THE EFFECT OF NITROGEN AND PHOSPHORUS FERTILIZERS ON GROWTH AND DEVELOPMENT OF BROMEGRASS (<u>BROMUS INERMIS</u> LEYSS)

by

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TABLE OF CONTENTS

INTRODUCTION

There have recently been rather extensive investigations of the response of plants to nitrogen and phosphorus fertilizers. Now that war time restrictions on fertilizer production have lifted, a study of crop response to these fertilizers has become increasingly important.

In the past, most of the work with fertilizers has been with cash crops, relatively little attention being given to the improvement of grass and other forage crops by fertilization. The increased supply and a cheaper source than formerly prevailed together with a greater appreciation of the value of grass in the farm program, have resulted in increased attention to the improvement of pasture crops by fertilization. Too often in the past pastures have not been considered as a crop.

Bromegrass (Bromus inermis Leyss), the leading cultivated grass in the eastern half of Kansas, has given a favorable response to the application of nitrogenous fertilizers at the Kansas Agricultural Experiment Station and other stations throughout the area where it is adapted. It is a native of Central Europe and China. It was introduced into the United States about 1884 (Whitman, 1941) and has been grown widely throughout the country. Although some seed may have been brought in by immigrants, the earliest recorded importation (Newell and Keim, 1934) was made by the California Agricultural Experiment Station, through France from Hungary. It is one of our important cool season grasses, especially well adapted to a dry to subhumid cool climate. At the same time it is capable of withstanding moderate to high temperatures during the summer months. Fuelleman (1941) working at Illinois stated:

> Observations and data show that approximately 90 percent of the total growth occurs before August 1, and indicate that bromegrass is not only drouth resistant but also drouth escaping. Rapid spring growth and high early seasonal yields tend to prolong grazing through mid-summer dry periods until the time when temperatures and precipitation are more favorable for fall growth recovery.

Bromegrass is one of the cool season grasses that has extended the grazing season in both the tall- and short-grass area of the Midwest and the Great Plains by adding from two to four months to the grazing season on many farms.

Bromegrass produces a dense sod and spreads aggressively by rhizomes. The roots are profusely branched, forming a heavy root mass, especially near the soil surface. Because of the aggressiveness and matting habit of growth, it has proved of great value in erosion control. The roots of bromegrass may penetrate to a depth of seven or eight feet, but the general working level is the upper three and one-half feet of soil.

A characteristic habit of bromegrass is its tendency to become "sod-bound" after three to five years in pure stands. This condition is characterized by a yellowish, stunted appearance with varying degrees of unproductiveness. In extreme cases, plants appear dormant throughout the season producing practically no forage or seed.

The so-called "sod-bound" condition in bromegrass fields has been recognized by agriculturists for many years. The condition is especially serious on those fields used for seed production but is also a factor in lowering the carrying capacity of recently established bromegrass pastures. For several years in Kansas this condition has been thought to be associated with a deficiency of available nitrogen since it has been shown both experimentally and by farm practice that nitrogen either in the form of commercial fertilizer, animal urine, or legumes improved the growth of bromegrass in an otherwise "sod-bound" field. The "sod-bound" condition is not peculiar to bromegrass alone but has been observed in other tame grasses and in native grasses when they were long established on cultivated areas.

Myers and Anderson (1942) reported no positive evidence to indicate that a toxic constituent was produced by bromegrass. They found 200 pounds of ammonium sulfate per acre sufficient to overcome any detrimental effect of the previous growth of bromegrass may have had on subsequent grass production.

This "sod-bound" condition has been attributed largely to a lack of available nitrogen. Various sources of available nitrogen will correct in an old stand and delay in a new stand of bromegrass this "sod-bound" condition.

The inclusion of a legume, such as alfalfa in a planting with the bromegrass is often an effective method of delaying the appearance (Frolick and Newell, 1941). The use of nitrogenous fertilizers will overcome the condition and this treatment has produced significant increases in yield of forage and seed.

For the most part, the response of bromegrass to nitrogen has been studied from the standpoint of top growth and seed yields.

Anderson et al. (1946) has shown marked increases in yield of forage, percent protein in the forage and in yield of bromegrass seed as a result of nitrogen applications. Various investigators, Enlow (1929), Dodd (1935), Gardner (1939), Tyson (1939), Robinson (1942), Ahlgren et al. (1944), Brown and Munsell (1943), have reported increases in both dry matter and percentage protein in the forage resulting from applications of nitrogen to native grass stands.

Most of the work with fertilizers on grasses has been concerned with the response of the above ground parts of the plants. Some excellent work has been reported relative to the effects of nitrogen on the root systems of grasses. Information on this subject is much more limited than on the response of the part of the plant above ground.

Most of the results reported thus far have been on applications of fertilizers on established stands of grasses. Investigation at the Kansas Agricultural Experiment Station has indicated that under greenhouse conditions as well as field conditions bromegrass responds to phosphate fertilizer applied at the time of seeding. Phosphorus has been an important factor in seedling establishment.

An important and growing feature of our soil management systems is the use of nitrogen fertilizers for meeting the crop's nitrogen requirements. The more effective ways of using these fertilizers are rather well known by farmers in many sections of the country. In other sections and for some crops, the best methods have not been developed and the farmers' knowledge of fertilizer use is limited.

This direct use of nitrogen, whether in mixed fertilizers or as nitrogen materials, is essentially a supplement to the nitrogen supplied by the soil and cropping system.

The use of chemical nitrogen is not incompatible with soil management for efficient and stable production. It is often essential for such production.

It was the purpose of this study to determine some of the effects of applications of nitrogen and phosphorus fertilizers upon bromegrass, considering seed and forage yield, forage quality, and root development. These factors were studied in the greenhouse and under field conditions.

REVIEW OF LITERATURE

The roots of grasses have commanded the attention of investigators for many years. Much of the early work was in the form of descriptions and habits of root systems.

Half of a plant and often more is frequently hidden from view; rhizomes, corns, etc. are buried in the earth and roots extend far into the soil. Because the soil hides the roots from view, they are the least understood and least appreciated part of the plant.

The root system of a plant includes all its roots considered collectively. The root system of a given species, in its general appearance can be distinguished from that of another type of plant. Weaver (1926) stated that the general characters of the root systems of species are often as marked and distinctive as are those of the aerial vegetative parts, and although these may be greatly modified when subjected to different environmental conditions, they still retain the characteristic impress of the species in its usual habitat.

The root system of a given plant may, however, vary in its structure, extent, weight, number, and direction of its roots according to the conditions under which it is grown. The general behavior of roots in the soil is thus the resultant of the influence of many factors, the most important of which are moisture, nutrients, oxygen supply, temperature, physical texture of the soil, light, and gravity. A knowledge of root competition under different natural and cultural conditions is not only of much practical value but also it readily finds numerous scientific applications.

Miller (1938) quotes work done by Frank, Sanborn and others in 1892 in which plants were grown in various types of pots and glass jars in an effort to study their roots. Factors studied at that time included: amount of root material, location, and shape of root systems. They found that nitrogen fertilizer caused greatly branched root systems.

Hays (1889) in conducting some early work on corn roots was unable to obtain useful information on the development of corn roots by washing away the soil. King (1895) improved the working method by isolating a prism of soil and placing a cage of poultry wire netting around the prism. With the cage in place, sharpened wires were pushed through the prism of soil and cage to hold the roots while washing away the soil. Plaster of Paris was then poured on the top surface to hold all plants in place. Weaver (1920) used the direct method of root examination. For this work a trench was dug eight to 12 inches from the plant to be studied and as deep as necessary.

Laird (1930) found none of the described methods of root separation adapted to his studies in Florida. A different method was devised which proved more satisfactory in many of the porous sands of Florida. Perforated iron cylinders eight inches in diameter and 40 inches long were made from 12 guage iron. An iron collar was placed on one end and the sleeve driven into the soil. The sand and soil were then washed from the roots which were thus exposed, available for study. From his studies with Bermuda, Centipede, and St. Augustine grass it appears that mowing often enough to prevent seed formation not only increases the root development, but also produces a better sod than does non-mowing.

Haynes (1943) reported that in certain pasture management studies there has been observed an apparent increase, in roots near the soil surface, that seemed to be related to practices involved. It seemed that these differences were real and worthy of an attempt at indentification of their causes. His measurements of root growth in turf studies have shown effects of varying degree of clippings and the interaction effects of closeness of clipping and fertility treatments. In general these studies showed reduction in root growth when continued clipping was practiced. These reductions appeared to be a result of reduced metabolism caused by the constant removal of portions of the plant where synthesis is carried on. Measurements showed marked reductions in root density, (quantity of roots per unit volume of soil), of turf grasses due to interactions of severe foliage denudation and nitrogen application. The explanation which he presented for them is upon the basis of an unbalanced nitrogen metabolism. Unlike "luxury" consumption of potash and phosphorus, an excess of available nitrogen appears to affect the nature of end products of photosynthesis. In this situation carbohydrates are used principally in protein synthesis until excess amino acids are exhausted. Due to severe reductions of the photosynthetic area, the plant is unable to synthesize carbohydrates in excess of those used in nitrogen metabolism. This results in a very limited supply for storage and root tissues.

Biswell and Weaver (1933) reported on experiments indicating that for at least several weeks in the spring, all, or nearly all, of accumulated storage material was used by the growing shoots and only after these were fairly well established were new roots developed. The work also gave indication that if the tops were removed at the time when root reserves were just starting to build up, the process was repeated and the development of the root system greatly retarded.

