THE EFFECT OF NITROGEN AND PHOSPHORUS FERTILIZERS ON ROOT DEVELOPMENT AND ON SEEDLING GROWTH IN BROMEGRASS (BROMUS INERMIS LEYSS)

by

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INTRODUCTION

With the possibility of a more extensive use of nitrogenous fertilizers as a result of the conversion of munition plants to the production of fertilizers, there has recently been a rather extensive investigation of the response of plants to nitrogen.

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 possibility of a cheaper source of nitrogen than has formerly prevailed, together with greater realization of the value of grass in the farm program, has resulted in increased attention to the improvement of pasture crops by fertilization.

Bromegrass (*Bromus inermis* Leyss), the most important tame grass of eastern Kansas, has given a favorable response to the application of nitrogenous fertilizers at the Kansas Agricultural Experiment Station and at other stations throughout the area where it is adapted. It is a native of central Europe and China, and has been extensively cultivated in Hungary and Russia. It was introduced into the United States about 1884 (Whitman, 1941) and has been grown widely throughout the country. It is especially well adapted to a dry to subhumid, cool climate. At the same time it can withstand 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 produces a highly palatable and nutritious pasture or hay crop. Fuelleman (1941) reported that chemical analyses show a high protein and ash content.

Bromegrass produces a very dense sod and spreads aggressively by rhizomes. The roots are profusely branched, forming a heavy mass of roots, 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.

This condition has been attributed largely to a lack of available nitrogen. Fertility in the soil will delay the appearance of the 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. Newell (1943) has shown marked increases in yield of forage, percent protein in the forage, and yield of bromegrass seed as a result of nitrogen applications. Harrison (1941) has reported marked increases in forage and seed yields of bromegrass as a result of spring applications of nitrogen. Churchill (1944) reported marked increases in seed yield resulting from fall and early spring applications of 40 and 80 pounds of nitrogen per acre. Various investigatore, Enlow (1929), McClure (1929), Dodd (1935), Gardner (1939), Tyson (1939), Eheart (1941), Robinson (1942), and Ahlgren et al. (1944), have reported increaees in both dry matter and percent of protein in the forage resulting from applications of nitrogen to native grasslands.

Although 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 application of fertilizers on established stands of grasses. Preliminary investigation at the Kansas Agricultural Experiment Station has indicated that under greenhouse conditions bromegrass responds to phosphorus fertilizer applied at the time of seeding.

Therefore, it was the purpose of this study to determine the response of the root system of bromegrass to fertilizer applications of nitrogen and phosphorus, and to determine the response of bromegrass seedings to those fertilizers under greenhouse and 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. Ten Eyck (1904) and Weaver (1920) described the root system of bromegrass. This early work has led to the study of various factors which affect the root systems of plants.

Biswell and Weaver (1933) stated that experiments indicated that for several weeks at least (in the spring) all, or nearly all, of the accumulated storage material was used by the growing shoots and only after those were fairly well established were new roots developed. They stated that if the tops were removed at that point, the process was repeated and the development of the root system greatly retarded. Weaver and Harmon (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.

Concerning the life of roots, Stoddard (1935) stated that tests indicate that both seminal and nodal roots of prairie grasses, even under adverse conditions, may live in excess of two years. Stuckey (1941) reported that active production of new root growth begins in October, continuing slowly through the winter and reaching a maximum in April. She noted that after the middle of June few, if any, roots were formed because of high soil temperatures.

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 contained within the top three inches, about 25 percent in the three to six inch depth, 15 percent in the six to nine inch depth, and 10 percent in the nine to twelve inch depth. They stated that bromegrass continues to build up root fiber year after year at a fairly rapid rate. A ten-year-old field had produced 8803 pounds of root fiber per acre foot. The total increase in weight with aging of stand took place uniformly throughout the top foot of soil.

Weaver and Zink (1946) 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.

Cook (1943) observed that the weight of roots is not considered so reliable a measure of the efficiency of the root system as linear measurements, because it ignores the extent and diameter or functioning surface of the individual roots.

He found, however, that the weight of roots was closely proportional to the total axial length of roots.

Pavlychenko (1942) reported that the number of roots per plant of bromegrass in sod was extremely low compared with the number of roots produced by widely spaced specimens. The depth of roots of plants grown in sod was much less than that of spaced ones.

Nedrow (1937) reported that a low water content of the soil greatly increased production of roots in proportion to the development of the shoots. The actual amount of roots produced, however, decreased with lower water content of the soil.

Laird (1930) reported that application of NH_4PO_4 increased the dry weights and development of the root systems 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 drouth. He concluded that:

> While judicious fertilization may for a time stimulate the utilization of the carbohydrate reserves, it is not amiss to appreciate that such stimulation may also accelerate their accumulation when the plant is given an opportunity for such storage.

