertilizer always caused the soil potassium to reflect the rate of potassium application. These results are in agreement with Carter et al (1959) and many others.

Potassium fixation and removal by plants did not occur fast enough during 1959 and the winter of 1960 to remove



all the potassium that was applied. As a result there was a continued buildup of potassium in the soil through May, 1960, even though a heavy yield of forage was removed in the spring. Evidently a great deal of potassium fixation occurred during June and July when the temperatures were high and the soil was dry. Burn and Barber (1960) attributed fixation of potassium to temperature instead of moisture content. McLean and Simon (1958b), however, attributed a great deal of fixation to drying. Bradfield et al. (1945) and Blue (1959) failed to get accumulations of exchangeable potassium in the soil from fertilizer applications over a period of years.

Figure 20 indicates that an equilibrium might have been reached in 1960, since the curve for the four application rates of  $K_2O$  are similar and are always separated to about the same magnitude. The differences in soil  $K_2O$  correspond closely to differences in  $K_2O$  applied.

Applications of  $K_2O$  reduced the  $MgO$  in the soil but had little effect on  $CaO$  and  $P_2O_5$ . It is probable that high  $K_2O$  did reduce the  $CaO$  content slightly, but since the soil  $CaO$  was so high in comparison to  $MgO$ , it was not detected in the analysis. Whittaker (1959), Haas and Gruppe (1959), and many others have also observed the reduction of  $MgO$  and  $CaO$  by applications of  $K_2O$ . High rates of  $K_2O$  causes some release of calcium and magnesium

from the clay particles, permitting them to leach out. The data in this experiment and that of Wells and Parks (1960) indicate that  $K_2O$  applications show very little influence on the pH of the soil.

#### Stand Count

Stand reductions similar to those reported by Olson and Dreier (1956), Ward and Blaser (1961), and many others were observed only on bluegrass seedlings. Orchardgrass and fescue are evidently better able to survive the stresses of high osmotic pressure or toxic conditions brought on by ammonium nitrate applications.

Damages due to KCl similar to those reported by Brown (1958), Carter (1957), and Olson and Dreier (1956) were not in evidence in this experiment. In fact, the statistical analysis showed a very slight improvement in the stand due to KCl. Washko (1949) also reported a correlation between available potassium and seedling growth.

#### Potassium and Nitrogen Effects on Color

The distinct green color of the forage species on low potassium plots is difficult to explain. A similar dark color is well known for plants receiving nitrogen applications. Richards (1932) reported that leaves of potassium deficient barley plants were light yellow.

Janssen and Bartholomew (1929) and Nightingale et al (1930) reported that potassium deficient tomato plants were darker green than normal plants.

Magnesium is a constituent of chlorophyll, and both high nitrogen and low potassium rates increase magnesium uptake; thus it seems logical that chlorophyll was responsible for the dark green color. Chlorophyll analysis, however, did not show any differences between potassium rates. It was suggested that perhaps water content might have something to do with the color, so water content was determined on the last cutting. These results showed that the high potassium rates stimulated the water content of grass. Possibly the water does have some effect, but it is difficult to explain. If the chlorophyll were more concentrated on low potassium plots, the chlorophyll analysis should have detected it.

#### Plant Chemical Composition

Seeding effects on mineral composition: There was no evidence that the potassium, magnesium, or calcium content of fescue or orchardgrass was different when the grasses were grown separately or in association with each other. There was little difference in the content of any of the ions in either of the species when grown in association with either of the other species. The calcium content of

fescue was higher when fescue was growing in association with bluegrass than when it was growing with orchardgrass on October 11, 1960, but this trend was not consistent. In fact, the trend was reversed in a previous harvest, but the differences were not significant.

Bluegrass takes up less potassium than either orchardgrass or fescue with a given rate of potassium. These differences in potassium uptake explain why there is more potassium left in the soil in pure bluegrass plots than in orchardgrass or fescue plots.

Nitrogen effects on mineral composition: Additions of nitrogen to the soil increased the calcium and magnesium contents of all species of plants. The effect of increased nitrogen applications on the potassium content was inconsistent, but they usually reduced it slightly. These results are quite common and have been observed by Blaser (1955), Drake and Colby (1958), McLean (1955), and many others. McLean attributed the increase in uptake of calcium and magnesium resulting from nitrogen application to the increased cation exchange capacity of roots.

The  $\text{NH}_4\text{NO}_3$  combines with water in the soil to form  $\text{HNO}_3$  and  $\text{NH}_4\text{OH}$ . The  $\text{NH}_4\text{OH}$  is changed to  $\text{HNO}_3$  by the microbes in the soil; therefore, the soil becomes acid with nitrogen applications.

Potassium effects on mineral composition: It is well known that addition of any element to the soil results in increased uptake of this element by plants growing in the soil. If an element is added in large amounts it prevents the uptake of other elements and often causes a deficiency. In this experiment when  $K_2O$  was added the potassium content of the plant was increased, with a resulting decrease in calcium and magnesium. In most instances when potassium was low, additions of nitrogen reduced the potassium content of the plant but did not when the potassium supply was high.

Potassium content in the plants was usually a reflection of the amount in the soil. Plants take up excesses of potassium; therefore, each increment increase in potassium fertilization increases the level in the soil and in turn increases the level in the plant. Nitrogen applications usually reduced soil potassium by replacing the potassium on the exchange complex. The ammonium ion may also have blocked release of fixed potassium (Scott and Welsh, 1959), thereby reducing potassium availability. This "fixed" potassium, then, could not replenish the available form, thus causing the potassium content of the plant to be reduced when no potassium or small amounts were added.

The optimum level of potassium in the plant for

maximum growth was rather high. Small increases in yield were obtained for each additional increment of  $K_2O$  applied; therefore, economics would be an important factor in setting limits. It appears that the optimum level should be above 1.5 percent; possibly 2 percent would be a better figure. This level would vary with the season and should be higher in the spring and fall than in summer.

Water content: Richards (1932) and Gregory and Richards (1924) reported a reduction in percentage of water in plants similar to that found in this experiment. Other workers have also noted small increases in percentage of water with increases in potassium application. The photograph in Figure 32 illustrates the succulent condition of a fescue plant receiving high applications of  $K_2O$  in comparison to one with no  $K_2O$ . It is apparent that some factor in both nitrogen and potassium is responsible for the more succulent condition of plants. Increase in osmotic pressure of the cell sap due to nitrogen and potassium might be responsible for some of the water increases.

Nitrogen in the forage: The results from one harvest showed that increasing nitrogen rates increased the level of nitrogen in the plant and reduced the level of potassium slightly. These data are in accordance with those

of Blaser (1955), Drake and Colby (1958), and others. Evidently the mass action effect of the nitrogen additions is enough to cause some increase in nitrogen uptake. The nitrogen causes accelerated plant growth which dilutes the potassium in the plant.

**LABORATORY EXPERIMENTS ON POTASSIUM UPTAKE****Experiment I**

**Potassium concentration and temperature  
on the absorption of potassium by  
excised roots of various forage species**

**Introduction: Cool season species, such as wheat and crimson clover, grow at lower optimum temperatures than warm season species, such as sudangrass or sericea lespedeza. This difference in growth of plants is evidence of different physiological processes within the plant. Ion uptake is correlated with respiration; therefore, rapidly growing plants having a higher respiration rate should take up cations at a faster rate than the slower growing plants. Since wheat and crimson clover have a more rapid growth at cool temperatures than sudangrass and lespedeza, the former should take up more cations at cool temperatures than the latter species.**

**Some workers support the thesis that uptake of cations is closely related to the cation exchange capacity of the roots. They say that legumes have a higher cation exchange capacity than grass. Grasses, therefore, take up more monovalent cations, such as potassium, while legumes take up more of the divalent**



cations, such as calcium. Advocates of this theory base their assumptions on the following expression:

$$\frac{\sqrt{[D]_i}}{[M]_i} = k \frac{\sqrt{[D]_o}}{[M]_o}$$

where  $[D]_i$  and  $[D]_o$  refer to the concentration of the divalent cation in the root and the ambient solution, respectively, and  $[M]_i$  and  $[M]_o$  are the corresponding concentrations of the monovalent cations. If a theoretical situation is set up where  $k \sqrt{\frac{[Ca]}{[K]}}$  in the soil solution is one, and the cation exchange capacities of roots from two plants growing in the soil are 56 and 20, then the following situation would be true according to the theory. The root with the cation exchange capacity of 56 would have 49 milliequivalents of calcium and 7 milliequivalents of potassium per 100 grams of roots ( $\frac{49}{7} = 1$ ); whereas, the root with the cation exchange capacity of 20 would have 16 milliequivalents of calcium and 4 milliequivalents of potassium per 100 grams of roots ( $\frac{16}{4} = 1$ ). To maintain the constant the root with the high cation exchange capacity would contain seven times as much calcium as potassium, but the root with the low cation exchange capacity would contain only four times as much.

This experiment was conducted to study nutrient uptake of various species at different temperatures.

Various concentrations of KCl solutions were used to determine if the species behaved differently under high and low potassium stress.

Methods and materials: The experiment consisted of two replications of the following treatments in a factorial arrangement.

<u>Species</u>	<u>KCl Solution</u>	
	<u>Temperature (°C.)</u>	<u>Concentration</u>
Wheat	4.5	.001 <u>N.</u>
Grimson Clover	10.0	.01 <u>N.</u>
Orchardgrass	15.6	.1 <u>N.</u>
Serecia Leapedeza	21.1	
Sudangrass	26.7	

5 species x 5 temperatures x 3 concentrations = 75 treatment variables.

Seed were sown in greenhouse flats filled with vermiculite, then they were watered throughout their growing period with a weak nutrient solution consisting of 0.6 ml 1 N.  $\text{Ca}(\text{NO}_3)_2$ , 0.4 ml 1 N.  $\text{MgSO}_4$ , 0.4 ml 1 N.  $\text{NaH}_2\text{PO}_4$ , and 0.4 ml of 1 N.  $\text{NaNO}_3$  per liter. After three weeks sufficient roots had accumulated for the experiment. The roots were excised just below the seed residue, then washed free of vermiculite and placed in distilled water until the treatments began.