Weaver and Harman (1935) stated that root samples from pastures in various stages of degeneration show consistent decreases in the amount of underground plant materials, apparent often after only two years of overgrazing.

Stoddard (1941) stated that concerning the life of roots, tests indicate that both seminal and nodal roots of prairie grasses, even under adverse conditions, may live in excess of two years. Root growth and its influence on the subsequent development of the plant has always been recognized as important in respect to food and water relationship, and although numerous observations on root development have emphasized the total amount and extent of roots, it seems that few investigators have studied the time of the year at which growth occurs.

Stuckey (1941) reported on a series of studies to determine at what time of the year new roots are produced on perennial grass plants, and how long they survive. The behavior of all species tested was much alike for the first year. The seminal roots were alive six to eight weeks, gradually being replaced by adventitious roots from the crown. For some species the whole root system was regenerated annually, with an active production of new growth beginning in October, continuing slowly through the winter months and increasing rapidly after the spring thaw in March, with its maximum in April. After the middle of June few, if any, new roots were formed and there was no appreciable growth of existing roots until October. Most of the old roots disintegrated soon after the new ones developed. These species included timothy, meadow fescue, perennial rye grass, Colonial bent and redtop. With other species it was found that the development of roots during the first year was essentially the same as described above, but only a small percentage of the roots disintegrated. After the first spring only a few new roots were developed. Most of the roots developed in the second season were at the nodes of new rhizomes. The species with "perennial" roots are Kentucky bluegrass, Canada bluegrass, crested wheatgrass, and orchard grass.

It was also noted by Stuckey (1941) that cell division was observed in root tips at temperatures very close to 32 degrees F., while root growth stopped during the summer months which coincided with periods of high soil temperature. There was an indication that the production of new roots may be inhibited by the developing flower primorda.

While carrying on a study of plant formations and association of the semi-arid southeastern Washington in 1912-1914, Weaver (1915) found that for a proper understanding of development and structure of these associations a knowledge of the root systems of the more important prairie species was imperative.

Due to the tenacious structure of the soil and the great depth of most roots, it was found impracticable to wash out the root systems. The method employed was to dig a trench two feet wide and eight to 16 feet long to a depth of about six feet on the hillside where roots were to be examined. This offered an open face into which one might dig with a hand pick, excavating a root system almost in its entirety. All roots examined were of mature perennial plants. The practice followed was to examine six or more roots of a given species and then write a working description of the roots. As new roots of the same species were studied any variation from the original description was carefully noted and in this way reliable results were obtained for the species studied.

Weaver (1920) and co-workers reported the great concentration of roots of most grasses was in the first 12 inches of soil, although some of the roots of sod forming grasses penetrated to a depth of seven to eight feet. He continues by pointing out that it has been proven that crops absorb water in large quantities from subsoil and that both quantity and quality of yield can be greatly modified by the addition of fertilizers in the subsoil. It was shown also by Weaver that water was absorbed by plants from several levels. During the period of ripening the bulk of absorption was carried on by younger portions of roots in deeper soils. Results showed clearly that absorption by a plant during different stages of its life does not depend upon total root surface or root mass, but is determined mainly by the area of functioning parts of the root system.

Cook (1934) reported an investigation which led him to suggest that a knowledge of root systems may do much to explain the difference in drought resistance displayed by plants. He stated that many methods have been devised to study varietal selections to determine relative drought resistance. These include general field observations, chemical analysis, rate of transportation, and controlled artificial drought test. These, however, he feels are subject to the criticism that they tend to ignore the extent depth, and character of the root system. He found, however, that the weight of roots was closely proportional to the total axial length of roots.

Stevenson and White (1941) investigating the root production of bromegrass, found that 87.75 percent of the total roots were produced in the first foot of soil, seven percent in the second foot, and a decreasing proportion as depth increased to five feet. They reported that about 50 percent of the total roots of the top foot are concentrated within the top three inches, about 25 percent in the three to six inch depth, and 15 percent in the six to nine inch depth, and 10 percent in the nine to 12 inch depth. They found that bromegrass continues to build up root fiber year after year at a fairly rapid rate. A ten-year-old field has produced 8803 pounds of root fiber per foot per acre. The total increase in weight with aging of sod stand took place uniformly throughout the top foot of soil.

Weaver and Zink (1945) reported that the maximum amount of root material was formed by blue grama and little bluestem after two growing seasons, and after three by big bluestem. Big bluestem produced 5.5 tons of roots per acre after three years of growth.

In studies by Bell and DeFrance (1944) on the effect of fertilizer treatment upon root accumulation, sod plugs were removed periodically during 1939 and 1940. Estimates of root weights are made from these plugs. Sod plugs were taken by means of a steel tube with an opening seven-eights of an inch in diameter which was inserted into the ground to a depth of eight inches. Three such plugs were taken from each plot. The top inch of each plug was removed due to top growth and an accumulation of leaves and stems. The plugs were placed on a wire screen and separated from soil by washing with a gentle stream of water from a hose. After washing, the roots were dried rapidly and placed in porcelain crucibles. Each crucible of roots was then ignited at dull red heat until the organic material was completely ashed. The loss on ignition was used to measure organic portion of roots in each plug. Loss of weight on ignition is believed to be a more satisfactory method of estimating root weights than simply using dry weight, since dry weights include considerable fine sand which clings to the roots.

Laird (1930) reported that applications of nitrogen and phosphorus increased the dry weights and development of the root system of the different grasses under consideration.

Graber (1931) found that heavy nitrogenous fertilization of bluegrass made possible the stimulation of top growth at the expense of root growth. He noted that the limitation of root growth resulting from low reserves may increase the plants susceptibility to drought. He came to the conclusion that judicious fertilization may for a time stimulate the utilization of the carbohydrate reserves, and such stimulation may also accelerate their accumulation when the plant is given an opportunity for such storage.

Turner (1922) reported that the increased ratio of stems to roots which results from increasing the amount of nitrate in the soil may be explained on the basis of increased use of carbohydrates in the tops because the greater nitrogen supply makes for greater growth. This results in a decrease in the supply of carbohydrates for the roots which may bring about an absolute or a relative reduction of root growth.

Sprague (1932) reported that there is some evidence that the provision of nitrogen in a readily available form tends to restrict root growth as compared with application of nitrogen in a slowly available form. He found no obvious correlation between the supply of available phosphorus and root growth.

Sommer (1936) working with peas, buckwheat, corn, tomatoes, wheat, crested wheatgrass, and cotton, observed that the type and size of root systems might be an important factor in the relationship of the phosphate concentration to the type and size of root systems. It was demonstrated that all other conditions being the same, the minimum concentration for satisfactory growth varied with the kind of plant. The difference in the amount necessary for physiological activities, or there may be a difference in the rate at which root systems absorb the necessary ions, or both. Observations by Sommers on the root system of plants grown in these solutions indicated that higher phosphate concentrations did not stimulate root development; that is, did not cause a greater percentage increase for roots than for tops. Most studies on the effect of phosphate on root systems take into consideration only the increases in root weight and do not compare these increases with those of the tops. If the relative increase of the tops is as great or greater than that of the roots, a considerable part of the increase in the size of the roots of plants grown at higher phosphate concentrations may be due to the greater amount of food synthesized. The studies made by Sommer were, therefore, made on the basis of root-top ratio (weight) and not on absolute weights.

Haynes (1943) reported that an increase of roots near the surface and a decrease of roots below two inches was associated with surface application of nitrogen. He called attention to the importance of this increase in root concentration at the surface, in erosion control.

Willard (1932) found that heavy fertilization with nitrogen greatly decreased the relative amount of underground parts. The actual amount of roots in the fertilized area was notably less than in the unfertilized area for a period after the fertilizer was applied, but toward the end of the season the amount of roots was nearly equal in the two areas. He noted an increase in nitrogen content of roots as a result of heavy nitrogen applications. The underground parts contained a higher percent of nitrogen than the tops.

Only a limited amount of work has been reported regarding the response of bromegrass seedlings to fertilization. Fuelleman et al. (1941) reported that seedings made on soil low in nitrogen had frequently failed in Illinois.

DeFrance (1938) concluded that a fertilizer with a 10-6-4 ratio was most satisfactory for turf fertilization. Twenty percent nitrogen in the fertilizer gave the highest quality rating for vigor, color, and density, but the turf was too soft and springy. Fertilizers with five percent nitrogen produced the finest textured grasses, but they were more susceptible to invasion of clover and weeds.

The so-called "sod-bound" condition of bromegrass has been the subject of considerable discussion. Benedict (1941) reported work which indicated that "sod-binding" of bromegrass might at least in part result from an accumulation of growth inhibiting substances in the soil. He grew plants in sand watered with nutrient solutions and found that when dried bromegrass roots were added to the sand, the yield of bromegrass was materially decreased.

Newton (1939) studied soil nitrification after bromegrass, using growing crops as indicators of nitrification rates. He reported bromegrass to be poorer than timothy or western rye grass in its after-effects on wheat. He stated:

> This raises the question as to whether such creeping-rooted grasses that form a closely knit sod may depress nitrification by preventing adequate areation of the soil.

In one-year-old sod, the nitrogen absorption to plow depth was greatest in bromegrass, but in the three and five year old sods bromegrass was lowest.

Myers and Anderson (1942) concluded that excessive carbon in relation to nitrogen brought about by the continued growth of bromegrass probably caused the so-called "sod-bound" soil in the fields under consideration. They suggest deficiencies in soil fertility as possible casual factors responsible for the "sod-bound" condition.