Turner (1922) made the following explanation:

> The increased ratio of stems to roots which results from increasing the amount of nitrates in the soil solution 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. From his data he concluded that:

> Since relatively high ratios of soluble nitrogen to carbohydrate reserves have been shown to favor top growth rather than root development, it seems possible that early spring application of available nitrogen fertilizer in abundance may reduce the quantity of new roots formed and thus limit utilization of the soil resources for the remainder of the season.

Turner (1926) stated that there was no inhibiting effect of NO_3 upon the roots, but as the tops are stimulated to use more of the photosynthetic carbohydrates, the roots decrease in number and, therefore, show relatively less growth.

Weaver et al. (1922) noted that in every case where roots came in contact with a fertilized layer of soil they not only developed much more abundantly and branched more profusely, but such a layer apparently retarded normal penetration into the soil below.

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

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 very 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.

Very little work has been reported regarding the response of bromegrass seedlings to fertilization. Fuelleman et al. (1943) reported that seedings made on soil low in nitrogen have frequently failed in Illinois.

There has been considerable discussion and controversy regarding the cause of the so-called "sod-bound" condition in bromegrass. Benedict (1941) 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. His work indicated that "sod-binding" of bromegrass might at least in part result from an accumulation of growth inhibiting substance in the soil.

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

Soil nitrification after bromegrass was studied by Newton (1939) using growing crops as indicators of nitrification rates. Bromegrass was distinctly 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 aeration 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.

MATERIALS AND METHODS

Root Study in the Field

A series of fertilizer plots was established in the fall of 1944 on the farm of W. S. Morgan, at Zeandale, Kansas, eight miles east of Manhattan. The bromegrass was of Achenbach origin and was seeded in September, 1939. The soil was a highly fertile silty clay loam located in the Kansas River valley. The area was practically level and very uniform in appearance.

The first fertilizer application was made September 30, 1944, 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. Phosphorus was applied at the rate of 80 pounds of P_2O_5 per acre. Each rate of nitrogen appeared twice with phosphorus and twice without phosphorus. The replications were placed in two adjoining series with the plots in each arranged according to decreasing amounts of nitrogen (Fig. 1).

Pounds of nitrogen per acre

	200	140	0	100	60	0	20	200	0	140	100	0	60	20
No Phosphorus														
80 lbs. P_2O_5/A.														

Fig. 1. Diagram showing the arrangement of each series of bromegrass fertilizer plots at the W. S. Morgan farm.

The same arrangement was followed on all dates of application except for two applications made in the spring of 1946, in which no phosphorus was applied. In addition to the first series starting September 30, 1944 (M1), applications were made at the following dates: March 26, 1945 (M2), September 24, 1945 (M3), February 16, 1946 (M5), and April 24, 1946 (M7). Also, one replication of series M1 was refertilized at identical rates September 24, 1945, and one replication of series M2 was refertilized at identical rates February 16, 1946. The series number appearing after the dates above will be used in following discussions.

The nitrogen was applied in the form of ammonium nitrate (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.

Yields of forage and seed were obtained on these plots in the spring of 1945. They were grazed during the fall of

1945 and no yields were obtained. Those plots receiving heavy rates of nitrogen were grazed most heavily. The vegetation on these plots appeared to be more palatable, since the cows grazed on these areas in preference to unfertilized plots.

On January 5-8, 1946, root samples were obtained from the three series fertilized September 30, 1944 (M1), March 26, 1945 (M2), and September 24, 1945 (M3). 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 taken 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 areas, etc. were avoided.

On May 11, 1946, samples were taken from the series which had received two fall applications and from the one receiving two spring applications of fertilizer. The remainder of the series were sampled on June 20, 1946.

The soil was removed from the roots by washing with a fine spray of water over a wire screen having 15 meshes per inch. It was often necessary to soak the cores of soil thoroughly to facilitate washing, and it was generally necessary to knead the soil with the hands. Water was sprayed over the roots until no evidence of soil remained. Some very fine roots probably escaped through the screen, but losses were very 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. The roots sampled during the winter were ground and analyzed for nitrogen.

Roots were also sampled from field seedling fertility plots, to be described later, and also from greenhouse tests.

Yields of forage were obtained during May and June on the spring fertilized plots.

Response of Seedlings to Nitrogen and Phosphorus in the Greenhouse

In order to study the response of bromegrass seedlings to fertilizer treatment in the greenhouse, soil was obtained from five different sources and brought into the greenhouse in the fall of 1945.

Two lots of Labette gravely silt loam soil were obtained from the E. C. McMillen farm in Neosho County, 12 miles southeast of Chanute, Kansas, on October 30, 1945. One lot was taken from a "sod-bound" bromegrass field which had been seeded in 1937, and the second lot was taken from an adjacent cultivated field which had been in oats 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 November, 1945, 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 "sod-binding". The soil was obtained in the same manner as that taken in Neosho County.

The roots of the bromegrass sods were removed, run through a hammer mill 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.