Fifty ml of the KCl solution was placed in each

of 75, ten inch test tubes; the tubes were inserted into a water bath maintained at the proper temperature. After the temperature of the solution in the test tubes became stable, the roots were added and an aerator consisting of a capillary tube attached to an air compressor was inserted into each test tube. The roots were aerated for exactly three hours, then they were removed, rinsed and dried at approximately 80°C. Dry weights were recorded, and the samples were ashed in a muffle furnace for two hours at 450°C. Twenty ml of a 1.5 N. HNO<sub>3</sub> solution was added to the ash and made up to 100 ml with distilled water. This solution was analyzed with a Beckman D. U. flame spectrophotometer. The results are presented in milligrams of potassium per gram of dry weight.

Endogenous potassium was determined from samples not subjected to the treatments.

Results: Table 7 shows the potassium in the roots of the various species as affected by the temperature and concentration of the absorption medium. Table 8 shows the same data after being corrected for endogenous potassium.

Temperature effects: It was postulated that cool season species, such as wheat and crimson clover, would take up more potassium at a low temperature than the warm season species, such as seresia lespedeza and sudangrass. The results of this experiment failed to support such a

Table 7. Milligrams of potassium per gram of dry weight of roots of various species of plants after absorption for three hours at various temperatures and normalities of potassium chloride.  
(Mean of two replications)

Species	0.001 N.		0.01 N.		0.1 N.		0.001 N.		0.01 N.		0.1 N.		Mean
	4.5°C.		10.0°C.		10.0°C.		21.1°C.		26.7°C.		26.7°C.		
Wheat	5.94	10.88	43.45	20.09	7.96	7.60	33.39	16.31					
Crimson Clover	23.46	26.15	36.07	28.56	20.38	24.14	43.71	29.41					
Orchardgrass	14.39	17.33	38.61	23.44	8.06	13.80	36.66	19.51					
Lespedeza	21.87	16.51	45.99	28.12	27.67	21.50	36.67	28.61					
Sudangrass	8.23	12.87	37.23	19.44	9.31	10.04	39.04	19.46					
Mean	14.78	16.75	40.27	23.93	14.67	15.41	37.89	22.66					
Wheat	8.50	12.96	45.41	22.29	5.89	8.15	26.31	13.45					
Crimson Clover	24.47	29.22	46.44	33.37	28.57	31.46	32.71	30.91					
Orchardgrass	11.79	20.28	36.30	22.79	12.19	20.04	39.45	23.89					
Lespedeza	31.12	27.27	51.08	36.49	27.74	15.74	38.13	30.53					
Sudangrass	5.67	13.27	30.30	16.41	8.88	12.30	19.20	13.46					
Mean	16.31	26.60	41.90	26.27	16.65	19.54	31.16	22.45					
Wheat	7.02	8.00	27.52	14.18	7.06	9.52	35.21	17.26 <sup>a</sup>					
Crimson Clover	24.69	27.13	41.36	31.06	24.31	27.62	40.05	30.66 <sup>c</sup>					
Orchardgrass	14.41	18.06	27.94	20.14	12.17	17.90	35.79	21.95 <sup>b</sup>					
Lespedeza	25.79	25.98	38.73	30.17	26.84	23.40	42.12	30.78 <sup>c</sup>					
Sudangrass	9.49	12.16	24.87	15.50	8.31	12.13	30.13	16.86 <sup>a</sup>					
Mean	16.28	18.27	32.08	22.21	15.74 <sup>d</sup>	18.11 <sup>d</sup>	36.66 <sup>e</sup>	23.50					

\* Means with the same letter contain similar levels of potassium.

Table 8. Potassium uptake (mg K per g dry root) by various species of plants after absorption for three hours at various temperatures and normalities of potassium chloride.  
(Mean of two replications corrected for endogenous potassium)

Species	0.001 N.	0.01 N.	0.1 N.	Mean	0.001 N.	0.01 N.	0.1 N.	Mean
	<u>4.5°C.</u>				<u>10.0°C.</u>			
Wheat	.37	4.57	37.14	13.78	1.65	1.29	27.08	10.00
Crimson Clover	-1.50	1.19	11.11	3.60	-4.58	-.82	18.75	4.45
Orchardgrass	-1.16	1.78	23.06	7.89	-7.49	-1.75	21.11	3.96
Lespedeza	-2.24	-7.65	21.87	3.99	3.56	-2.61	12.55	4.50
Sudangrass	-2.70	2.96	26.30	8.85	1.04	.92	28.11	10.02
Mean	-1.60	.57	23.89	7.62	-1.17	-.60	21.51	6.58
	<u>15.6°C.</u>				<u>21.1°C.</u>			
Wheat	2.19	6.64	39.10	15.98	-.42	1.84	20.00	7.14
Crimson Clover	-.49	4.26	21.48	8.41	3.61	6.50	7.75	5.95
Orchardgrass	-3.76	4.73	20.75	7.24	-3.36	4.49	23.90	8.34
Lespedeza	7.01	3.15	26.97	12.37	3.62	1.62	14.02	6.42
Sudangrass	-5.26	2.34	19.37	5.48	1.17	1.37	8.27	3.60
Mean	-.07	4.22	25.53	9.89	.92	3.16	14.79	6.29
	<u>26.7°C.</u>				<u>Mean of all Temperatures*</u>			
Wheat	.71	1.69	21.21	7.87	.75	3.20	28.90	10.95 <sup>a</sup>
Crimson Clover	-.27	2.17	16.40	6.10	-.65	2.66	15.09	5.70 <sup>b</sup>
Orchardgrass	-1.13	2.51	12.39	4.59	-3.38	2.35	20.24	6.40 <sup>b</sup>
Lespedeza	1.68	1.87	14.61	6.05	2.72	-.73	18.00	6.66 <sup>b</sup>
Sudangrass	-1.44	1.23	13.94	4.57	-1.44	1.76	19.20	6.50 <sup>b</sup>
Mean	-.09	1.89	15.71	5.83	-.40 <sup>c</sup>	1.85 <sup>c</sup>	20.29 <sup>d</sup>	7.25

\* Means with the same letter are in a similar uptake category.

trend.

Species and concentration effects: Figure 33 shows the relative endogenous potassium contents of the species and the total amount taken up at each of the concentrations.

The endogenous potassium content of the grasses was very low (0.63, 1.0, and 1.6 percent for wheat, sudangrass, and orchardgrass, respectively) in comparison to the legumes (2.4 and 2.5 percent, respectively, for seresia lespedeza and crimson clover). The 0.001 N. KCl solution increased the potassium content of wheat and seresia lespedeza only. There was no significant increase at the 0.01 N. KCl concentration, although all the species except seresia lespedeza showed an increasing trend. Tremendous increases in potassium were apparent for all species at the 0.1 N. KCl concentration. The potassium composition of the two legumes was almost doubled, that for orchardgrass and sudangrass was tripled, while that for wheat was increased more than five-fold.

The differences in potassium content between the species became smaller as the potassium concentration of the absorption medium was increased. For instance, there was a difference of 20 mg per g dry weight of root between wheat and lespedeza roots at the 0.001 N. KCl concentration, but this difference was reduced to only 7 mg

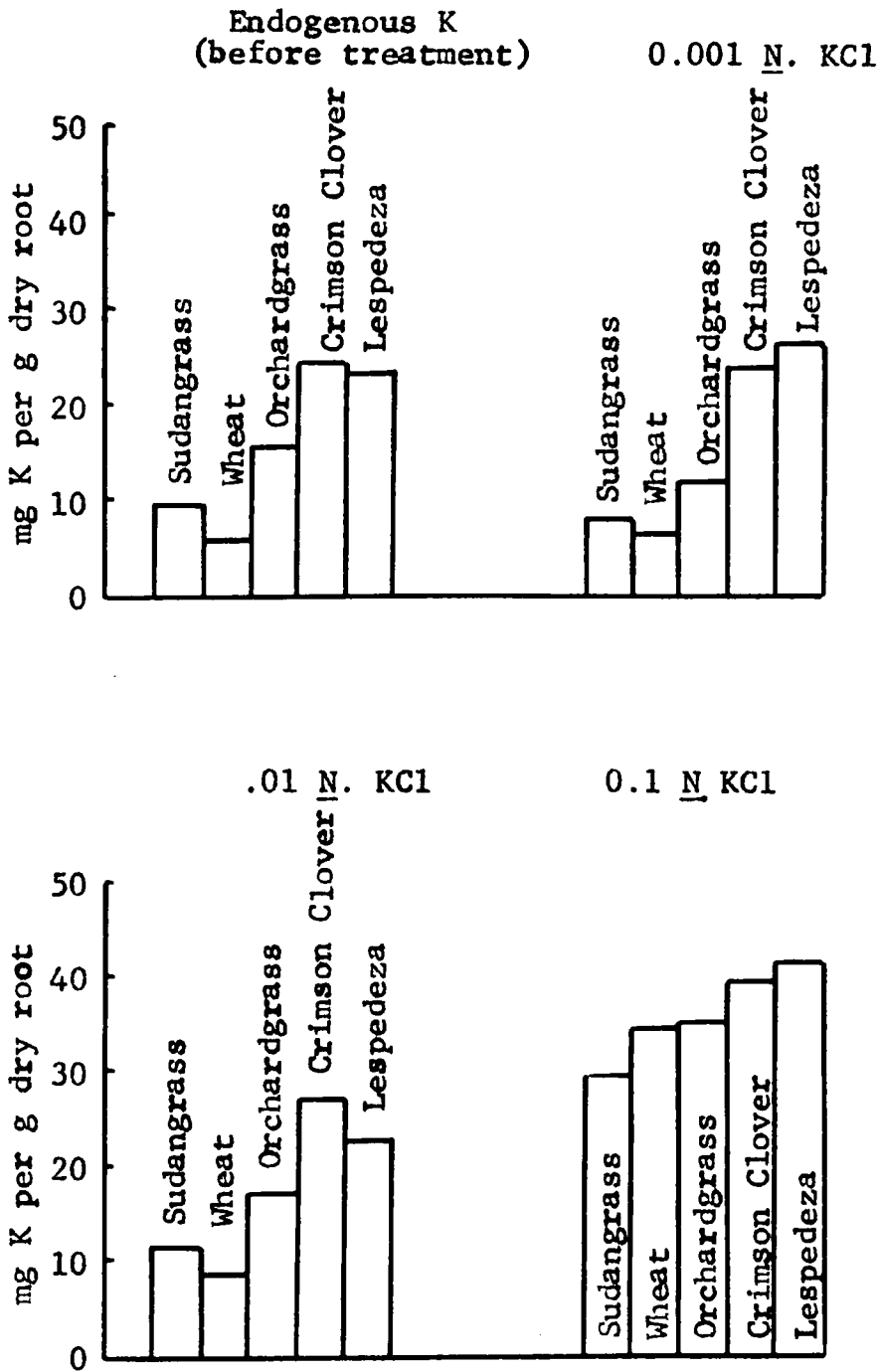


Figure 33. Concentration of potassium in excised roots of various plant species before treatment and after three hours in aerated KCl solutions (mean of five temperatures and two replications).

per g at the 0.1 N. concentration. Figure 34 shows the average potassium uptake of the five species at each of the KCl concentrations. It shows that wheat, being lowest in endogenous potassium, has taken up more potassium than any of the other species. At the 0.1 N. concentration the amount of potassium taken up by species having a lower initial potassium content was greater than those having the higher concentration. Perhaps the initial concentration of a cation is one of the main factors which should be considered in absorption studies. It was much more important in this experiment than the type of species.