Many species of plants, and more particularly those used for hay and pasture purposes, are sown in mixtures. The data presented by Ahlgren and Aamodt (1939) would indicate that harmful interaction may occur between various species and strains of pasture grasses and legumes. These interactions were, no doubt, profoundly influenced by environmental conditions. There is need of an intensive fundamental study relative to the nature of these interactions and effects on grass and legume species now commonly used in pasture and meadow mixture.

Thorton and Nicol (1934) reported on experiments wherein lucerne (alfalfa) and Italian rye grass were grown together in pots in sand. Their experiments established the point that there was a real gain of nitrogen by a non-legume where grown in association with a legume. They believe that legumes growing with grasses in a pasture do not merely act as a direct source of protein for animals, but also contribute to the nitrogenous intake of the grasses. In their experiments the results of the growth of grass indicated that considerable more nitrogen than had been supplied was found in the grass. The recovery varied from two to nearly six times the initial application of nitrogen, even on the assumption that none of the nitrate had been taken up by the lucerne.

Weaver and Crist (1924) reported on investigations of the effects of absorption of nutrients from deep levels upon quantity and quality of yield. Nitrogen fertilizer at any level tended to lessen root depth and greatly increased branching. Phosphates did not noticeably increase root development. Nutrients were absorbed in large quantities at every level to 30 inches. Although the plants used the largest amount of salts from the surface foot, they also took large additional quantities from the deeper levels when it was available. It was found that the absorption of nutrients at levels below the surface foot affects materially the quality and quantity of the yield. The additive effect was not lost even when the surface foot was abundantly supplied with a similar nutrient. This brings out the point that the chemical composition of the subsoil and the soil solution is very important. These experiments showed the importance of the subsoil as a source of nutrients for crops and also emphasized the values to be gained by fertilizer practices which take into consideration the composition of the subsoil.

Our knowledge of the effect of carbonaceous material on the availability of plant nutrients; more commonly nitrogen, as the result of the activities of soil organisms, leads to the generalization that excessive carbon in relation to nitrogen brought about by the continued growth of bromegrass probably caused the so-called "sod-bound" condition. The rapid destruction of almost any compound of energy value to microbes under proper nutrient and environmental conditions was demonstrated by Robbins when the usage of the term toxin in soils was in its infancy. Myers and Anderson (1942) concluded that a search should be made for deficiencies in soil fertility as a possible causal factor responsible for "sod-bound" conditions observed under a variety of soil conditions.

Brown and Munsell (1943) reported that when nitrogen was applied in spring applications to permanent pastures, most of the additional feed grew in May and early June. During that time the palatability and feeding value decreased so rapidly it was necessary to graze the area to capacity during these months to keep the herbage in a leafy condition. These workers also found that spring applied nitrogen on pastures increased the acreage of supplementary pasture necessary to carry the same number of animals throughout the season.

The least summer decline occurred on the pastures where nitrogen was withheld until June. The summer nitrogen application was much less effective in increasing growth than spring treatments.

Brown and Munsell reported that the percentage of additional feed necessary for their May - early June load of stock during the remainder of the season was as follows: spring application of nitrogen 29 percent, spring plus summer applications of nitrogen 33 percent and summer application of nitrogen 47 percent.

Robinson and Pierre (1942) reported that plots receiving part of nitrogen application in spring and part in summer gave about the same total yield as plots receiving the whole application in the spring. In most cases the split application gave a more desirable seasonal distribution of growth during favorable seasons. Spring applications gave higher yields than fall applications. During unfavorable years the effect of the nitrogen was carried over until growing conditions became more favorable.

Aberg et al. (1943) reported on studies made in the field with legumes and grasses grown alone and in combination. In nearly all cases plant associations were compensating. Bromegrass and timothy grown in association gave an increase in yield of bromegrass which was nearly offset by the loss in yield of timothy. There was no evidence of either an antagonistic or beneficial effect from their association.

Results from the same crops grown in the greenhouse and field were in many cases reversed. This lack of agreement emphasized the importance of environmental conditions in studies of crop associations.

Roberts and Olson (1942) published results on a greenhouse study of several legumes and two grasses grown in various associations. The legumes included red, alsike, white, and sweetclover, alfalfa, and lespedeza, and two grasses, redtop and bluegrass. It was concluded that in no case were both the grass and the legume benefited or injured when grown in association. In general an increase in one component of the mixture resulted in a decrease in dry weight of the other in comparison with their respective yields when grown alone. A similar conclusion was drawn in respect to nitrogen content of the crops.

Woodman and Underwood (1932) reported on a prominent feature of agricultural development in recent years in the British Isles. Intensive methods of management of British grasses, a term used to describe the new development of rotational or sectional grazing included a succession of flushes of young herbage of high nutritive value throughout the entire season.

These changed conditions of management call for a more liberal use of nitrogenous fertilizers.

Greenhill and Page (1931) reported the mineral content of forage showed definite variation during the season. Lime, and to a less extent phosphorus and nitrogen, increased to a summer maximum and decreased again later. The actual range of variation and period of maximum value appeared to be influenced by the type of pasture and nature of grazing.

Shutt, Hamilton and Selwyn (1932), studying protein content of young grasses, reported that herbage from one to three weeks growth is a rich protein feed. Grass cut for hay averaged less than one-half the protein content of younger grass. Protein content of grass falls off with age or, in other words, lengthening the period of growth reduces the percentage of protein.

Munsell and Brown (1939) reported results suggesting the seasonal peaks in total nitrogen of the herbage by adding or withholding available nitrogen fertilizers. In their work it was pointed out that most of the effects of the nitrogen were reflected in the succeeding cutting. The second cutting after the application showed little or no effect.

The value of legumes in pasture mixtures is well recognized, but some of the specific effects of such associations and their practical applications are still somewhat obscure. It is generally conceded that legumes improve the quality of pastures through an increase in the protein content of the mixed herbage.

Wagner and Wilkins (1947), in a preliminary report, present data showing an increased protein content of orchard and bromegrass as the percentage of an associated legume increased. Their results would suggest that Ladino clover might be more effective than alfalfa in increasing the protein content of spring growth of associated grasses.

Singleton (1946) reported the immediate effect of application of readily available nitrogenous fertilizer at the rate of 100 pounds nitrogen or more per acre has been a reduction in the amount of roots below the level of unfertilized plots. The end result of application of nitrogen has been an increase in the amount of roots by all rates of nitrogen. Applications of phosphorus had no effect on root development in the field.

Singleton (1946) also found that bromegrass seedlings gave significant responses to applications of phosphorus and greater response to combinations of phosphorus and nitrogen.

MATERIALS AND METHODS

Response of Bromegrass Seedlings to Nitrogen and Phosphorus in the Greenhouse

In order to study the response of bromegrass seedlings to fertilizer treatment under greenhouse conditions, soil was obtained from five different sources and brought into the greenhouse in the fall of 1946.

Two lots of soil were Labette gravely loam, obtained from the E. C. McMillen farm in Neosho County, 12 miles southeast of Chanute, Kansas, on December 9, 1946. One lot was taken from a "sod-bound" field of bromegrass which had been seeded in 1937, and the second lot was taken from an adjacent cultivated field which had been in small grain and lespedeza the past season. In obtaining the soil the surface litter was removed and the upper six inches of soil taken for the experiment. Each lot of soil was collected from several separate locations in the fields.

In December, 1946, three lots of soil were obtained from the College farm. The soil was Geary silty clay loam. One lot was obtained from a "sod-bound" bromegrass field, seeded in September, 1939; another from an adjacent cultivated field; and a third from a fence row between the two fields where an old stand of bromegrass was growing vigorously with no apparent signs of becoming "sod-bound". The soil was obtained in the same manner as that taken in Neosho County.

The roots of the bromegrass sods were removed, dried, run through a hammermill, and returned to the soil from which they were removed. The soil was then put in glazed pots, seven inches in diameter at the top, and approximately nine and one-half inches deep. The soils were potted on a dry basis using eight pounds of dry soil to each pot.

Six fertilizer combinations with three replications of each were applied to each of the five soils, making a total of 90 pots. Nitrogen fertilizer was applied at rates of 0, 100, and 200 pounds of elemental nitrogen per acre. Each nitrogen rate appeared with and without phosphatic fertilizer which was supplied at the rate of 160 pounds per acre of P_2O_5. The fertilizer was thoroughly mixed with the entire soil mass of each pot concerned. The source of nitrogen was ammonium nitrate (33% nitrogen), and of phosphorus, superphosphate (20% P_2O_5).

Small seedlings of the Achenbach strain of bromegrass were transplanted into these pots December 27, 1946. Eight seedlings were transplanted into each pot to insure a stand of uniformly spaced plants. All seedlings that did not become established during the first week were replaced at the end of seven days with other plants. The three replications were placed in three separate blocks on a greenhouse bench. Pots were randomized within replications, and the arrangement within replications, as well as the arrangement of the blocks, was changed every ten days.

The moisture equivalent was determined on each soil and the amount of water required for the soil in each pot was calculated. On this basis the pots were weighed every second day and water added as required to bring the soil up to its moisture equivalent.

The top growth was clipped February 24, 1947 and the roots were obtained from one replication. The second clipping was made April 3, 1947 and the roots were obtained from the two remaining replications. The experiment was terminated at this date.

All material was dried at 98° C. for 24 hours and weighed to the nearest one-hundredth of a gram.