Six fertilizer combinations with three replications of each were applied to each of the five soils, making a total of ninety pots. Nitrogen was applied at rates of 0, 50, and 100 pounds per acre. Superphosphate was applied at the rate of 80 pounds P_2O_5 per acre. Each nitrogen rate appeared with and without phosphorus. 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).

Bromegrass of the Achenbach strain was planted in these pots December 1, 1945. The plants were thinned to insure eight separate and uniformly spaced plants in each pot. The three replications were placed in three separate blocks on a greenhouse bench. Pots were randomized within replications, and the arrangement was changed every ten days.

The top growth was clipped February 2, 1946, and the roots were obtained from one replication. The second clipping was made March 6 and roots were taken from the second replication. Clippings were made on the third replication on April 24 and June 1, the roots being taken and the experiment terminated on this date.

The material in all cases was dried at 98° C. for 24 hours, weighed to the nearest one hundredth of a gram, and ground for nitrogen determination.

Response of Seedlings to
Nitrogen and Phosphorus in the Field

Plots were seeded and fertilized at the Agronomy Farm March 22 and March 26, 1946. Two fields were selected for the study. One had produced cereals for several seasons and had not been in sod for many years. The second had been part of the bromegrass breeding nursery until the sod had been broken the previous summer. It had then lain uncropped until the start of this study.

The rates of nitrogen used in the study were 0, 20, 60, and 100 pounds per acre. The P_2O_5 rates were 0, 40, 80, pounds per acre. The rates of nitrogen and phosphorus were applied in all combinations, making 12 different treatments. Three replications of each treatment were made in each field. Each of the three replications was kept in a block and the treatments were randomized within replications. Plots in the first field were one rod square and those in the second were 14 feet by one rod.

In the first field the area was harrowed and packed, the fertilizer applied by hand as a top dressing, then the seed broadcast over the entire area of the plot. The area was packed a second time to cover the seed.

The second field was harrowed, packed, the seed broadcast, then harrowed to cover the seed, and packed. The fertilizer was then applied by hand as a top dressing.

Both fields were mowed uniformly the last of May to control weeds. All plots in the second field were clipped for yields July 1, with a mower, cutting a strip three feet by 12 feet. Two such samples were taken from each plot. The weeds were separated from the bromegrass and weighed separately. Samples of each were taken for moisture determination and calculation of dry weight.

Density counts were made in plots of each field to determine the effect of the fertilizer on the density of the vegetation. A heavy wire, one-eighth inch in diameter and ten feet long, was equipped with loops on each end by means of which it could be stretched along the ground and held in place by pegs. Counts were made of the number of grass culms and weeds touching the wire at the ground level. Four such readings were made on each plot, or a total of twelve in each field for each treatment.

Two root samples were taken from each plot in the second field with the same implement and in the same manner as described earlier. This gave a total of six samples from each of the twelve treatments.

CLIMATOLOGICAL DATA

The fall of 1945 and the first six months of 1946 were the driest on record at this station in many years. Table 1 gives the daily precipitation at Manhattan for 1945 and January to July of 1946. Only 8.96 inches of rain fell during the period August 1 to December 31, 1945, compared to a normal of 11.77 inches (Cardwell and Flora, 1942). During the period January 1 to July 31, 1946, only 10.49 inches of rain fell compared to a normal of 19.10 inches.

The low rainfall was accompanied by a very early spring in which growth of crops started two or three weeks ahead of normal. This used up all available moisture early in the season, and the effects of the drouth were apparent early.

The effect of this drouthy condition on the plots receiving heavy applications of nitrogen was very marked. Rates of nitrogen of 100 pounds per acre or more had caused severe burning in some plots as early as May 1. At that date the plots receiving late spring applications were not so badly burned as those fertilized in the fall or very early spring.

On June 7 nearly all plots showed signs of drouth damage. On some of the plots receiving high rates of nitrogen the plants had turned brown and dry.

In addition to the effect of the drouth, the pasture in which these plots were located had been grazed by dairy cows

Table 1. Daily precipitation, Manhattan, Kansas, 1945, and January to July, 1946.