A species by concentration interaction was noted in the analysis for both total potassium and potassium uptake. This interaction was caused by the odd response of lespedeza. Lespedeza took up almost 3.0 mg of potassium in the 0.001 N. solution while most of the other species lost potassium. In the 0.01 N. solution lespedeza lost an average of 0.73 mg while the other species were absorbing potassium. This trend was consistent for four out of the five temperatures.

Discussion: The differences in the initial potassium content of the species is good evidence for emphasizing the need for enlarging the number of species used in uptake studies. A large majority of such studies have



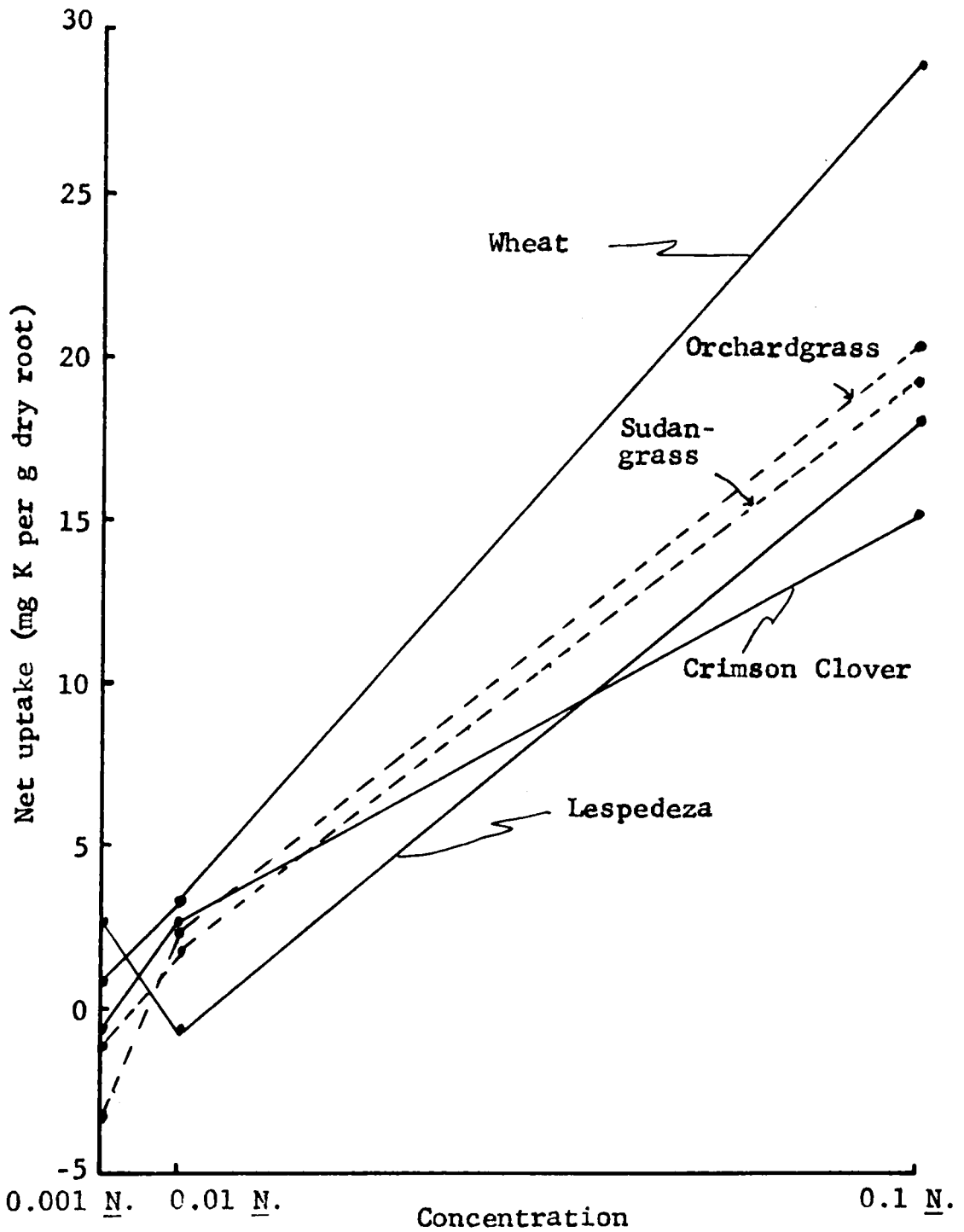


Figure 34. Effect of concentration of the KCl absorption medium on the uptake of potassium by roots of five forage species. Absorption period was three hours.

been with the barley plant. Collander (1941) pointed out the tremendous differences in ion uptake between species, and McCollum (1960) noted five-fold differences in ion uptake by different varieties of the same plant.

Broyer (1951), Ulrich (1942), and many others have shown that increasing the salt concentration increases the uptake. The results of this experiment are in agreement.

It is difficult to explain why no increases in potassium uptake were obtained with temperature increase, since Broyer (1950), Jacobson et al. (1957), and others have shown substantial increases. These workers, however, used radioactive tracers and thus could measure any movement of ions, whereas the analytical techniques used in this experiment measured net movement into the root only. This net movement had to be in relatively large quantities before differences could be detected with the techniques used. Since the absorption period was only three hours, very little net active accumulation, that is, accumulation into the inner space which makes up about three-fourths of the plant, could have occurred (Epstein, 1954; Butler, 1953; Conway and Downey, 1950; Epstein, 1955; and Hope and Stevens, 1952).

When roots are inserted into an absorption medium containing radioactive potassium, there is a rapid exchange of radioactive for non-radioactive potassium in

the outer space of the plant root. This process is similar to inserting a plant completely devoid of potassium into a potassium solution as far as uptake measurements are concerned. In this experiment some of the plants contained over two percent potassium; therefore, one would not expect a rapid net increase in root potassium due to rapid equilibration with the ambient solution.

This experiment, as well as the later ones, showed that legume roots were consistently higher in potassium than grass roots, even when no potassium had been administered. This fact is one of the reasons why the legumes failed to absorb as much potassium as grass, especially wheat. Broyer (1950) and Hoagland and Broyer (1936) pointed out that roots with a high salt content absorb additional salt at very slow rates in comparison to low salt roots. They also pointed out that high salt roots often lose salt when placed in a low salt medium. This was the case at the 0.001 N. potassium level in this experiment.

## Experiment II

Length of the absorption period on potassium uptake by excised roots and whole plants of soybeans from aerated and non-aerated solutions

Introduction: Ulrich (1941) and other workers have reported increases in cation uptake by excised roots with increases in temperature. Since there was no increase in cation uptake with temperature increase in Experiment I, it was postulated that the period of uptake was not optimum. The changes may have occurred very quickly and might have been obscured by an uptake period of three hours, or perhaps the uptake process was very slow and a longer uptake period should have been used. Overstreet and Jacobson (1946) showed that there is a very rapid uptake of radioactive rubidium for about five to ten minutes followed by a slower rate (but this rapid uptake is non-metabolic).

This experiment was designed to determine the length of the absorption period that would be best when non-radioactive KCl was the salt to be absorbed. Information was also obtained on the extent of transfer of potassium from the roots to the tops of the plant and the effect of aeration.

Methods and materials: Four week old soybean plants grown in a no potassium sand culture were taken from the

greenhouse and washed free of sand by a stream of tap water. The tops were removed from one half of the plants just below the first secondary root leaving the entire root system intact. The roots of the other half of the plants were not removed. All the roots were placed in distilled water for approximately one half hour until the treatments were started. Four root samples were used to determine endogenous potassium.

A solution of 0.005 N. KCl was placed in several one liter suction flasks. One half of these flasks received a fritted glass aerator while the remainder were not aerated. The source of oxygen for the aerated samples was an oxygen tank fitted with the proper reduction valves. The solutions had been poured about 24 hours prior to the beginning of the experiment; however, the flasks to receive oxygen were aerated for 15 minutes before inserting the roots. This aeration continued throughout the experiment.

About two grams of roots was inserted into each of the suction flasks at the same time. At the end of each time interval the solution was poured out and the roots were placed in a beaker without washing. See Experiment I for analytical procedures.

Results: Table 9 and Figure 35 indicate that very little absorption has occurred at three hours or less. The data show the optimum length for the absorption period

Table 9. Length of the absorption period on the potassium content of soybean roots and tops (mg K per g dry tissue). Absorption solution was 0.005 N. KCl.