Response of Bromegrass Plants to Nitrogen and Phosphorus in the Field

A series of fertilizer plots was established in the fall of 1946 on the Agronomy Farm. The bromegrass was of the Achenbach strain and was seeded in September, 1939. The soil was of average fertility and classified as Geary silty clay loam. The area was generally level to slightly rolling, and had a uniform stand of bromegrass with an occasional plant of orchard grass. The area had previously been included in a cow pasture, but in the summer of 1946 it was fenced to prevent grazing. In December, 1946 all top growth was mowed and removed from the plots.

The first fertilizer application was made September 10, 1946, using five rates of nitrogen plus checks, and one rate of phosphorus. Nitrogen rates as pounds of nitrogen per acre were: 200, 140, 100, 60, 20, 0. Superphosphate was applied at the rate of 80 pounds of P_2O_5 per acre. Each rate of nitrogen appeared twice with superphosphate and twice without. The plots receiving superphosphate were in a continuous pattern on the border row of plots of each series. Those receiving no superphosphate made up the center of each series. The nitrogen applications were randomized within each row of plots throughout each series, Fig. 1.

80*	140 **	100	0	60	20	200	
	60	20	200	140	100	0	0*
	100	0	60	20	200	140	0*
80*	200	140	100	0	60	20	

* Indicates pounds of P_2O_5 per acre.
** Indicates pounds of nitrogen per acre.

Fig. 1. Diagram showing the arrangement of series, Ag-5, bromegrass fertilizer plot on the Agronomy Farm.

The plot arrangement of Fig. 1 was used for series Ag-5. Other series were laid out in the same general pattern, except that the nitrogen rates were re-randomized for each series. In addition to the first series starting September 10, 1946 (Ag-5), applications were made at the following dates: November 14, 1946 (Ag-6), March 18, 1947 (Ag-7), and May 8, 1947 (Ag-8). The series number appearing after the above dates of application will be used in the following discussions.

The nitrogen was applied in the form of ammonium nitrate fertilizer (33% nitrogen). The rates of application were based on pounds of elemental nitrogen per acre. Phosphorus was applied in the form of treble superphosphate (45% P_2O_5). The ammonium nitrate was applied by hand, and the superphosphate was applied with a small garden fertilizer spreader.

These plots were not grazed in the fall of 1946, but the top growth was mowed and removed in December, 1946. Yields of forage and seed were obtained on these plots in the spring of 1947. Forage yields were taken at the time the bromegrass plants were about 90 percent past blooming.

Forage samples were taken from these plots on April 12 and 28, May 19, and July 21, 1947, for the purpose of protein analyses, which were made by the Chemistry Department. These samples were taken only from the plots receiving nitrogen applications of 200, 100, and 0 pounds per acre without superphosphate. All four series, according to dates of fertilizer application, were sampled for protein analysis.

In taking forage yields, an area three feet by 12 feet was cut from each plot with a power mower having a three-foot sickle. The forage was cut about two inches above the ground, the weight of the material from the area cut was recorded and a moisture sample weighed and placed in a kraft paper bag. After oven-drying the moisture sample, the moisture percent was determined for each plot and from this the yield of oven-dry forage per acre was calculated.

Seed yields were obtained by harvesting all seed from an area of 12.5 square feet from each plot. After drying and threshing, the seed yield per acre was calculated.

Root Study in the Field

On April 23, 1947 root samples were taken from the four series fertilized September 10, 1946 (Ag-5), November 14, 1946 (Ag-6), March 18, 1947 (Ag-7), and May 8, 1947 (Ag-8). The root samples were taken with a sod cutter which removed a core of soil and roots three inches in diameter and five inches in depth. Five such samples were dug from each plot. Each sample was taken from an area which appeared to be representative of the plot concerned, and the sod cutter was placed directly over a bromegrass plant. "Urine spots" (Gainey, Sewell, and Myers, 1937), bare spots, etc. were avoided.

On July 10, 1947 root samples were again taken from the four series of plots. These samples were taken in the same manner as the first root samples.

The soil was removed from the roots by washing with a fine spray of water over a 15-mesh wire screen. It was necessary to soak the cores of soil thoroughly to facilitate washing, and it was generally necessary to knead the soil gently with the hands during the washing. Water was sprayed over the roots until no evidence of soil remained. Some very fine roots probably escaped through the screen, but losses were low. The roots tended to form a mat on the screen which helped to hold those broken loose by the washing.

These roots were then dried at 98° C. for 36 hours and the net weight recorded to the nearest one-hundredth of a gram. These figures were then converted to pounds of dry matter per acre in the top five inches of soil.

CLIMATOLOGICAL DATA

Table 1 gives the daily precipitation at Manhattan for 1946 and January to July of 1947. The year 1946 as a whole averaged one of the warmest and one of the driest on record. The first four months of 1946 were very mild and by the end of April most crops were three to four weeks ahead of the season. May was a cool, wet month with a severe freeze in most parts of the state May 11, 1946.

June, July and the forepart of August, 1946 were abnormally warm and in most parts of the state precipitation was deficient.

In the Manhattan area, the crops and pastures suffered a severe drought during the summer of 1946.

Sufficient rainfall and warm weather in late August, September, and October revived the pastures and aided in the preparation of wheat land. November and December were mild and with sufficient moisture.

During the early part of the summer of 1946, plots receiving heavy nitrogen applications showed signs of burning. During the fall of 1946, the increased rainfall brought a vigorous growth of bromegrass. Plots receiving fall applications of nitrogen showed a heavy increase in foliage and a much deeper color than any of the check plots. These observations could be made within two weeks after the nitrogen was applied.

The spring of 1947 was late and cool. There was a good moisture supply but the season was so cool that the spring growth was slow in developing. The spring and early summer moisture was sufficient for a good growth of bromegrass and to show a good response to applications of nitrogen fertilizer. It was observed that in every plot receiving a heavy application of nitrogen, (200, 150, and 140 pounds per acre), there was severe lodging. Most of the plots were lodged so severely that it was impossible to harvest a seed yield. The seed failed to form properly because the plants began to lodge soon after blooming.

Table 1. Daily precipitation, Manhattan, Kansas, 1946, and January to July, 1947.

	1946												1947					
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
1			T				.03		.01		.02							.16
2					.02						T			.09				.05
3		T			.36				.98					.04	.20	.04		
4	.42		.06		T				.31	.05						.08		.50
5	.07		.95					.02	3.11		.05					.04	.10	.90
6				.08	T				2.21	1.22	.27		.04		.01	.02	.03	1.15
7			T		.13		.09		.05	.22	T							.04
8			.04	T			T	T	T	.04		T				2.03		
9	.22			.07	.15		T			.01	.48	T						
10				.29	.85		T	T	.06	.84	T				2.00	.02		
11	.08			.09	.07					T								
12			.01					.03				.53					.02	
13					.08	.07		6.00		.03			.02		.02			
14					.11	T		.02	.37			T						
15			.11	.65	.43			.46			T	T				.62	.24	
16			.43	.05			.67	.05		T	.14	T				.13	.01	.02
17			.07		.19					.80					.13		.60	
18		.26				.13				T				.25				.07
19	.11	.11			.11	1.62				.04		T				1.00	.05	1.77
20						.02			.12						.11			
21															.25	.10		.35
22														.75				
23	.50		.40	.22				T	T						.07		1.22	.25
24			.02					.01		T								
25						.05		T									T	
26								.46									.55	.26
27							.18					T	.01		.39		.17	.01
28							T	T	.11			T				.35	.14	
29				.01		.28		T				.07				.15	.66	
30	T				.03			T		.02							T	
31								T		.08			.01		.69			
Total Nor-mal	.95	.37	2.09	1.46	2.53	2.17	.97	7.05	7.33	3.35	.96	.60	.08	1.13	3.87	4.38	3.79	5.53

EXPERIMENTAL RESULTS

Response of Bromegrass Seedlings to Nitrogen and Phosphorus in the Greenhouse

The yield of both tops and roots of bromegrass showed significant increase as a result of applications of phosphorus with the seedlings in the greenhouse. Nitrogen had little effect alone, but in combination with phosphorus it produced the highest yields (Plates I through V). Table 2 gives the yield of tops of three replications clipped February 24, 1947.

Analysis of variance showed highly significant differences between means of soils and for interaction of nitrogen and phosphorus. There is also a significant difference for interaction of soil, nitrogen and phosphorus. This analysis is shown in Table 3.

The highest yields were produced by nitrogen and phosphorus in combination. There was no significant difference between the 200- and 100-pound nitrogen rates with phosphorus. The yield with phosphorus alone was significantly higher than nitrogen alone. The difference between 100 pounds of nitrogen alone and the check was not significant.

The cultivated soil from Neosho County produced significantly greater yields of top growth than did the "sod-bound" soil from Neosho County. The non-"sod-bound" soil from the fence row at the Agronomy Farm produced significantly greater yields than did the other local soils. The yield from the local non-"sod-bound" soil was significantly greater than that of the two "sod-bound" soils.

Table 2. Yield of top growth of bromegrass seedlings following applications of nitrogen and phosphorus on five soils in the greenhouse. Clipped February 24, 1947. Yields expressed as dry weight (grams) per pot.