	1945												1946						
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
1	T	.08			.44		1.04					.14			T				
2			.18	T	.41												.02		.03
3		T		.46										T			.36		
4		.02		.05		.02	.57		.01				.42		.06		T		
5			.03				.43	.11		.05			.07		.95				
6	T		.05			.16	.03									.08	T		
7					.25	1.31									T		.13		.09
8	.05						1.12		.04		.06				.04	T			T
9	T					.22	.02	T			.07		.22			.07	.15		T
10					.16			1.10								.29	.85		T
11			1.18	1.13				.55			.01					.09	.07		
12				1.01				T	.28			.10			.01				
13				.37	.01		.04		.26			T					.08	.07	
14	T		.10	.36	.37			.38	.04								.11	T	
15			.28	2.28	.02										.11	.65	.43		
16	T			.75	.56	2.46									.43	.05			.67
17	.22	T		T	.71	.01	.19		.21						.07		.19		
18	.04			T		.09	.04	.02				.05		.26				.13	
19		T	.37			.15	1.93	.01		.46		.09	.11	.11			.11	1.62	
20	T		.04		.03	.56												.02	
21	.16	1.10		T						.19	.06								
22		.01							.49										
23				.11									.05		.40	.22			
24			.27	.18	.41	.08			.16	.10		.30			.02				
25	.25	T		.65	.48	.10			.05	.08		.36						.05	
26		.04				.02	1.58		.09			.01							
27	.03				.49	.78	.52												.18
28	T	.06		.07			.02		2.06										T
29	T					.02			.06							.01		.28	
30				.05	.13	1.95		.08	.74				T				.03		
31																			
Total	0.75	1.31	2.50	7.47	4.50	7.93	7.53	2.25	4.49	0.88	0.20	1.14	0.87	0.37	2.09	1.46	2.53	2.20	0.97
Normal	0.75	1.14	1.48	2.67	4.31	4.50	4.25	3.89	3.44	2.16	1.55	0.83							

until April 1. Plots receiving high rates of nitrogen were kept closely grazed. These heavily grazed plots were first to show signs of drouth damage.

On June 13, 1946, notes were taken as to the estimated percent of top growth killed. These results are shown in Table 2. Very little burning was noted in the M7 series, the plots appearing green and making dense growth. Only two plots on the end of this series showed drouth damage. These plots were slightly higher than the average of the series which probably permitted the rainfall to drain off these plots.

Table 2. Estimated percent of top growth killed by drouth following varying rates of nitrogenous fertilizer. Notes taken June 13.

	Pounds of nitrogen per acre					
	200	140	100	60	20	0
M3 Series	73	48	78	59	31	54
M5 Series	10	10	75	75	15	18

EXPERIMENTAL RESULTS

Root Study in the Field

Surface applications of readily available nitrogen to established stands of bromegrass have produced significant increases in root yields. The complete data are given in Table 3. Analysis of variance showed a highly significant difference between means of nitrogen rates, dates of nitrogen application, and interaction between rate and date of

Table 3. Yield (lbs. per A.) of oven dry root material following varying rates of application of nitrogen and phosphorus fertilizers on established stands of bromegrass.

Series	Lbs. P_2O_5	Pounds of nitrogen per acre 200	140	100	60	20	0	Av.
M1	0	5180	3590	5020	4350	3730	6850	
Sampled		5160	3880	4920	3710	3070	6010	
1-8-46		4560	3300	4920	4940	4060	4190	
Fertilized		3620	3850	5230	7720	4990	2610	
once		5830	3370	4940	4560	3730	5350	
Av.		4870	3600	5010	5060	3920	5000	4570
	80	3070	3570	4920	3680	3310	6610	
		4440	2990	6590	5180	5070	5470	
		5490	5330	5490	4850	5470	7230	
		3880	4250	3880	4540	4510	4280	
		3810	3680	6390	4920	3110	6770	
Av.		4140	3960	5450	4630	4290	6070	4760
Series Av.		4500	3780	5230	4850	4110	5540	4670
M2	0	4320	3400	5660	4870	4520	2760	
Sampled		3640	3900	6770	4090	5830	2680	
1-7-46		5940	5780	4280	5060	4350	4110	
		7220	5630	5730	7540	4060	3190	
		6350	5110	3280	5020	4780	4800	
Av.		5490	4760	5140	5320	4710	3510	4820
	80	3250	4090	2990	3620	3950	4820	
		4970	5110	6440	4560	3710	4140	
		3500	6090	5020	5830	4210	2990	
		5580	6990	5680	4540	3070	4380	
		3160	4850	4350	4320	4180	1850	
Av.		4090	5430	4900	4570	3820	3640	4410
Series Av.		4790	5100	5020	4950	4270	3570	4620
M3	0	4320	3870	3830	3400	4040	3850	
Sampled		3350	4380	2930	5160	3310	4110	
1-5-46		2430	3690	4640	3490	3810	5390	
		5140	5040	3610	5070	3260	2280	
		4180	2760	3420	3400	5400	2520	
Av.		3880	3950	3690	4100	3960	3630	3870

Table 3 (cont.)