Absorption Period (hours)	Roots excised before absorption aerated not aerated	Roots not excised before absorption aerated not aerated	Tops not excised before absorption aerated not aerated
0	11.82*		11.89*
0	10.56*		4.79*
0	9.53*		
0	7.25*		
1/60	14.05		
1/12	9.18		
1/6	12.53	12.86	13.46
1/3	14.24	6.46	14.74
1/2	8.13	11.19	10.11
1	14.10	10.93	10.61
2	16.59	13.79	11.08
3	18.71	12.96	14.39
5	27.60	12.54	12.33
10	32.05	20.74	13.47
24	36.51	29.87	12.35
48	42.44	21.43	7.77
		11.50	
		6.91	
		11.63	
		14.74	
		10.16	
		13.33	
		25.11	
		28.68	
		38.90	
		29.01	
	9.60		
	15.77		
	12.32		
	15.83		
	15.09		
	15.08		
	16.03		
	16.80		
	23.31		
	32.09		
	36.73		
	25.24		

\* Endogenous

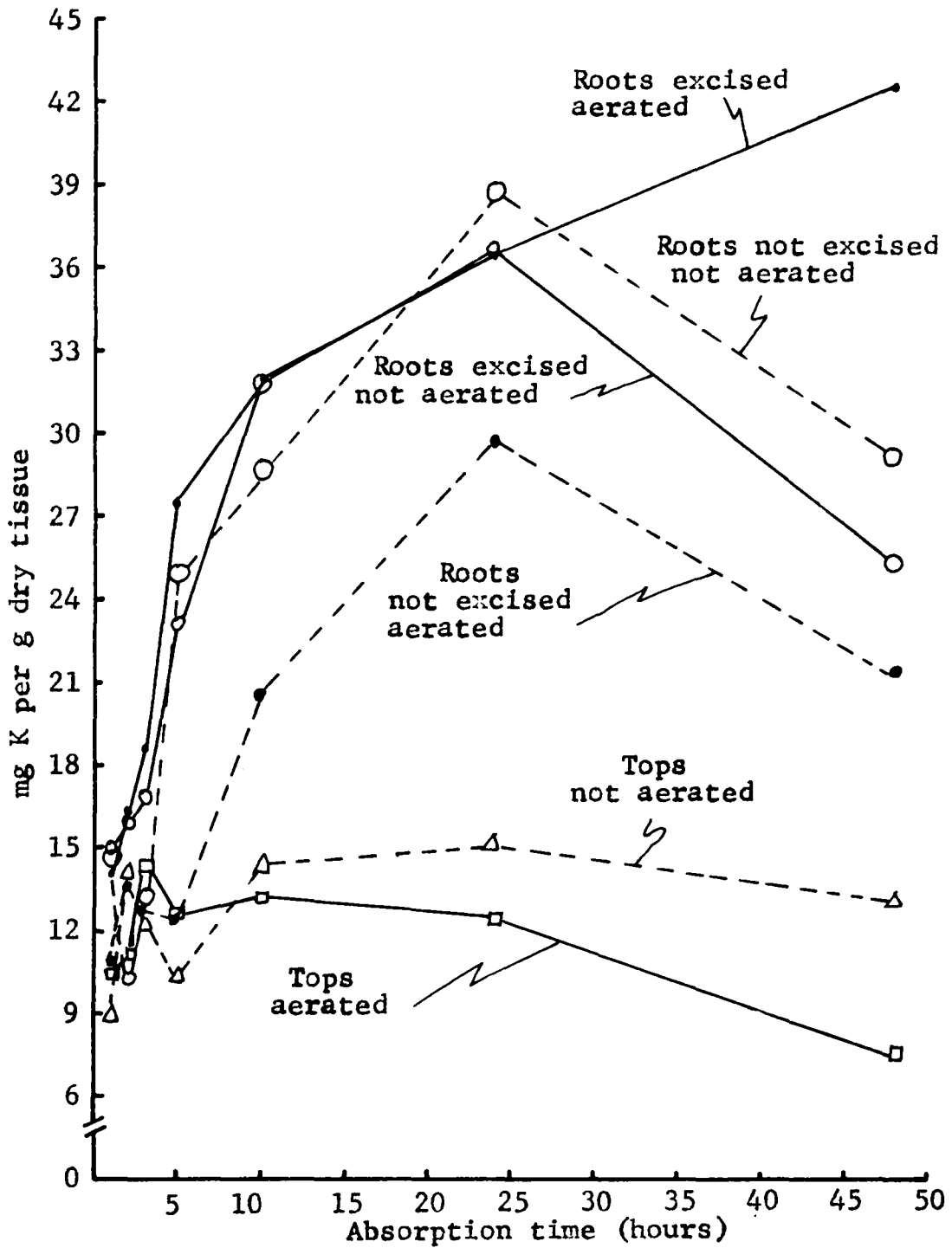


Figure 35. Length of absorption period on the potassium content of soybean roots and tops. Absorption solution was 0.005 N. KCl.

for soybeans should be in the range of 10 to 24 hours. All roots reached their maximum potassium content in the 24 hour absorption period, with the exception of the excised aerated roots which were still increasing after 48 hours. Since these variables were not replicated, it could not be determined if this difference at 48 hours was real.

Aeration did not increase the uptake in this experiment. Neither was there any evidence of a net translocation of potassium from the root to the tops of the soybean plants.

By moving the decimal point one place to the left, the percentage of potassium in the plant parts is obtained (Table 9). It should be noted that these four week old roots contained about one percent potassium prior to being placed into the KCl solution. After an absorption period of about 24 hours this percentage was increased to about three to four percent, which is considered very high for legumes. The reader should keep these percentages in mind while studying the results of the subsequent uptake experiments.

Discussion: This experiment indicated that one of the reasons for no temperature response in the previous experiment was the short uptake period. In this experiment we would not expect a very rapid non-metabolic



uptake, because there was already a considerable amount of potassium in the root. Metabolic uptake, however, must have occurred. It was concluded that an absorption period of from 12 to 24 hours should be used to conduct absorption experiments of this nature. Hoagland and Broyer (1936) also found that barley reached maximum absorption at 24 hours.

Hoagland and Broyer (1936) pointed out that it was unnecessary to aerate large open tanks when growing roots in solution culture. This experiment also showed no benefit from aeration, even though one liter suction flasks were used. The root volume, however, was not large and there was no other growth in the flasks to use up oxygen.

### Experiment III

Temperature of the absorption medium on the potassium uptake by excised roots of four plants

Introduction: Several workers have proposed that grasses compete with legumes for potassium, because grasses have a lower root cation exchange capacity and thus will absorb mostly monovalent cations. On the other hand, legumes, having a higher cation exchange capacity, will absorb more divalent cations.

It has been observed that grasses of cool season grass-legume mixtures start growth earlier in the spring than most of the legume associates. This earlier growth permits the grass to have first chance at the potassium supply. The legume, therefore, would have access to only that remaining. The purpose of this experiment was to observe the ability of two grasses and two legumes to absorb potassium from a KCl solution at various temperatures. If cool season plants absorb potassium at lower temperatures than do warm season plants, then the optimum temperature for the growth of a particular plant might be more important for potassium absorption than would root cation exchange capacity.

Methods and materials: Two warm season plants, corn and soybeans; and two cool season plants, English peas and

rye, were planted in quartz sand in flats in the greenhouse. The peas and rye were placed in a cool section of the greenhouse where the temperature was allowed to drop as low as 60°F. at night. The corn and soybeans were kept in a warmer section where the temperature did not drop below 70°F. The flats were watered with a nutrient solution lacking potassium.

When sufficient roots had accumulated (approximately four weeks) five gram portions of wet roots of each species were washed with tap water and stored for one to two hours in damp paper towels until the treatments started. One liter of 0.005 N. KCl solution was prepared for each species and allowed to come to the designated temperature. The roots were then rinsed in distilled water and placed into the solution. This solution was placed in a thermostatically controlled chamber which was maintained at a designated temperature  $\pm 0.5^{\circ}\text{C}$ . for 24 hours. No aeration was supplied in this experiment. At the end of 24 hours the roots were removed, rinsed in distilled water, and stored in a beaker until the chemical analysis was performed. See Experiment I for analytical procedures.

The temperatures used were 10°, 20°, and 30°C. Only one temperature could be run at one time; hence, several days were required to complete the experiment. Three replications were run, making the total duration of the

experiment nine days.

**Results:** Table 10 and Figure 36 summarize the results of this experiment. The two grasses were low in endogenous potassium having only about 0.2 percent, whereas the two legumes contained about three and one-half times as much. The two legumes increased in potassium with temperature increase through 20°, then began to decrease rapidly. Soybeans contained the highest potassium content of the four species at all temperatures. Peas was next highest in potassium content at 10° and 20° but showed a net loss of potassium at 30°C. Corn roots were lowest in potassium at all temperatures.

The potassium uptake curve (Figure 36) indicates more clearly what was happening. This graph shows that potassium uptake by corn was affected very little by temperature, while potassium uptake by rye decreased steadily as the temperature rose above 10°C. Soybeans showed a substantial increase in potassium uptake as the temperature rose from 10° to 20°C. while the uptake by peas changed very little. As the temperature rose from 20° to 30°C., potassium uptake by both soybeans and peas decreased rapidly at about the same rate.

**Discussion:** Except for the values obtained for corn, the results of this experiment tend to follow the theory that warm season species take up potassium at higher temperatures

Table 10. Potassium content and uptake by excised roots of various plants after absorption for 24 hours in a 0.005 N. KCl solution at three temperatures.

(mg K per g dry weight,  
mean of three replications)

<u>Temperature °C</u>	<u>Species</u>				<u>Mean</u>
	<u>Soybeans</u>	<u>Corn</u>	<u>Peas</u>	<u>Eye</u>	
	Potassium Content*				
Endogenous	7.09	1.70	6.78	2.15	4.43 <sup>a</sup>
10	17.77	6.35	15.06	14.26	13.36 <sup>b</sup>
20	22.26	5.50	15.45	12.24	13.86 <sup>b</sup>
30	11.01	5.12	4.19	6.46	6.69 <sup>a</sup>
Mean	14.53 <sup>c</sup>	4.67 <sup>d</sup>	10.37 <sup>a</sup>	8.78 <sup>c</sup>	9.59
	Uptake** (Total K - endogenous K)				
10	10.68	4.65	8.28	12.11	8.93 <sup>a</sup>
20	15.17	3.80	8.67	10.09	9.43 <sup>a</sup>
30	3.92	3.42	-2.59	4.31	2.26 <sup>b</sup>
Mean	9.92 <sup>c</sup>	3.96 <sup>d</sup>	4.79 <sup>d</sup>	8.84 <sup>c</sup>	6.88

\* Means with the same letter contain similar levels of potassium.