Treatment		Source of soil* I	II	III	IV	V	Average
50 lbs. nitrogen		0.18	0.55	0.59	0.38	1.73	
		0.11	0.36	0.72	0.40	1.81	
		0.10	0.50	0.64	0.32	1.63	
	Av.	0.13	0.47	0.65	0.37	1.72	0.67
100 lbs. nitrogen		0.09	0.35	0.74	0.33	2.48	
		0.08	0.27	0.71	0.33	2.31	
		0.09	0.51	0.37	0.32	1.48	
	Av.	0.086	0.38	0.61	0.326	2.09	0.69
50 lbs. nitrogen + 80 lbs. P_2O_5		2.01	2.38	2.49	2.46	3.81	
		1.65	2.16	2.72	2.51	3.56	
		1.41	2.99	2.98	2.56	2.97	
	Av.	1.70	2.51	2.73	2.51	3.44	2.58
100 lbs. nitrogen + 80 lbs. P_2O_5		2.27	2.99	3.68	2.83	2.94	
		1.92	3.18	3.56	2.12	3.42	
		1.80	1.83	2.50	2.18	3.60	
	Av.	1.99	2.67	3.24	2.37	3.32	2.72
80 lbs. P_2O_5		0.44	1.02	0.70	1.08	1.58	
		0.43	1.22	0.45	1.15	1.62	
		0.37	1.06	0.47	0.92	1.55	
	Av.	0.41	1.10	0.54	1.05	1.58	0.93
Check		0.08	0.23	0.38	0.32	1.12	
		0.08	0.51	0.50	0.32	1.12	
		0.08	0.57	0.40	0.40	1.16	
	Av.	0.08	0.44	0.43	0.35	1.13	0.48
Grand Av.		0.73	1.26	1.37	1.16	2.21	1.34

* I "Sod-bound" soil, Neosho County.
II Cultivated soil, Neosho County.
III "Sod-bound" soil, local.
IV Cultivated soil, local.
V "Non-sod-bound" soil, local.

Table 3. Analysis of variance of yield of top growth of bromegrass in greenhouse pots following nitrogen and phosphorus applications on different soils. Clipped February 24, 1947.

Source of variation	DF	SS	V
Total	89	107.84	
Between soils	4	21.13	5.28**
Between nitrogen rates	2	18.35	9.18
Between phosphorus rates	1	48.09	48.09
Interaction S x N	8	1.84	.23
Interaction S x P	4	1.08	.27
Interaction N x P	2	11.52	5.76**
Interaction S x N x P	8	1.29	.16*
Error	60	4.54	.076

* Indicates significance at five percent level.
** Indicates significance at one percent level.

The greatest response to nitrogen alone and phosphorus alone was produced on the non-"sod-bound" local soil. The "sod-bound" soil from Neosho County gave lower yields in all treatments. The lowest yield on local soils in all treatments was obtained on the cultivated local soil.

The yields of the second clipping of tops, made April 3, 1937 are given in Table 4. These yields include only the second and third replications. The treatments gave similar results to the first clipping except that the yield with phosphorus alone was the same as with nitrogen alone. The response to different soils was the same as at the first clipping.

The height of plant was measured a few days before the first clipping. These heights are recorded by graph in Fig. 2. The greatest height was produced by phosphorus and nitrogen in combination, followed by phosphorus alone. Phosphorus alone gave a greater height than nitrogen alone on all soils. There was no significant difference between the nitrogen and the check.

The number of culms per pot was determined at the time of the first clipping. The greatest number of tillers was produced by nitrogen and phosphorus in combination, followed by phosphorus alone. There was no significant difference between the nitrogen and the check.

Between soils the greatest tillering occurred on the cultivated and non-"sod-bound" soil. In both treatment and soil means the yield of tops was closely associated with the number of culms.

The weight of roots produced per pot at each of the two dates of sampling is given in Table 6. The root growth at the second

Table 4. Yield of top growth of bromegrass seedlings following applications of nitrogen and phosphorus on five soils in the greenhouse. Clipped April 3, 1947. Yields expressed as dry weights (grams) per pot.

Treatment		Source of soil* I	II	III	IV	V	Average
50 lbs. nitrogen		0.28	0.70	1.39	0.54	1.97	
		0.21	0.72	1.33	0.39	1.38	
	Av.	0.24	0.71	1.36	0.46	1.67	0.89
100 lbs. nitrogen		0.16	0.52	1.22	0.56	2.00	
		0.20	0.83	0.92	0.83	1.81	
	Av.	0.18	0.67	1.07	0.69	1.90	0.90
50 lbs. nitrogen + 80 lbs. P_2O_5		2.50	3.15	2.66	2.84	2.73	
		2.34	3.98	3.11	3.56	3.71	
	Av.	2.42	3.56	2.88	3.20	3.22	3.05
100 lbs. nitrogen + 80 lbs. P_2O_5		2.73	3.78	3.77	2.69	3.23	
		3.25	3.41	3.33	3.27	3.52	
	Av.	2.99	3.59	3.55	2.98	3.37	3.29
80 lbs. P_2O_5		0.69	1.14	0.61	1.15	1.00	
		0.86	1.03	0.61	0.98	0.97	
	Av.	0.77	1.08	0.61	1.06	0.98	0.90
Check		0.11	0.73	0.68	0.57	0.75	
		0.25	0.68	0.83	0.80	0.89	
	Av.	0.18	0.70	0.75	0.68	0.82	0.62
Grand Av.		1.13	1.71	1.70	1.51	1.99	1.61

* I "Sod-bound" soil, Neosho County.
II Cultivated soil, Neosho County.
III "Sod-bound" soil, local.
IV Cultivated soil, local.
V "Non-sod-bound" soil, local.

Table 5. Analysis of variance of yield of top growth of bromegrass in greenhouse pots following nitrogen and phosphorus applications on different soils clipped April 3, 1947.

Source of variation	DF	SS	V
Total	59	86.29	1.46
Between soils	4	4.86	1.22
Between nitrogen rates	2	22.00	11.00
Between phorphorus rates	1	39.80	39.80**
Interaction S x N	8	1.05	.13
Interaction S x P	4	2.14	.53
Interaction N x P	2	13.30	6.65**
Interaction S x N x P	8	1.65	.21**
Error	30	1.49	.05

* Indicates significance at five percent level.
** Indicates significance at one percent level.

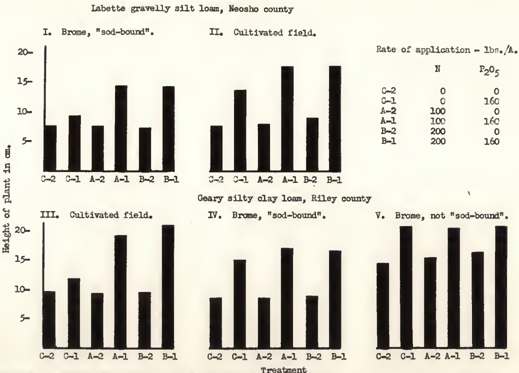

Fig. 2. Effect of nitrogen and phosphorus fertilizer on the growth of brome-grass seedlings in the greenhouse.

Table 6. Yield of roots of bromegrass seedlings at two different dates following applications of nitrogen and phosphorus to pots in the greenhouse. Samples taken February 24, (1) and April 3, (2) 1947. Yields expressed as dry weight (grams) per pot.

Treatment		Source of soil I	II	III	IV	V	Average
100 lbs.	(1)	0.46	1.28	0.45	1.36	2.63	1.23
nitrogen	(2)	1.38	2.09	2.78	1.80	2.60	
	(2)	0.59	2.19	2.89	1.50	2.99	
	*Av.	0.98	2.14	2.83	1.65	2.79	*2.07
200 lbs.	(1)	0.19	0.91	1.95	1.58	3.98	1.72
nitrogen	(2)	0.03	2.38	3.09	1.96	5.69	
	(2)	0.35	1.29	2.92	1.64	5.09	
	*Av.	0.19	1.83	3.05	1.80	5.39	*2.45
100 lbs.	(1)	6.51	4.83	5.45	3.17	8.81	5.75
nitrogen	(2)	9.37	7.30	9.44	5.37	5.82	
+ 80 lbs.	(2)	1.11	11.87	7.77	6.98	2.77	
P_2O_5	*Av.	5.24	9.58	8.60	6.17	4.29	*6.83
200 lbs.	(1)	3.87	4.43	7.02	3.66	5.43	4.88
nitrogen	(2)	7.11	13.06	6.64	3.69	11.10	
+ 80 lbs.	(2)	11.65	4.69	9.56	10.57	13.60	
P_2O_5	*Av.	9.38	8.75	8.10	7.13	12.35	*6.91
80 lbs.	(1)	0.99	3.58	3.20	4.78	5.44	3.59
P_2O_5	(2)	2.63	6.60	3.38	3.49	6.34	
	(2)	2.55	3.17	3.50	4.16	3.06	
	*Av.	2.59	4.88	3.44	3.82	4.70	*3.88
Check	(1)	0.18	0.51	1.46	0.56	2.44	1.02
	(2)	0.37	1.84	3.26	1.21	2.44	
	(2)	0.78	1.64	3.02	2.80	4.45	
	*Av.	0.57	1.74	3.14	2.01	3.44	*2.18
February Av.		2.01	2.59	3.25	2.35	4.78	2.99
*April Av.		3.15	4.82	4.90	3.76	5.49	*4.42

* Average of two replications (2) clipped on April 3, 1947.

clipping is shown in Plates I through V. Two hundred pounds of nitrogen with 160 pounds P_2O_5 per acre produced the greatest yield of roots. Next in order was 100 pounds of nitrogen with 160 pounds of P_2O_5, followed by P_2O_5 alone. P_2O_5 alone was significantly higher than 100 pounds of nitrogen alone and checks. Under field conditions P_2O_5 alone showed no significant difference in root materials.