Series	Lbs. P_2O_5	Pounds of nitrogen per acre 200	140	100	60	20	0	Av.
	80	4060	5510	4870	3880	4440	3500	
		3590	4300	4750	4800	4510	3450	
		3520	3540	4090	3500	3690	2570	
		3070	3230	4070	3280	3990	3190	
		4610	4630	4470	3970	3750	2690	
Av.		3770	4240	4450	3890	4080	3080	3920
Series Av.		3830	4100	4070	4000	4020	3360	3890
M1	0	5420	6870	5040	3710	4040	3830	
Sampled		5160	4250	5450	4230	4040	2950	
5-11-46		4970	6820	5830	3450	4040	3120	
Fertilized		6060	5890	6700	6300	4610	2900	
twice		4730	4070	5800	5400	4730	3710	
Av.		5270	5580	5760	4620	4290	3300	4800
	80	3000	5800	5800	5010	3310	2870	
		5060	5230	6020	2590	3540	2900	
		6160	4830	3690	4730	3730	2970	
		5890	4440	4190	3880	4710	4160	
		5260	5680	5920	5680	3260	4470	
Av.		5070	5200	5120	4380	3710	3470	4490
Series Av.		5170	5390	5440	4500	4000	3390	4650
M2	0	6210	5560	4300	5230	4070	2830	
Sampled		3680	6680	5320	4090	4500	4260	
5-11-46		4940	2920	4990	3810	4110	4780	
Fertilized		3680	5400	3880	3970	4450	2830	
twice		3870	4730	5400	6730	4950	5800	
Av.		4480	5060	4780	4770	4420	4100	4600
	80	3420	5010	5040	3850	4000	3800	
		4900	4920	4990	4300	3470	4440	
		4640	3310	5920	6320	4230	5210	
		4280	4850	3990	5470	5700	2810	
		3830	6350	5960	4850	3500	6270	
Av.		4210	4890	5180	4960	4180	4510	4650
Series Av.		4350	4970	4980	4860	4300	4300	4630

Table 3 (concl.)

Series	Lbs. P_2O_5	Pounds of nitrogen per acre 200	140	100	60	20	0	Av.
M3 Sampled 6-20-46	0	3440	3850	3950	2730	3380	4640	
		3760	5490	4260	4900	3970	3300	
		3610	2950	4630	3950	4870	3040	
		4210	3310	3210	4400	2640	4090	
		3540	2610	3210	4070	2380	3920	
Av.		3710	3640	3850	4010	3450	3800	3740
M5 Sampled 6-20-46	0	3970	3950	2920	4760	3570	3230	
		4070	5280	3260	4350	3620	2760	
		4610	2160	3710	4260	3760	2800	
		3140	4440	3590	4970	3210	3000	
		3020	3570	3810	3540	3310	2420	
Av.		3720	3880	3460	4380	3490	2840	3640
M7 Sampled 6-20-46	0	2000	3620	4180	3400	4000	3450	
		2570	2090	1850	5490	4190	3590	
		3350	3210	3640	3040	3500	2070	
		2930	1660	3300	3660	3760	5560	
		5070	3190	3180	3610	5890	3300	
Av.		3180	2750	3230	3840	4270	3590	3480
Grand Av.		4300	4380	4620	4500	4050	3880	

application, as shown in Table 4 below. This analysis includes those series from which samples were taken at each rate of nitrogen with and without phosphorus. It does not include those series fertilized September 24, 1945 (M3), February 16, 1946 (M5), or April 24, 1946 (M7) in which the phosphorus plots were not sampled in the spring of 1946.

For convenience in the following discussion, the complete group of plots fertilized at one date will be termed a series, and the series numbers given earlier will be used.

In the above analysis, considering the means of nitrogen rates with a least significant difference of 382, the 60-, 100-, 140-, and 200-pound nitrogen rates were significantly higher than the 20-pound rate which, in turn, was significantly higher than the check. The differences between the 60-, 100-, 140-, and 200-pound rates were not significant.

Considering the series means with a least significant difference of 348, the fall sampled series (M3) was significantly lower in yield of roots than the other four series. The differences between the top four series were not significant.

The fall sampled series (M3) was significantly lower than the other series within the nitrogen rates of 200, 100, and 60 pounds per acre. At the 140-pound rate this series, together with the fall sampled series (M1) (fertilized once), was significantly lower in yield of roots than the other three series. The effect of the 20-pound rate of nitrogen was the same in all series.

Table 4. Analysis of variance of the effect of nitrogen and phosphorus fertilizer on yield of roots of bromegrass in established stands.

Sources of variation	DF	SS	V
Total	299	3,588,363	
Between N levels	5	298,207	59,641**
Between P treatment	1	5,747	5,747
Interaction N x P	5	61,480	12,296
Between dates of application	4	268,052	67,013**
Interaction N x D	20	546,236	27,312**
Interaction P x D	4	40,464	10,116
Interaction N x P x D	20)		
Error	240)	2,368,177	9,198

** Indicates significance at one percent level.

The application of phosphorus did not affect the yield of roots. Analysis of 300 samples showed no significant differences in root yield as a result of applications of 80 pounds of P_2O_5 per acre.

Those series not included in the above analysis were analyzed with all plots receiving nitrogen alone. The results of this analysis were practically the same as those reported above. There was, however, no significant difference between the 20-pound nitrogen rate and the check. Series M3, M5, and M7 included in this analysis were significantly lower in yield of roots than the M1 or M2 series.