\*\* Means with the same letter are in a similar uptake category.

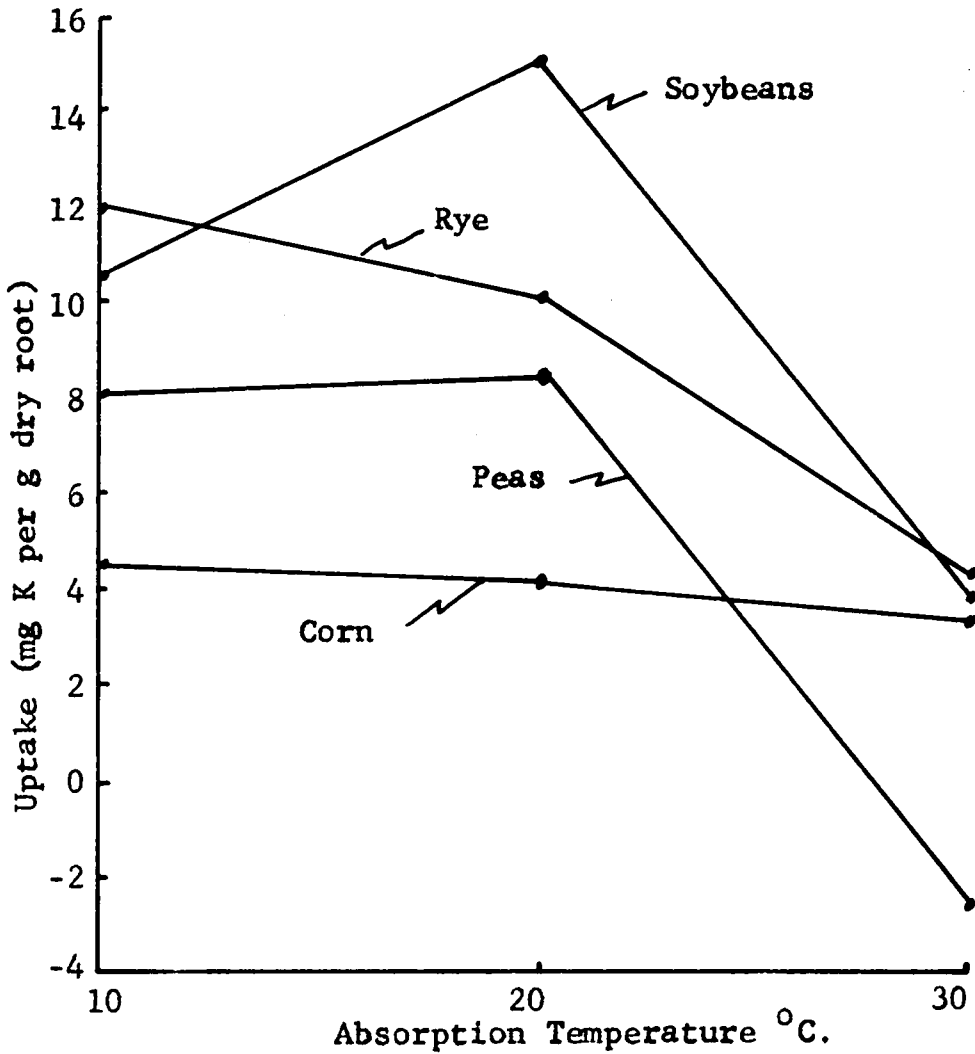


Figure 36. Potassium uptake by excised roots of various plants after absorption for 24 hours in 0.005 N. KCl at three temperatures. Values are means of three replications corrected for endogenous potassium.

better than cool season species, while the reverse occurs at low temperatures. Neilson et al. (1960) also observed that potassium uptake by corn was affected very little by temperature or decreased as the temperature increased. Rye reacted exactly as was predicted. It is one of the coolest season species, and it was one of the highest potassium absorbers at 10°C. Higher temperatures tended to reduce its capacity to take up potassium. Soybean, being a warm season species, absorbed about one and one-half as much potassium at 20° than at 10°C. It might have absorbed even more at 25°C if this temperature had been included. Thirty degrees C. was too high for any of the species to absorb much potassium, and it was especially detrimental to peas. Subsequent experiments verified this effect of high temperature on potassium uptake by peas.

### Experiment IV

Potassium uptake and respiration of various plant roots as affected by temperature

Introduction: Experiment I showed no effect of temperature on potassium uptake while Experiment III showed highly significant effects of temperature on the different species. It was decided that another experiment should be run to verify or disprove the previous results. A more desirable method of growing roots was used, which is a mass production modification of the procedure used by Mehlis (1944).

Methods and materials:

Root culture technique: Roots were grown in sheet metal tanks 2' x 2' x 8" filled to within one inch of the top with nutrient solution. Each species was grown in a separate tank. The solution was aerated by allowing compressed air to bubble vigorously through a capillary tube placed in each corner of the tanks. A wire grate with wires spaced two inches apart was placed over the top of each tank, and two layers of cheese cloth were placed over this grate allowing each end to dip into the nutrient solution. A frame made of this same grating material was placed over each tank allowing about six inches between grates. This grate was covered with cheese cloth in a like manner, followed by a clear plastic sheet



to reduce evaporation and to maintain a 100 percent relative humidity. At first, all metal parts were coated with varnish, but this was unsatisfactory. A coating of asphalt roofing compound was subsequently used. Tanks were placed on a laboratory bench with no supplementary light other than fluorescent ceiling fixtures.

The temperature of the solution was kept at  $25^{\circ}\text{C.} \pm 1^{\circ}\text{C.}$  by a small immersion type (thermostatically controlled) aquarium heater.

The nutrient solution consisted of a one-fourth concentration of the Hoagland and Arnon potassium deficient solution (Hoagland and Arnon, 1938) with a slight modification. Rates used were 1.25 ml  $\underline{\text{N}}$ .  $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ , 0.5 ml  $\underline{\text{N}}$ .  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ , and 0.25 ml  $\underline{\text{N}}$ .  $\text{NaH}_2\text{PO}_4$  per liter of nutrient solution.

Seed of rye and sudangrass were placed directly on the cheese cloth of the first grate. Soybeans and peas germinated too slowly when sown in this manner; therefore, the first two runs were germinated in a commercial type germinator. The remaining runs were germinated directly on the tank by placing the seed on the first cheese cloth and placing another directly on top of the seed. After germination, the top cloth was removed. Since the time required for germination was different, the plantings were made to give the same length of time from

germination. The number of days required from planting to germination was three, three, two, and one for peas, soybeans, sudangrass, and rye, respectively, when germinated on the tanks. If peas and soybeans were germinated in the germinator, five and four days, respectively, were required from seeding to germination. All seeds were treated with Arasan prior to germination. The cheese cloth and seeds were moistened frequently with nutrient solution to prevent the accumulation of salts. When the roots had penetrated through the cheese cloth into the nutrient solution, the top grate and cheese cloth were removed. After nine days sufficient roots had accumulated for the experiment. Varieties of seed were Lee soybeans, Laxtonian peas, Abruzzi rye, and Sweet sudangrass.

A disease infestation caused considerable damage to pea and soybean roots grown for the 10 and 20<sup>o</sup> runs. After these runs all the equipment and tanks were sterilized with "Baker's" commercial disinfectant prior to seeding, and seeds were all separated from each other on the tanks. By using these precautions satisfactory roots were obtained.

Potassium absorption and respiration technique:

Roots were excised with a razor blade at the point where they penetrated the cheese cloth. Ten grams of wet roots was weighed, rinsed with distilled water, then

stored in a damp paper towel until they were placed in the KCl solutions. At the same time four, 10 gram samples of each species were set aside for endogenous potassium determination. Roots were then placed in the KCl solutions for 24 hours. See Experiment I for analytical procedures.

The apparatus consisted of a train of three, 3 liter bottles of 3 N. NaOH and one, 3 liter bottle of water, an incubator controlled to within  $\pm 0.5^{\circ}\text{C.}$ , and nine  $\text{CO}_2$  absorption towers, each connected to a one liter suction flask containing 150 ml 0.1 N. NaOH. Each tower was filled with perforated glass beads. The absorption solution (500 ml of 0.005 N. KCl - 0.0001 N.  $\text{CaCl}_2$ ) was placed in a 500 ml suction flask fitted with a capillary tube for aeration. Nine such flasks were placed on each of two shelves in the incubator. Compressed air was forced through the 3 N. NaOH where  $\text{CO}_2$  was removed, then it passed into the incubator and through a manifold with nine outlets into each of the nine flasks on a shelf. The air bubbled through the capillary tube into the solution and out through the outlet of the suction flask, thus picking up  $\text{CO}_2$  released by the roots in the KCl solution. The air from each flask passed down to the second shelf, bubbled through another flask of KCl containing roots of the same species as that of the first

shelf, then it passed out of the incubator into the one liter suction flask of NaOH by way of the outlet on the flask. The air pressure forced the NaOH up through the tower to a height of two to three feet before bubbling started. The CO<sub>2</sub> picked up from the root flasks was removed by the NaOH and the CO<sub>2</sub>-free air was expelled through the top of the tower. After the 24 hour run the apparatus was disconnected, the towers were washed with distilled water three times, and the NaOH and washings were collected in the suction flask. Fifty ml of saturated BaCl<sub>2</sub> solution was added to the NaOH solution to precipitate the CO<sub>2</sub> as BaCO<sub>3</sub>. The remaining NaOH was titrated with HCl. The milliequivalents of CO<sub>2</sub> absorbed was calculated by deducting the HCl required for titration of a sample after the run from that required for a blank (without roots).

The equipment available permitted only one temperature to be run at a time; therefore, there was a lapse of about three weeks between each temperature trial. A new batch of roots was grown for each temperature. The seven temperatures were randomized and fell in the following order: 5, 15, 25, 10, 20, 30, and 35°C. Duplicates of each species of roots were also randomized on each shelf.