Considering the soil means, the "non-sod-bound" soil gave the highest yield, followed by the two cultivated soils, and finally the "sod-bound" soils.

The soil or treatment producing the greatest yield of tops also produced the greatest yield of roots. With only a few minor exceptions the same order of yields in both soils and treatments held for both roots and tops.

The combination of nitrogen and phosphorus alone produced about the same increase in root yields in all soils.

Root Study in the Field

Surface applications of nitrogen and phosphorus to established stands of bromegrass produced significant differences in root yields. The data are given in Table 7. Analysis of variance given in Table 8 shows a difference due to nitrogen, phosphorus and date of application, but is not consistent according to dates or rates. The means given in Table 7 show different ranking for treatments by date or rate. The interaction of date, nitrogen, and phosphorus was highly significant. This indicates that the treatment and dates of application did have an effect but were

Table 7. Average yield of oven dry root material (lbs. per acre) from established bromegrass stands with varying rates and dates of nitrogen and phosphate fertilizer applications. Sample taken April 3, 1947.

	P_2O_5 per A.	Pounds N per acre						
		200	140	100	60	20	0	Average
Ag-5	0#	7,045.34	6,268.28	9,946.37	7,977.82	5,853.85	5,214.94	
Fertilized	80#	6,596.38	7,580.65	7,908.74	5,698.44	9,445.60	5,404.88	
9-15-46 Av.		6,820.86	6,924.47	8,927.56	6,838.13	7,649.73	5,309.91	7,078.44
Ag-6	0#	6,889.93	7,114.42	6,112.87	6,233.75	5,681.17	6,717.25	
Fertilized	80#	6,769.06	7,183.49	6,147.41	5,871.12	5,646.64	6,717.25	
11-14-46 Av.		6,829.50	7,148.96	6,130.14	6,052.44	5,663.91	6,717.25	6,423.70
Ag-7	0#	10,723.43	6,769.06	6,993.54	5,940.19	9,601.01	4,317.00	
Fertilized	80#	4,576.02	4,317.00	5,301.28	9,601.01	6,492.77	8,426.78	
3-18-47 Av.		7,649.73	5,543.03	6,147.41	7,770.60	8,046.89	6,371.89	6,921.59
Grand Average		7,100.03	6,538.82	7,068.37	6,887.06	7,120.18	6,133.02	6,807.93

Table 8. Analysis of variance of the effect of nitrogen and phosphorus fertilizer on yield of roots of bromegrass in established stands.

Source of variation	DF	SS	V
Total	359	913.63	
Between dates	2	9.39	4.69
Between nitrogen rates	5	15.60	3.12
Between P_2O_5 rates	1	3.03	3.03
Interaction D x N	10	77.71	7.77
Interaction D x P	2	5.88	2.94
Interaction N x P	5	35.22	7.05
Interaction D x N x P	10	142.01	14.20*
Plot variance	36	169.21	4.70**
Sampling error	288	473.58	1.64

* Indicates significance at five percent level.
** Indicates significance at one percent level.

not consistent in their results. The plots fertilized in September, 1946 gave the highest total yield of root material.

Response of Bromegrass Plants to Nitrogen and Phosphorus Fertilizers in the Field

Field plots were established at four dates of fertilizer application as follows: September, 1946 (Ag-5), November, 1946 (Ag-6), March, 1947 (Ag-7), May, 1947 (Ag-8). The yields of top growth from these plots are given in Table 9 and the analysis of variance of the top growth is given in Table 10. Analysis of variance showed a significant difference between dates of fertilizer application and a highly significant difference between rates of nitrogen application. The analysis showed a highly significant difference for the interaction of dates of application, nitrogen rates and phosphorus rates.

Applications of superphosphate did not give a significant increase at either date of application. Plots receiving superphosphate in November and March gave a lower yield than plots receiving no superphosphate. The 100-pound rate of nitrogen produced higher yields on the plots which were fertilized in November and March. The 200-pound rate of nitrogen produced higher yields on the plots fertilized in September, while the plots fertilized in May gave a higher yield with the 140-pound rate. In comparing the average yields of the nitrogen plots at each date of application it will be seen that the March application gave the greatest yield.

Table 9. Yield of top growth of bromegrass in the field following applications of nitrogen and P_2O_5 fertilizers at different dates. Yields expressed as dry weight (lbs.) per acre. Plots were clipped June 5, 1947.

	P_2O_5 per A.	Pounds of nitrogen per acre						
		200	140	100	60	20	0	Average
Ag-5	0#	4,523.0	4,244.8	4,239.2	4,484.6	3,481.2	2,020.8	
Fertilized		4,979.3	3,187.4	3,114.5	2,821.6	2,516.2	2,043.7	
9-15-46	Av.	4,751.2	3,716.1	3,676.9	3,653.1	2,998.7	2,032.3	3,471.4
	80#	4,262.8	3,738.7	4,446.5	4,146.9	2,109.0	2,477.2	
		4,622.8	4,194.2	4,678.8	4,508.5	3,383.0	2,200.1	
	Av.	4,442.8	3,966.5	4,562.7	4,327.7	2,746.0	2,338.7	3,730.7
Series	Av.	4,597.0	3,841.3	4,119.8	3,990.4	2,872.4	2.185.5	3,601.1
Ag-6	0#	5,700.1	4,594.7	5,862.9	5,188.6	3,369.5	2,918.9	
Fertilized		5,686.7	6,162.7	5,977.1	4,030.6	4,806.5	2,849.6	
11-14-46	Av.	5,693.4	5,378.7	5,920.0	4,609.6	4,088.0	2,884.3	4,762.3
	80#	5,977.1	6,216.8	5,444.7	5,210.8	4,140.4	1,777.5	
		4,779.1	5,085.6	5,970.0	4,604.0	3,766.1	2,775.3	
	Av.	5,378.1	5,651.2	5,707.4	4,907.4	3,953.3	2,276.4	4,645.6
Series	Av.	5,535.8	5,515.0	5,813.7	4,758.5	4,020.7	2,580.4	4,704.0
Ag-7	0#	4,898.2	6,967.2	6,290.0	5,610.2	5,124.2	2,387.9	
Fertilized		3,352.0	5,965.7	6,747.8	6,042.2	3,054.0	3,787.4	
3-18-47	Av.	4,125.1	6,466.5	6,518.9	5,826.2	4,089.1	3,087.7	5,018.9
	80#	4,703.1	6,863.0	6,929.5	3,591.3	4,056.2	2,480.7	
		4,588.2	6,309.2	7,042.4	4,209.4	3,341.7	3,591.3	
	Av.	4,645.7	6,586.1	6,986.0	3,900.4	3,699.0	3,036.0	4,808.9
Series	Av.	4,385.4	6,526.3	6,752.5	4,863.3	3,894.1	3,061.9	4,913.9

Table 9. (concl.).

P_2O_5 per A.	200	140	100	60	20	0	Average
		Pounds of nitrogen per acre					
[illegible]	[illegible]	[illegible]	[illegible]	3,994.5	2,782.6	2,438.6	
[illegible]	[illegible]	[illegible]	[illegible]	3,932.7	2,920.0	2,694.9	
[illegible]	[illegible]	[illegible]	[illegible]	3,963.6	2,851.3	2,566.8	3,700.1
80#	4,032.7	4,639.2	4,756.6	3,808.8	4,524.7	2,083.5	
	4,039.2	4,124.4	3,961.3	3,425.4	3,203.6	3,331.3	
Av.	4,036.0	4,381.8	4,359.0	3,617.1	3,864.2	2,707.4	3,827.6
Series Av.	4,027.8	4,632.9	4,137.3	3,790.4	3,357.8	2,637.1	3,763.9
Grand Average	4,720.2	4,663.1	4,690.3	4,179.8	3,417.0	2,467.7	4,023.0

Table 10. Analysis of variance of the yield of top growth of bromegrass in the field following applications of nitrogen and phosphorus fertilizers at different dates.

Source of variation	DF	SS	V
Total	95	175,590,795	1,848,324
Between dates	3	40,935,947	13,645,315*
Between nitrogen rates	5	73,053,122	14,610,624**
Between P_2O_5 rates	1	100,988	100,988
Interaction D x N	15	23,527,029	1,568,468
Interaction D x P	3	3,561,678	1,187,226
Interaction N x P	5	10,547,678	2,109,535
Interaction D x N x P	15	18,796,200	1,253,080
Error	48	5,058,053	105,376

* Indicates significance at five percent level.
** Indicates significance at one percent level.

Forage samples were taken from the fertilizer plots Ag-5, Ag-6, Ag-7 and Ag-8 for the purpose of studying the effect of fertilizer applications upon the protein content of bromegrass. Table 11 gives the percent protein contained in bromegrass top growth for different dates and rates of fertilizer applications.

The 100-pound rate of nitrogen gave an increase over the check in each plot and the 200-pound rate gave even greater increases. The protein content in all plots declined rapidly as the spring growth became older. This is shown in Table 11.

Surface applications of readily available nitrogen to established stands of bromegrass produced significant increases in seed yield. The complete data are given in Table 12. Analysis of variance showed a significant difference between the means of nitrogen rates, interaction between date and rate of nitrogen, and interaction between dates of application, P_2O_5 rates and nitrogen rates, as shown in Table 13.