At the 140-pound rate the fall sampled M1 (fertilized once) and M3 were significantly lower than the spring sampled M1 (fertilized twice). Series M7 was lowest in all nitrogen rates except the 20-pound rate. It should be noted that in this series (M7), which was fertilized April 14 and sampled June 20, the 200-, 140-, and 100-pound rates of nitrogen produced smaller yields of roots than the check. Only the 140-pound rate was significantly lower, however. These plots made a very dense top growth and the roots were sampled when the tops had reached maximum development, 67 days after fertilization.

Considering all of the data, all rates of nitrogen gave increased yields of roots over checks. The greatest root development was produced at the 100-pound rate of nitrogen as is shown in Plate I, Figure 2. Application of nitrogen above 100 pounds per acre caused a smaller increase in root growth.

The number of days of growth between fertilization and sampling was determined for each series, and the correlation between this factor and the yield of roots was calculated. This correlation coefficient, +.896 with seven degrees of freedom, was highly significant (Snedecor, 1940). These data are given in Table 5.

The mean yield of roots in the spring was correlated with the mean forage yield for each rate of nitrogen on sereis M2, M5, and M7. Series M7 gave a correlation coefficient of -.827 which, with five degrees of freedom, is significant. Series M2 and M5 gave small positive correlations which did not approach significance. These results are given in Table 6.

There were numerous urine spots (Gainey, Sewell and Myers, 1937) throughout the area of the experiment which produced heavier top growth than was produced on plots receiving 200 pounds of nitrogen per acre. Ten root samples were taken from these spots in the spring of 1946. The average root production of these ten samples was 3960 (±903) pounds per acre. The average of all spring sampled 20-pound nitrogen rates was 3970 pounds per acre.

Applications of nitrogen increased the protein content of the fall sampled roots as shown in Table 7. Analysis of variance showed a highly significant difference between nitrogen treatments, between series, and for interaction of nitrogen and series. Twenty pounds of nitrogen produced a significantly lower percentage of protein than did the check.

Table 5. Relation of the number of growing days between fertilization and sampling, and the yield of roots of bromegrass (r = +.8957**).

Series	Number of growing days	Yield of roots (pounds per acre)
M1 (fertilized twice)	371	4650
M2 (fertilized twice)	301	4630
M1 (fertilized once)	300	4670
M2 (fertilized once)	230	4620
M3	161	3740
M5	110	3640
M7	56	3480
M3	51	3890

** Indicates significance at one percent level.

Table 6. Average yield of tops and corresponding yield of roots (Lbs. per A.) from established bromegrass stands with varying rates and dates of nitrogen application.

Lbs. N/A.	M2		M5		M7	
	Tops**	Roots	Tops**	Roots	Tops***	Roots
200	1982	4480	1998	3720	3449	3180
140	2120	5060	1588	3880	3140	2750
100	879	4780	1097	3460	2212	3230
60	494	4770	251	4380	1149	3840
20	320	4420	307	3490	613	4270
0	231	4100	191	2480	400	3590
	r = +.231		r = +.199		r = -.827*	

* Indicates significance at five percent level.
** Clipped May 16, 1946.
*** Clipped June 20, 1946.

EXPLANATION OF PLATE I

Fig. 2. The effect of applications of varying amounts of readily available nitrogenous fertilizer on root development in established stands of bromegrass. Each dot represents the average of 65 observations, including all dates of fertilization and sampling.

Fig. 3. The effect of applications of readily available nitrogenous fertilizer on root development of bromegrass seedlings in the field. Each dot represents the average of 18 observations. (Planted and fertilized March 26, sampled July 1).

PLATE I

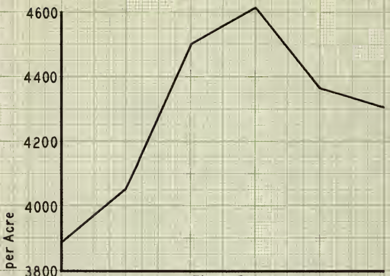

Figure 2

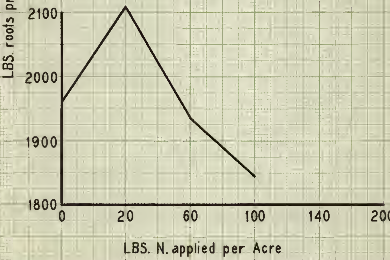

Figure 3

Table 7. Percent protein in roots from established bromegrass stand, sampled in January, following varying rates of nitrogen, with and without phosphorus.