## Results

Potassium uptake: The net uptake of potassium from the absorption medium for 24 hours is presented in Table 11. The data are presented graphically in Figure 37.

The values for endogenous potassium (mg per g dry weight) given below were deducted from the total potassium content to obtain the data in Table 11.

<u>Temperature</u> <u>°C.</u>	<u>Peas</u> <u>mg/g</u>	<u>Soybeans</u> <u>mg/g</u>	<u>Rye</u> <u>mg/g</u>	<u>Sudangrass</u> <u>mg/g</u>
5	25.09	18.77	4.30	6.71
10	16.87	27.88	6.82	4.54
15	29.23	28.10	5.76	5.30
20	18.53	33.31	7.03	3.07
25	23.32	25.96	7.31	7.21
30	28.30	31.16	12.91	6.18
35	26.06	35.15	9.86	5.97

Each of these values is an average of from two to four, 10 gram samples taken from the tanks when the roots were harvested. Time of season, disease, and other factors caused the high variation in the endogenous potassium. The lapse of from three to four weeks between each of the temperature trials caused time of the season to be confounded with treatment in the experiment.

Figure 37 shows sharp drops in potassium uptake for all species at the 10° and 20° temperatures. At these two dates the seed had been damaged by disease during germination; hence, the reliability of data for these

**Table 11. Uptake of potassium from .005 N. KCl by roots of rye, sudangrass, peas, and soybeans as affected by temperature of the medium.**

(Mean of four samples of each species at each temperature)

<u>Temperature</u> <u>°C.</u>	<u>Rye</u>	<u>Sudangrass</u>	<u>Peas</u>	<u>Soybeans</u>	<u>Mean</u>
5	6.29	5.14	1.59	- .28	3.19
10	2.07	2.19	-1.06	-6.13	- .73
15	3.67	5.91	2.25	- .44	2.84
20	.74	2.09	-3.42	-9.03	-2.40
25	5.49	9.42	7.95	7.42	7.57
30	5.01	10.22	1.64	9.41	6.57
35	2.75	13.43	-4.93	7.05	4.58
<b>Mean</b>	<b>3.72</b>	<b>6.91</b>	<b>.57</b>	<b>1.14</b>	<b>3.09</b>

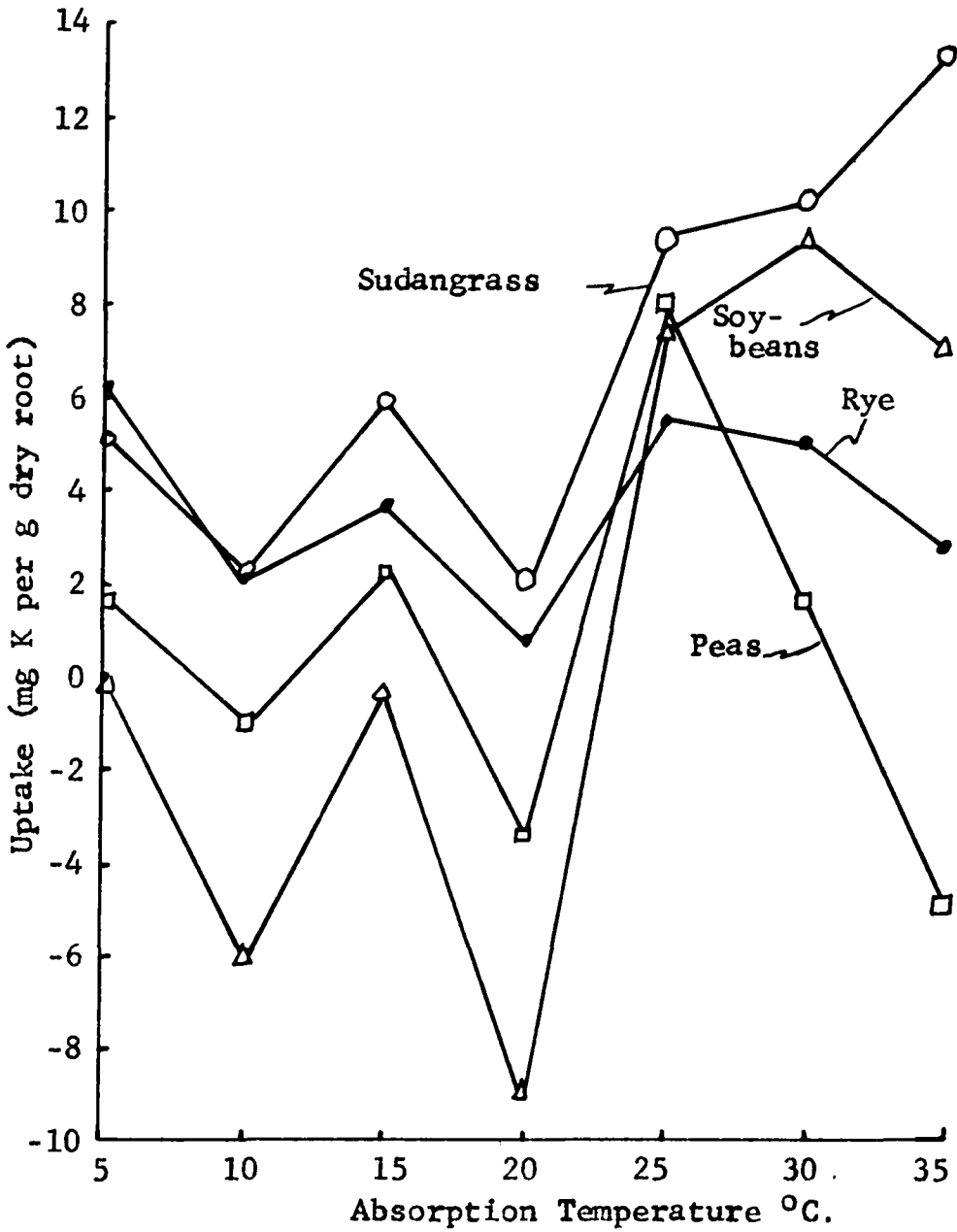


Figure 37. Potassium uptake by various plant species as affected by the absorption temperature. Absorption solution was 0.005 N. KCl.

two temperatures is questionable.

A statistical analysis was run individually for each temperature. Bartlett's test for homogeneity of variance was conducted for the temperatures. This test indicated that the error terms were highly heterogeneous; therefore, pooling of the temperatures could not be justified. The temperature means were tested by calculating weighted mean squares as outlined by Snedecor (1956). This test showed large differences in potassium uptake at each temperature.

In this experiment, as well as in the previous ones, the legumes were much higher in endogenous potassium than the grasses. Figure 37 shows that the grasses absorbed more potassium than the legumes at temperatures of 20°C. or lower. It is possible that high endogenous potassium prevented the legumes from absorbing much potassium at these temperatures.

All the species maintained similar relationships to each other at temperatures of 20° or lower. Rye and sudangrass were never significantly different from each other throughout the lower temperatures. Peas averaged taking up about four mg per g less potassium than sudangrass in this range, while soybeans, having a net loss, lost on the average 3.5 mg potassium more than peas.



It was postulated that the cool season species would take up more potassium at the low temperatures than the warm season ones. The data did not show such a trend. There seems to be more differentiation between the potassium uptake of legumes and grasses than there is between warm and cool season species at temperatures of 20°C. or lower. The fact that soybean, a warm season species, failed to take up any potassium indicates that the temperature for maximum growth is an important factor.

The 25°C. temperature was the focal point for species differentiation as the temperatures were increased. The statistical analysis did not show significant differences between species at 25°C. All species except rye absorbed more potassium at 25°C. than at any lower temperature. The uptake was 9.42, 7.95, 7.42, and 5.49 mg per g for sudangrass, peas, soybeans, and rye, respectively. Above twenty-five degrees C. the cool season species dropped steadily in potassium uptake. Peas dropped to 1.64 mg per g at 30°C. and even lost 4.93 mg per g at 35°C. Rye dropped to 5.01 mg per g at 30° and 2.75 mg per g at 35°C. The warm season species, however, continued to increase in potassium uptake as the temperature climbed above 25°C. Sudangrass, which is well adapted to high temperatures, was still rising at 35°C. where it absorbed 13.43 mg per g.

Soybean, which is also well adapted to high temperatures, rose to 9.41 mg per g at 30°, then it declined slightly to 7.05 mg per g at 35°C. Although the cool season species failed to absorb more potassium than warm season species at low temperatures, they absorbed much less than warm season species at high temperatures.

Respiration: It was suggested that one of the reasons why the roots of Experiment I failed to respond to temperature variables was that respiration by the excised roots might not be occurring. This experiment was designed to determine if respiration were actually occurring and to what extent it occurred at each temperature. The apparatus used permitted the measurement of respiration and potassium uptake simultaneously. Respiration by rye, sudangrass, peas, and soybeans at the various temperatures is presented graphically in Figure 38. The data are presented in milliequivalents CO<sub>2</sub> released per gram of dry weight.