These data and analysis include seed yields from only four rates of nitrogen application. In all plots the 200-pound per acre application and the 140-pound application had produced a rank growth of forage and very little seed. The bromegrass on these plots had lodged to such a degree that it was impossible to harvest a seed yield.

Considering date of fertilizer applications, series Ag-6, fertilized November 14, 1946 and Ag-7, fertilized March 18, 1947 gave the greatest yield of seed. In all series the yields were in the same order as the rates of nitrogen applications. The 100-pound rate gave the greatest yield, followed by 60, 20 and 0 pounds per acre. All rates of nitrogen gave increased yields of seed over checks.

Applications of superphosphate did not significantly increase seed yields. In series Ag-6 and Ag-8 applications of superphosphate decreased the yield of seed.

Table 11. Protein content of top growth of bromegrass at different dates of clipping, following applications of nitrogen and phosphorus. Expressed in percent protein, moisture free basis.

Date fertilized	Lbs. N per A	Date sampled 4-12-47	4-28-47	5-19-47
	0	25.3	14.13	10.6
9-12-46	100	28.8	16.8	15.4
	200	31.8	25.3	17.8
11-14-46	100	31.8	24.7	13.9
	200	35.8	29.2	19.9
3-18-47	100		26.3	16.3
	200		30.0	19.7
5-8-47	100			16.0
	200			17.1

Table 12. Yield of bromegrass seed from field plots following applications of nitrogen and P_2O_5 fertilizers at different dates and rates of application. Yields expressed as dry weight (lbs.) per acre. Plots were harvested July 25, 1947.

		P_2O_5 Lbs./A	Pounds of nitrogen per acre 100	60	20	0	Average
Ag-5		0	645.64	599.56	337.00	246.37	
Fertilized			684.36	425.11	318.98	227.66	
9-15-46	Av.		665.00	512.34	327.99	237.02	435.59
		80	727.07	594.02	398.70	261.53	
			769.48	408.70	395.05	273.96	
	Av.		743.28	501.36	396.88	270.25	479.19
	Series Av.		706.64	506.85	362.44	253.64	457.39
Ag-6		0	1,035.18	725.08	434.92	430.17	
Fertilized			1,041.42	506.08	526.02	390.45	
11-14-46	Av.		1,038.30	615.58	480.47	410.31	636.17
		80	611.59	552.46	324.58	145.76	
			625.70	506.08	579.08	242.00	
	Av.		618.65	529.27	451.83	193.88	448.41
	Series Av.		828.48	572.43	466.15	302.10	542.29
Ag-7		0	1,022.29	556.69	366.37	259.17	
Fertilized			853.06	553.62	413.68	118.47	
3-18-47	Av.		937.68	555.16	390.03	188.82	517.92
		80	713.89	687.81	521.04	345.36	
			700.47	599.63	501.48	209.15	
	Av.		707.18	643.72	511.26	277.26	534.86
	Series Av.		822.43	599.44	450.65	233.04	526.39

Table 12. (concl.).

	P_2O_5 Lbs./A	Pounds of nitrogen per acre 100	60	20	0	Average
Ag-8	0	650.24	294.68	201.66	238.70	
Fertilized		610.14	361.92	231.54	129.58	
5-8-47 Av.		630.19	328.30	216.60	184.14	339.81
	80	330.41	268.30	217.79	165.32	
		275.61	225.89	182.57	152.13	
Av.		303.01	247.10	200.18	158.73	227.26
Series Av.		466.60	287.70	208.39	171.44	283.54
Grand Average		706.04	491.61	371.91	240.06	452.40

Table 13. Analysis of variance of the yield of seed of bromegrass, in field plots, from applications of nitrogen and phosphorus. Harvested July 25, 1947.

Source of variation	DF	SS	V
Total	63	68,897.50	
Between dates of applications	3	7,315.28	2,438
Between nitrogen rates	3	31,449.32	10,483.10*
Between P_2O_5 rates	1	932.31	932.31
Interaction D x N	9	2,308.97	356.55*
Interaction D x P	3	5,705.67	1,901.89
Interaction N x P	3	2,606.72	868.90
Interaction D x N x P	9	7,534.66	837.18*
Error	32	11,044.57	354.14

* Indicates significance at five percent level.

DISCUSSION

Response of Bromegrass Seedlings to Nitrogen and Phosphorus in the Greenhouse

Greenhouse studies have shown significant responses of bromegrass seedlings to phosphorus and to nitrogen and phosphorus in combination, but only a small response to nitrogen alone. The greatest response was obtained from a combination of nitrogen and phosphorus. The yield of top growth showed no difference between 100- and 200-pound rates of nitrogen.

"Sod-bound" soils produced a significantly lower yield than the "non-sod-bound" and non-brome soils. These "sod-bound" soils gave only limited response to either nitrogen or phosphorus alone, producing a lower yield than the corresponding cultivated soil checks and also lower than sod soil in which the brome had not become "sod-bound". Within the same treatment the yield of the "sod-bound" soils was always the lowest.

These results show the productive capacity of the "sod-bound" soils to be lower than the corresponding cultivated soils. The yields of the "sod-bound" soils were increased by applications of nitrogen and phosphorus, but the yields of the cultivated soils were increased even greater by the fertilizer treatment. This would indicate that there are other factors besides nitrogen and phosphorus related to this "sod-bound" condition.

The height of plants produced by the different soils and treatments in general followed the same order as the yields.

Response of Bromegrass Plants to
Nitrogen and Phosphorus in the Field

Observations were made on the effect of nitrogen and phosphorus fertilizers on seed yield of bromegrass in established stands under field conditions.

Surface applications of phosphorus to established stands of bromegrass gave no increase in seed yield. Significant increases in yield of seed were obtained from applications of nitrogen.

All plots receiving applications of 200- and 140-pounds of nitrogen per acre were so severely lodged at maturity that it was impossible to harvest seed. There were far fewer seed heads on these heavily fertilized plots and the plants were so badly lodged that the seed heads did not develop properly.

The 100-pound nitrogen rates gave the highest seed yields followed by the 60-pound, the 20-pound, and lastly, the checks. Series Ag-6, fertilized November, 1946, gave the greatest responses to applications of nitrogen, with the 100-pound rate producing the greatest seed yield.

Surface applications of nitrogen gave a significant increase in the protein content of the top growth of bromegrass under field conditions. The protein percentage of all plots was highest at the early spring date of sampling. At the time of the second sampling the protein percentage had decreased by about 40 percent, and at the third date of clipping all plots had again decreased by about the same amount. At all dates of sampling the 200-pound application of nitrogen gave the highest protein percentages, followed by the 100-pound application.

Response of Bromegrass Roots to Nitrogen and Phosphorus in the Field

Observations were made on the effect of nitrogen and phosphorus fertilizers on root development in the field with established stands of bromegrass. Surface applications of phosphorus to established stands of bromegrass gave no increase in root yield. This is in agreement with Sprague (1932) who found no correlation between the supply of available phosphorus and root growth of perennial grasses.

Significant increases were shown in yield of both tops and roots resulting from phosphorus applications to bromegrass seedlings in the greenhouse. The greatest yield of roots was produced by a combination of nitrogen and phosphorus. In the greenhouse the relative response of all soils to this treatment was equally great. When considering the yields of top growth it was found that the "sod-bound" soils gave greater responses to a combination of nitrogen and phosphorus than did the cultivated and "non-sod-bound" soils.

The application of nitrogenous fertilizers to established stands of bromegrass resulted in an increase in yield of roots. The greatest and most significant increase was a result of an interaction of date of application, rate of nitrogen and rate of phosphorus fertilizer applications. Considering all the data, 200 pounds of nitrogen per acre produced the greatest amount of roots. All rates of nitrogen produced more root growth than the checks.

SUMMARY

1. The effects of varying rates and dates of application of nitrogen and phosphorus fertilizers on root developments, seedling development and mature plant response in bromegrass (*Bromus inermis* Leyss) are reported. Rates of ammonium nitrate fertilizer used in the field were equivalent to 200, 140, 100, 60, 20, and 0 pounds of elemental nitrogen per acre. Superphosphate applications were equivalent to 80 and 0 pounds per acre of P_2O_5 . Rates of ammonium nitrate fertilizer used in the greenhouse were equivalent to 200 and 100 pounds of elemental nitrogen per acre. Superphosphate applications were equivalent to 160 and 0 pounds per acre of P_2O_5.

2. Root yields are expressed as pounds of moisture free root material in the top five inches of soil. Yields of top growth are expressed as pounds of moisture free material produced per acre of bromegrass.

3. Bromegrass seedlings gave significant responses to applications of phosphorus and greater response to combinations of nitrogen and phosphorus in the greenhouse. Field applications on established stands of bromegrass did not give comparable results; phosphorus gave little or no increase either alone or in combination with nitrogen.

4. Soil from "sod-bound" bromegrass fields gave significantly lower yields of roots and tops of bromegrass seedlings than did cultivated soil from "non-sod-bound" bromegrass sod. This reduction in yield was consistent throughout this experiment.

5. Increased yields resulting from fertilization of greenhouse seedlings were accompanied by significant increases in number of culms and in height of plants.

6. When applied to established stands of bromegrass, applications of nitrogen and phosphorus fertilizers made at different dates did not have a significant effect upon the yield of roots. The interaction of these factors, (date and rate of nitrogen and phosphorus applications), gave a significant increase in the yield of roots. This would indicate that rates of nitrogen and phosphorus as well as date of application had on effect upon the yields, but were not consistent. Additional studies will need to be made to establish the combinations of these factors having the greatest effect on yields of bromegrass roots in established stands.