Lbs. P_2O_5	Lbs. N/A.	M1*	M1**	M2	M3	Average
80	200	8.06	7.75	7.38	12.81	9.00
	140	6.81	8.81	7.31	10.81	8.44
	100	6.63	7.81	7.25	9.31	7.75
	60	6.31	7.06	6.94	7.81	7.03
	20	7.31	4.31	7.12	7.31	6.51
	0	7.81	6.50	7.00	7.69	7.25
Av.		7.16	7.04	7.17	9.29	7.66
0	200	7.88	8.38	7.38	10.88	8.63
	140	6.94	8.63	7.12	10.00	8.17
	100	6.75	7.25	7.50	9.56	7.77
	60	7.06	7.19	6.69	7.94	7.22
	20	6.44	7.18	6.50	7.38	6.88
	0	8.06	7.94	7.69	7.75	7.86
Av.		7.19	7.76	7.15	8.92	7.71

* Fertilized once.
** Fertilized twice.

Increasing the rate of nitrogen above 20 pounds gave consistent, small increases in protein percentage. Series M3 gave significantly higher percentages than any other series, giving greater response to the higher rates of nitrogen.

Five samples of roots were obtained from an unfertilized bromegrass field seeded in 1929 north of Abilene, Kansas. The yield of roots from these samples was 6068 pounds per acre (±701) in the top five inches of soil compared with 3660 pounds per acre for unfertilized plots at Zeandale, Kansas, seeded in 1939. Although it is realized that these two fields are not comparable, it appears that the large difference in quantity of root material was due to age of stand. These results are in agreement with Stevenson and White (1941) who observed that bromegrass continued to build up root materials year after year at a fairly rapid rate.

Response of Seedlings to Nitrogen and Phosphorus in the Greenhouse

Significant increases in yield of both tops and roots of bromegrass were obtained as a result of applications of phosphorus with the seed in the greenhouse. Nitrogen had little effect alone, but in combination with phosphorus it produced the highest yields (Plates II and III). Table 8 gives the yield of tops of the three replications clipped February 2, 1946.

Analysis of variance shows highly significant differences between means of soils and treatments and for interaction of soils and treatments. This analysis is shown in Table 9.

Table 8. Yield of top growth of bromegrass seedlings following applications of nitrogen and phosphorus on five soils in the greenhouse. Clipped February 2, 1946. Yields expressed as dry weight (grams) per pot.

Treatment		Source of soil* I	II	III	IV	V	Average
50 lbs. nitrogen		0.19	0.49	0.26	0.34	1.16	
		1.08	0.44	0.25	0.34	0.70	
		0.21	0.66	0.28	0.38	0.97	
	Av.	0.49	0.53	0.26	0.35	0.94	0.517
100 lbs. nitrogen		0.28	0.50	0.23	0.64	0.89	
		0.23	0.48	0.28	0.25	0.89	
		0.41	0.65	0.44	0.37	1.08	
	Av.	0.31	0.54	0.32	0.42	0.95	0.508
50 lbs. nitrogen + 80 lbs. P_2O_5		0.75	1.51	0.76	1.16	1.04	
		0.55	1.42	0.71	1.04	0.95	
		0.55	1.54	0.96	1.22	1.24	
	Av.	0.62	1.49	0.81	1.14	1.08	1.027
100 lbs. nitrogen + 80 lbs. P_2O_5		0.57	1.20	0.79	1.36	1.24	
		0.47	1.04	0.75	0.88	1.17	
		0.87	1.27	1.07	1.45	1.18	
	Av.	0.64	1.17	0.87	1.23	1.20	1.021
80 lbs. P_2O_5		0.34	1.25	0.30	0.71	0.70	
		0.55	1.17	0.31	0.56	0.76	
		0.39	1.13	0.44	0.77	0.85	
	Av.	0.43	1.18	0.35	0.68	0.77	0.682
Check		0.13	0.64	0.22	0.38	0.62	
		0.16	0.62	0.24	0.35	0.55	
		0.18	0.56	0.29	0.56	0.68	
	Av.	0.16	0.61	0.25	0.43	0.62	0.412
	Grand Av.	0.439	0.921	0.477	0.709	0.926	0.694

* 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 9. Analysis of variance of yield of top growth of bromegrass in greenhouse pots following nitrogen and phosphorus application on different soils. Clipped February 2, 1946.

Sources of variation	DF	SS	V
Total	89	12.506	
Between soils	4	3.914	0.9785**
Between treatments	5	5.446	1.0892**
Interaction S x T	20	1.716	0.8580**
Between blocks	2	0.201	0.1005*
Error	58	1.229	0.0212

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

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

The highest yields were produced by nitrogen and phosphorus in combination. There was no difference between the 100- and 50-pound nitrogen rates with phosphorus. Phosphorus alone was significantly higher than nitrogen alone. The difference between 50 pounds of nitrogen alone and the check was barely significant.

The "non-sod-bound" soil from the fence row gave the greatest response to nitrogen alone, and the cultivated soil from Neosho County gave the greatest response to phosphorus alone. The combination of nitrogen and phosphorus gave the greatest yield in the two cultivated soils and in the "non-sod-bound" soil from the fence row. The "sod-bound" soils gave the lowest yields in all treatments.