A statistical analysis was run at each temperature. Only the 25, 30, and 35° temperatures showed differences between varieties. Heterogeneity of the error variances prevented pooling of the analyses at each temperature. It is apparent, however, from Figure 38 that there was a general increase in respiration as the temperature increased. There was a plateau in the respiration curve

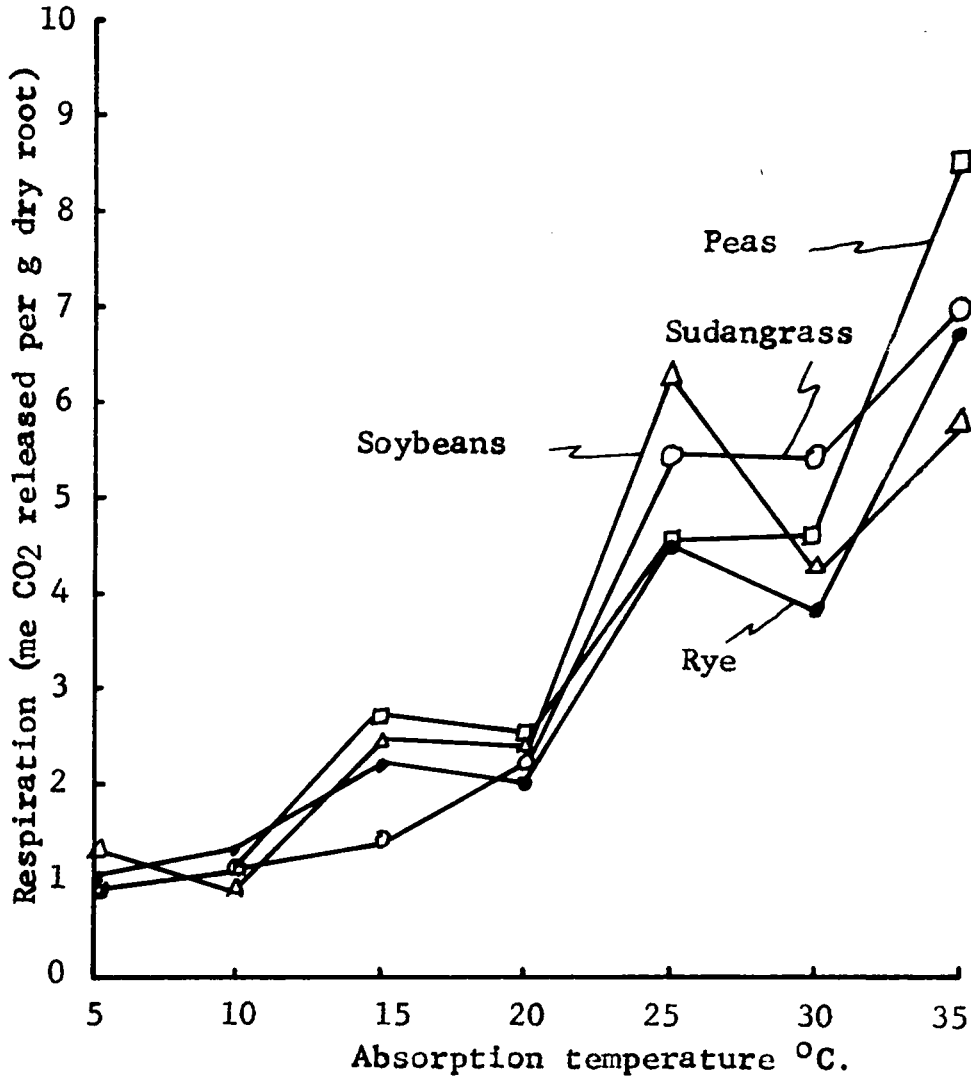


Figure 38. Respiration by various plant species as affected by the absorption temperature. Absorption solution was 0.005 N. KCl.

corresponding to the two dips in the potassium uptake curve. The reduction in potassium uptake by peas and rye at 30 and 35°C. was not accompanied by a corresponding reduction in respiration. Peas had the highest respiration rate at 35° but actually lost potassium.

Discussion: If the results of this experiment are compared with Experiment III, it can be seen that soybeans and peas tend to have the same shape of curve, but the temperatures of the flex points do not correspond. In Experiment III there was considerable uptake at 10°, whereas in this experiment soybeans and peas lost potassium at that temperature. In Experiment III the uptake of potassium by rye decreased steadily at temperatures above 10°, whereas in this experiment it decreased steadily above 25°C. In Experiment III peas and soybeans reached their peak in potassium uptake at 20° and dropped steadily to a minimum at 30°. In this experiment peas and soybeans were at a minimum at 20°C. Peas reached a maximum at 25°, then dropped steadily while soybeans reached a maximum at 30°. It is significant that peas lost potassium at the highest temperature of both experiments.

Another important consideration is that all species were grown at 25°C. in this experiment, and the maximum uptake for all was at the same temperature. In

Experiment III peas were grown at a cooler temperature than soybeans and reached a maximum potassium uptake at a cooler temperature. It appears that the temperature at which the plants were grown might exert an influence on the temperature of maximum absorption.

Respiration might well be necessary for potassium uptake, but this experiment indicates that potassium uptake is not a requirement for respiration. Respiration not associated with salt uptake is referred to as ground respiration (Broyer, 1951). The  $Q_{10}$  for respiration of approximately two is in accordance with the data of Ulrich (1941). Broyer (1951) pointed out that respiration was highly correlated with ion uptake. Such an association is indicated in this experiment up to 25°, but above 25° it does not hold.

It was postulated that the reason for no response to temperature increases in Experiment I was due to lack of respiration. This is possible, since the roots used in Experiment I were older than the roots used in this experiment, but the high initial potassium content and short absorption period were probably more important. It is evident that lack of respiration was not responsible for the low potassium uptake by peas at 35°C. in this experiment.

## Experiment V

### Effect of temperature on the absorption of potassium by peas and soybeans

Introduction: In Experiment IV the 10 and 20°C. points on the potassium uptake curves seemed excessively low. Since disease caused some damage to the roots at these temperatures, it was felt that additional information should be obtained. There was a great deal of confounding in Experiment IV resulting from its extended duration; therefore, verification of the curves at the higher temperatures was desired, also.

Methods and materials: The root growing technique was identical with that of Experiment IV except that all the seed were pre-germinated in an electrically controlled germinator, then the radicles of each seed were pushed through a pencil hole in the cheese cloth covering the tank. A few layers of Kimpak germination paper were placed directly over the seed and moistened periodically. The growing shoot pierced this paper readily. This type of germination paper remained moist and, in general, gave much better results than the cheese cloth canopy used in Experiment IV.

Peas and soybeans were used in this experiment; one tank of each species was planted each day for five successive days. Nine days after planting, the roots

were harvested. Five, 10 gram samples of peas and five, 5 gram samples of soybeans (wet weight) were weighed for the absorption trial. Two to five similar samples of each species were weighed for the determination of endogenous potassium, depending on the amount of roots available. Yield of soybean roots per tank was about one half that of peas.

The absorption technique was identical with that of Experiment IV, but respiration was not measured and an absorption period of 12 hours was used.

Results: The results are presented graphically in Figure 39. This graph shows the values for potassium uptake after correction for endogenous potassium. A statistical analysis revealed that endogenous potassium varied considerably from tank to tank; therefore, endogenous potassium was calculated separately for each tank and deducted from the total potassium in roots grown in that tank. Endogenous potassium varied from 30.6 to 46.2 mg per g dry weight for soybeans and from 34.2 to 40.6 for peas. With such high values for endogenous potassium, it is surprising that any potassium was taken up.

Potassium losses for both species similar to that at 20°C. in Experiment IV did not appear. Soybeans, however, did lose potassium at 13°C. Temperature did

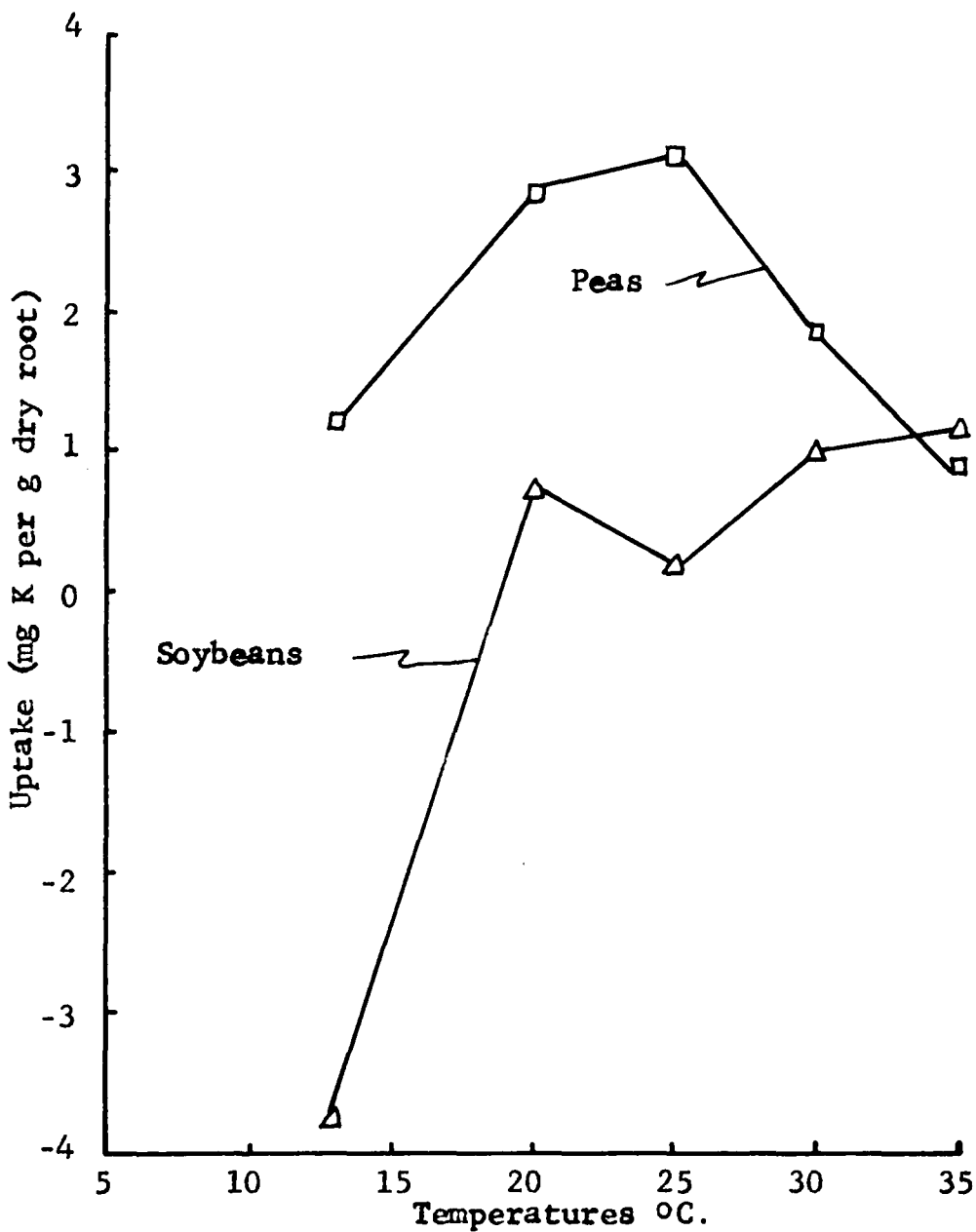


Figure 39. Uptake of potassium by excised roots of peas and soybeans at various temperatures. (twelve hour absorption period in 0.005 N. KCl)



not significantly affect the uptake of potassium by soybeans above 20°C., but there was a slight increasing trend. Peas reached maximum uptake at 25°, then took up less potassium as temperatures increased in both experiments. Roots of peas did not show a net loss of potassium at 35°C. in this experiment. A "wild" sample of peas was omitted from the average of the values at 30°C.