7. Applications of nitrogen to established stands of bromegrass gave significant increases in yields of forage. Applications of 100 pounds of nitrogen per acre gave the highest yield of forage when applications were made in November and March. When applications were made in September and May the 200 and 140 pound applications gave the highest yields but these were lower than yields from 100 pounds of nitrogen applied in November and March.

8. Applications of phosphorus had no effect on forage yield of established stands of bromegrass.

9. The protein content of bromegrass in established stands was significantly increased by applications of nitrogen fertilizer.

Applications of 200 pounds of nitrogen per acre gave the highest protein percentages. All protein percentages decreased greatly from the time of the first sampling (April 12, 1947) to the second sampling (April 28, 1947). An equal reduction in protein percentage was noted at the third date of sampling. This reduction in protein percentage was consistent throughout all plots tested, including the check.

10. Applications of nitrogen at rates of 200 and 140 pounds per acre caused severe lodging of bromegrass plants during the final stages of maturity. The heavy nitrogen plots were lodged to such an extent that seed heads did not develop properly and seed yields could not be obtained from those plots.

11. The maximum yields of seed were produced by 100 pounds of nitrogen applied in November and March. Nitrogen applied in September and May gave the greatest seed yields at 100 pounds per acre but these yields were less than those for the November and March applications.

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EXPLANATION OF PLATE I

The effect of nitrogen and phosphorus fertilizers on root development in the greenhouse on Neosho County "sod-bound" soil. Each root mass produced by eight plants. Upper, left to right: check, 160 pounds P_2O_5 per acre, 100 pounds of nitrogen per acre. Lower, left to right: 100 pounds nitrogen per acre plus 160 pounds P_2O_5 per acre, 200 pounds nitrogen per acre, 200 pounds nitrogen per acre plus 160 pounds P_2O_5 per acre.

EXPLANATION OF PLATE II

The effect of nitrogen and phosphorus fertilizers on root development in the greenhouse on Neosho County cultivated soil. Each root mass produced by eight plants. Upper, left to right: check, 160 pounds P_2O_5 per acre, 100 pounds of nitrogen per acre. Lower, left to right: 100 pounds nitrogen per acre plus 160 pounds P_2O_5 per acre, 200 pounds nitrogen per acre, 200 pounds nitrogen per acre plus 160 pounds P_2O_5 per acre.

PLATE II

EXPLANATION OF PLATE III

The effect of nitrogen and phosphorus fertilizers on root development in the greenhouse on Riley County "sod-bound" soil. Each root mass produced by eight plants. Upper, left to right: check, 160 pounds P_2O_5 per acre, 100 pounds of nitrogen per acre. Lower, left to right: 100 pounds nitrogen per acre plus 160 pounds P_2O_5 per acre, 200 pounds nitrogen per acre, 200 pounds nitrogen per acre plus 160 pounds P_2O_5 per acre.

PLATE III

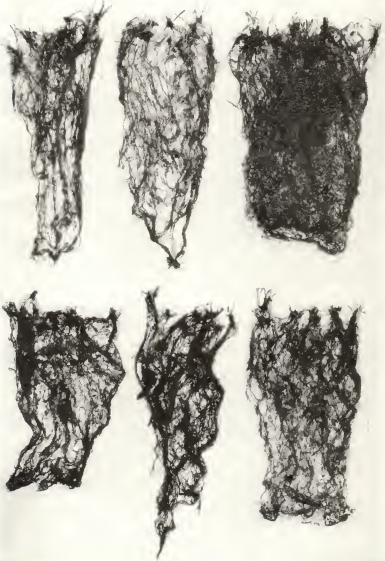
EXPLANATION OF PLATE IV

The effect of nitrogen and phosphorus fertilizers on root development in the greenhouse on Riley County cultivated soil. Each root mass produced by eight plants. Upper, left to right: check, 160 pounds P_2O_5 per acre, 100 pounds of nitrogen per acre. Lower, left to right: 100 pounds nitrogen per acre plus 160 pounds P_2O_5 per acre, 200 pounds nitrogen per acre, 200 pounds nitrogen per acre plus 160 pounds P_2O_5 per acre.

EXPLANATION OF PLATE V

The effect of nitrogen and phosphorus fertilizers on root development in the greenhouse on Riley County "non-sod-bound" soil. Each root mass produced by eight plants. Upper, left to right: check, 160 pounds P_2O_5 per acre, 100 pounds of nitrogen per acre. Lower, left to right: 100 pounds nitrogen per acre plus 160 pounds P_2O_5 per acre, 200 pounds nitrogen per acre, 200 pounds nitrogen per acre plus 160 pounds P_2O_5 per acre.

PLATE V



EXPLANATION OF PLATE VI

Fig. 3. The effect of fertilizer applications on the growth of bromegrass seedlings growing in Soil I, "sod-bound" brome soil from Neosho County. Lower, left to right: no nitrogen and no P_2O_5, no nitrogen and 160 pounds of P_2O_5 per acre, 100 pounds of nitrogen and no P_2O_5. Second row, left to right: 200 pounds of nitrogen and 160 pounds of P_2O_5, 100 pounds of nitrogen and 160 pounds of P_2O_5 per acre. Top center: 200 pounds nitrogen and no P_2O_5.

Fig. 4. The effect of fertilizer applications on the growth of bromegrass seedlings growing in Soil II, cultivated soil from Neosho County, Kansas. (Order of treatments the same as in Fig. 3).

Figure 3

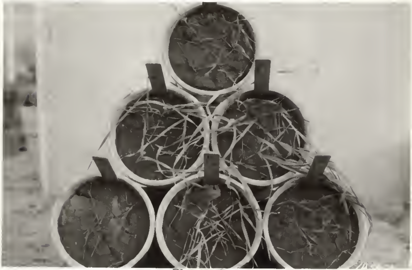


Figure 4

EXPLANATION OF PLATE VII

Fig. 5. The effect of fertilizer applications on the growth of bromegrass seedlings growing in Soil III, "sod-bound" bromegrass from Riley County. Lower, left to right: no nitrogen and no P_2O_5, no nitrogen and 160 pounds of P_2O_5 per acre, 100 pounds of nitrogen and no P_2O_5. Second row, left to right: 200 pounds of nitrogen and 160 pounds of P_2O_5, 100 pounds of nitrogen and 160 pounds of P_2O_5 per acre. Top center: 200 pounds of nitrogen and no P_2O_5.

Fig. 6. The effect of fertilizer applications on the growth of bromegrass seedlings growing in Soil IV, cultivated soil from Riley County, Kansas. (Order of treatments the same as in Fig. 5).

Figure 5

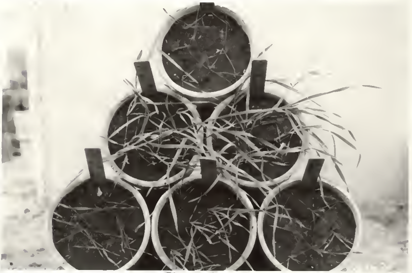


Figure 6

EXPLANATION OF PLATE VIII

Fig. 7. The effect of fertilizer applications on the growth of bromegrass seedlings growing in Soil V, "non-sod-bound" brome from Riley County. Lower, left to right: no nitrogen and no P_2O_5, no nitrogen and 160 pounds of P_2O_5 per acre, 100 pounds of nitrogen and no P_2O_5. Second row, left to right: 200 pounds of nitrogen and 160 pounds of P_2O_5, 100 pounds of nitrogen and 160 pounds of P_2O_5. Top center: 200 pounds of nitrogen and no P_2O_5.

PLATE VIII

Figure 7

EXPLANATION OF PLATE IX

Fig. 8. The growth of bromegrass seedlings on five untreated soils in the greenhouse. Upper, left to right: Neosho County "sod-bound" soil, Neosho County cultivated soil. Lower, left to right: local "sod-bound" soil, local cultivated soil, local "non-sod-bound" soil.

Fig. 9. The effect of application of 160 pounds of P_2O_5 per acre on the growth of bromegrass. (Order of soils the same as in Fig. 8)

PLATE IX

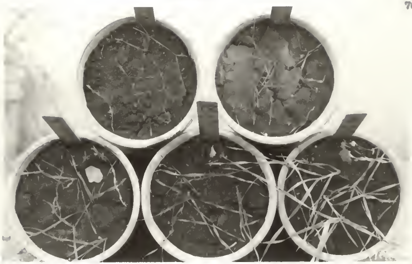


Figure 8

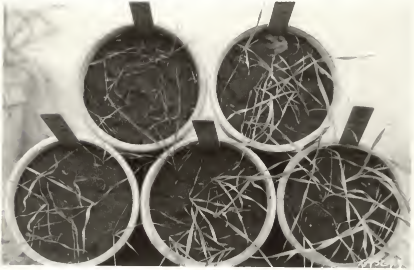


Figure 9

EXPLANATION OF PLATE X

Fig. 10. The effect of application of 100 pounds of nitrogen per acre on the growth of bromegrass seedlings on fine soils in the greenhouse. Upper, left to right: Neosho County "sod-bound" soil, Neosho County cultivated soil. Lower, left to right: local "sod-bound" soil, local cultivated soil, local "non-sod-bound" soil.

Fig. 11. The effect of application of 100 pounds of nitrogen plus 160 pounds of P_2O_5 per acre on the growth of bromegrass seedlings in the greenhouse. (Order of soils the same as in Fig. 10).

Figure 10

Figure 11

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