Discussion: The curve for peas in this experiment is similar to the curve for peas in Experiment III. They both show increases from 10 to 20° and decreases from 20 to 30°C. Experiment III did not have a point at 25°C.; therefore, uptake at this point cannot be compared. Probably the temperature at which the plants are grown exerts a great influence on the optimum temperature for potassium uptake.

The curve for peas (Figure 39) followed the curve of Experiment IV (Figure 37) very closely, even though the differences due to temperature were not as pronounced. The shorter absorption period and high endogenous potassium values probably account for the smaller differences. This experiment showed no evidence of a reduction in potassium uptake by peas and soybeans at 20°C. The low potassium uptake at 10° in Experiment IV might be valid, since the present experiment showed a reduction in potassium uptake at temperatures below 20°C.

### Overall Discussion of Laboratory Experiments

Species differed considerably in potassium uptake from KCl solutions. The initial potassium content of the plant roots was one of the main factors limiting potassium uptake from such solutions. Young legume roots had a much greater endogenous potassium content than young grass roots of the same age. These differences occurred when no potassium had been administered except that in tap water. High potassium roots either absorbed much less potassium or actually lost potassium to the ambient solution when the temperature was low. Evidently the respiration rate was slower at low temperatures; therefore, there was not enough energy available to maintain the high potassium content in the plant against the diffusion pressure gradient. Low potassium roots, such as grasses, were able to take up some potassium or at least hold what they had, because the diffusion pressure gradient was much less than that of the legumes. At high temperatures the respiration rate was rapid; therefore, more potassium was taken up. The potassium uptake mechanism of cool season plants seemed to be slowed down considerably at high temperatures. This deceleration probably was due to inactivation of some enzyme system or systems involved in uptake. Poor growth of cool season plants at high temperatures is evidence that adverse conditions prevail.

These conditions do not occur for the warm season plants until the temperature is higher.

Two out of three of the experiments showed losses in potassium from soybean roots at low temperatures. Older roots were used in the experiment which showed gains in potassium by soybeans from a KCl solution at 10°C. These older roots contained from one-half to one-sixth of the endogenous potassium found in the younger roots.

The data may have an application to field conditions. Grass and legume mixtures are often seeded early in the spring. The soil temperature is cool; therefore, the cool season grasses grow better than the legume associates. The fibrous grass root system spreads rapidly making a dense sod. The roots are low in potassium; therefore, more potassium is taken up. The legumes require warmer temperatures for optimum growth than grasses; hence, the legumes start growth later. The root is already comparatively high in potassium; thus very little potassium is taken up from the soil which has already been partially depleted by the grass. The smaller root area of the legume also limits its capacity to take up potassium. Such a suggestion might help to explain why alfalfa is dominant in an August seeded alfalfa-orchardgrass mixture and the reverse is true for a spring seeded mixture.

**SUMMARY AND CONCLUSIONS**

The effect of various rates of potassium and nitrogen fertilizers on mixtures and pure seedings of orchardgrass, tall fescue, and Kentucky bluegrass was studied in the field. Measurements were made for two growing seasons on botanical composition, yield, ground cover, soil pH, available  $K_2O$ ,  $MgO$ ,  $CaO$ , and  $P_2O_5$  in the soil, and potassium, calcium, magnesium, and water in the plant. Additional data were collected for seedling injury, color, and percentage of nitrogen.

Orchardgrass seedlings were much more aggressive than seedlings of tall fescue or bluegrass; therefore, mixtures containing orchardgrass tended to crowd out the other species. Fescue seedlings were much more aggressive than bluegrass seedlings; hence, fescue tended to crowd out bluegrass. Other species competed strongly with bluegrass seedlings and made up over fifty percent of the dry matter after two years.

Nitrogen fertilization increased the aggressiveness of orchardgrass in mixtures of orchardgrass and fescue; hence, the percentage of fescue in these mixtures was reduced when nitrogen applications were increased. Bluegrass was almost eliminated at all nitrogen levels when seeded with orchardgrass.

Potassium fertilizer applications of at least 100 pounds per acre increased the percentage of orchardgrass in orchardgrass-fescue and orchardgrass-bluegrass mixtures and increased fescue in fescue-bluegrass mixtures. Increasing rates of  $K_2O$  reduced the percentage of bluegrass in both pure stands and mixtures.

Orchardgrass, as a result of its rapid seedling growth, made a better ground cover than fescue or bluegrass during the first year, but its bunch type of growth often made it inferior the second year. Fescue produced a better cover than bluegrass the first year. High nitrogen rates increased ground cover during the first year when estimates were made prior to harvesting, but decreased it during the second season when estimates were made after harvesting. Strong competition between plants thinned the stand at high nitrogen levels. Applications of  $K_2O$  of at least 100 pounds per acre usually improved the ground cover.

Yields of orchardgrass were higher than those of fescue, and yields of fescue were higher than those of bluegrass during the seedling year. There were no differences between total yields of pure grass seedings or between mixtures during the second growing season. Yields of mixtures were less than pure grass seedings due to a more intense cutting treatment. Fescue yields were

less than orchardgrass yields in spring and greater than orchardgrass during late summer and fall. Increasing the rate of nitrogen at least to 300 pounds increased yields by about one ton per acre. Increasing the rate of  $K_2O$  to at least 100 pounds per acre increased yields of orchardgrass and fescue but had little effect on yields of bluegrass or weeds.

Orchardgrass depleted the soil of available  $K_2O$  to a greater extent than fescue, and fescue removed more  $K_2O$  than bluegrass. Growth of different grass species affected available  $CaO$  and  $MgO$  content and the pH of the soil very little. Nitrogen fertilization reduced the amount of available  $K_2O$ ,  $MgO$ , and  $CaO$  in the soil and reduced the pH. Potassium fertilization decreased available soil  $MgO$  and increased available  $K_2O$ .

Kentucky bluegrass had a lower potassium content than orchardgrass and fescue. Nitrogen fertilization increased the calcium, magnesium, and water content of all species. Potassium fertilization increased the potassium and water content but decreased the calcium and magnesium content.

Laboratory studies were conducted to determine the relative uptake of potassium by excised roots of various plants when concentration and temperature of the absorption medium were varied. From these data the following conclusions were made.

Warm season species took up more potassium at high temperatures than cool season species, but at low temperatures the endogenous potassium content of the roots was more important than temperature of optimum growth in limiting potassium uptake. Excised soybean roots usually lost potassium at low temperatures, and pea roots usually lost potassium at high temperatures. The temperature for maximum uptake varied depending on the condition of the experiment but was usually around 25°C. for cool season species. Uptake of potassium was increased with increase in the concentration of potassium in the absorption medium. Respiration and potassium uptake were similar at 25°C. or below but were not related at higher temperatures.

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## ABSTRACT

I. Growth and Composition of Three Grasses as Affected  
by Potassium and Nitrogen

II. Uptake of Potassium as Influenced by Temperature,  
Concentration of Solute, and Species

by

Ray Edward Worley

The effects of various rates of potassium and nitrogen were studied for pure seedings and mixtures of orchardgrass (Dactylus glomerata), tall fescue (Festuca arundinacea), and Kentucky bluegrass (Poa pratensis) in the field. Measurements were made on botanical composition, yield, soil chemical composition, and plant chemical composition during two growing seasons. Orchardgrass seedlings grew faster than fescue or bluegrass seedlings; hence, orchardgrass made up most of the yield the first season in mixed seedings. Fescue seedlings grew faster than bluegrass and made up most of the yield in mixtures where orchardgrass was not seeded. Nitrogen fertilization up to 300 pounds per acre increased the orchardgrass component of orchardgrass-fescue mixtures and increased yield of all seedings by about one ton per acre. Increasing rates of  $K_2O$  decreased the bluegrass component in both pure stands and in mixtures. Increases

in yield of about one-half ton of dry matter per acre usually occurred with increasing rates of  $K_2O$  up to 300 pounds per acre. Dry matter production per unit of nitrogen and  $K_2O$  was greater in the spring and fall than in summer.

Under liberal nitrogen fertilization fescue-bluegrass seedings were reverting to bluegrass, when available soil  $K_2O$  was low. Some of these treatments were about 50 percent bluegrass by October 11, 1960.

The total yield for each of the three pure grass seedings was about three tons in 1960. Spring season yields from orchardgrass and bluegrass seedings were greater than fescue; fescue produced more dry matter during the fall than the other grasses.

Orchardgrass depleted the available soil  $K_2O$  more than fescue, and fescue removed more  $K_2O$  than bluegrass. Nitrogen reduced the pH and available soil  $K_2O$ ,  $MgO$ , and  $CaO$ . Nitrogen stimulated growth, thereby causing a greater removal of calcium, magnesium, and potassium in the forage. Potassium fertilization reduced the available soil  $MgO$  and increased available  $K_2O$ .

Nitrogen fertilization increased calcium, magnesium, and water content of all species. Potassium fertilization increased the potassium and water content but decreased the calcium and magnesium content.

Laboratory studies were conducted to determine the relative uptake of potassium by excised roots of various plants when concentration and temperature of the absorption medium were varied. These studies revealed that warm season species took up more potassium at high temperatures than did cool season species. At low temperatures the high endogenous potassium content of the legume roots limited potassium uptake. Excised soybean roots usually lost potassium at low temperatures, and roots of peas usually lost potassium at high temperatures. Soybean roots reached maximum uptake of potassium in 12 to 24 hours. Uptake of potassium was increased with increase in concentration of the absorption medium. Respiration and potassium uptake were similar at 25°C. or below, but were not correlated at higher temperatures.