The yields of the second clipping of tops, made March 6, 1946, are given in Table 10. The response of the different soils was the same as at the first clipping. The treatments also gave results similar to the first clipping except that the 100-pound rate of nitrogen with phosphorus was significantly higher than the 50-pound rate with phosphorus.

The yields of the last two clippings of the third replication are shown in Table 11. The analysis of variance table is given in Table 12.

Table 10. Yield of top growth of bromegrass seedlings following applications of nitrogen and phosphorus on five soils in the greenhouse. Clipped March 6, 1946. Yields expressed as dry weight (grams) per pot.

Treatment		Source of soil*					
		I	II	III	IV	V	Average
50 lbs. nitrogen		0.65	0.78	0.38	0.49	1.30	
		.00	0.67	0.19	0.38	1.60	
	Av.	.33	0.73	0.29	0.44	1.45	0.64
100 lbs. nitrogen		.00	0.70	0.53	0.33	1.99	
		.00	0.61	0.68	0.29	1.41	
	Av.	.00	0.66	0.61	0.31	1.70	0.65
50 lbs. nitrogen + 80 lbs. P_2O_5		.15	2.23	1.58	1.77	2.09	
		.00	2.14	1.40	1.71	1.27	
	Av.	.08	2.19	1.49	1.74	1.68	1.43
100 lbs. nitrogen + 80 lbs. P_2O_5		.00	2.17	1.81	2.11	2.48	
		.32	2.08	1.69	2.04	1.91	
	Av.	.16	2.13	1.75	2.08	2.20	1.66
80 lbs. P_2O_5		.00	1.18	0.60	1.03	1.38	
		.00	1.17	0.69	0.80	1.21	
	Av.	.00	1.18	0.65	0.92	1.30	0.81
Check		.00	1.02	0.40	0.38	0.99	
		.00	0.74	0.35	0.70	1.07	
	Av.	.00	0.88	0.38	0.54	1.03	0.57
Grand	Av.	.09	1.29	0.86	1.00	1.56	0.96

* 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 11. Yield of top growth of bromegrass seedlings following applications of nitrogen and phosphorus on five soils in the greenhouse. Clipped April 24 (1) and June 1 (2), 1946. Yields expressed as dry weight (grams) per pot.

Treatment		Source of soil*					
		I	II	III	IV	V	Average
50 lbs. nitrogen	(1)	0.20	0.69	0.24	0.92	3.83	1.18
	(2)	0.60	1.21	0.25	1.01	1.92	1.00
	Av.	0.40	0.95	0.25	0.97	2.88	1.09
100 lbs. nitrogen	(1)	0.18	0.65	0.98	0.40	6.04	1.65
	(2)	0.30	1.35	1.56	0.81	3.11	1.43
	Av.	0.24	1.00	1.27	0.61	4.58	1.54
50 lbs. nitrogen + 80 lbs. P_2O_5	(1)	1.01	2.47	2.57	2.72	3.83	2.52
	(2)	1.93	1.60	1.28	1.50	2.29	1.72
	Av.	1.47	2.04	1.93	2.11	3.06	2.12
100 lbs. nitrogen + 80 lbs. P_2O_5	(1)	2.04	4.26	3.59	4.95	4.23	3.81
	(2)	1.58	2.86	1.94	3.00	3.57	2.59
	Av.	1.81	3.56	2.77	3.98	3.90	3.20
80 lbs. P_2O_5	(1)	0.41	1.56	1.18	1.00	2.71	1.37
	(2)	0.00	0.77	1.10	0.88	1.98	0.95
	Av.	0.21	1.17	1.14	0.94	2.35	1.16
Check	(1)	0.37	0.31	0.29	1.47	2.43	0.97
	(2)	0.42	0.46	0.22	0.91	1.57	0.72
	Av.	0.40	0.39	0.26	1.19	2.00	0.85
April 24	Av.	0.70	1.66	1.48	1.91	3.85	1.92
June 1	Av.	0.81	1.38	1.06	1.35	2.41	1.40

* 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 12. Analysis of variance of the yield of top growth of bromegrass seedlings from applications of nitrogen and phosphorus on five soils in the greenhouse. Clipped April 24 and June 1, 1946.

Sources of variation	DF	SS	V
Total	59	106.3120	
Between soils	4	37.7646	9.441 **
Between treatments	5	38.4779	7.696 **
Between dates	1	4.0301	4.030 **
Interaction S x T	20	13.8850	0.6943*
Interaction S x D	4	3.9024	0.976 *
Interaction T x D	5	2.1401	0.4280
Interaction S x T x D	20	6.1119	0.3056

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

One hundred pounds of nitrogen with phosphorus produced a significantly higher yield than 50 pounds of nitrogen with phosphorus, which, in turn, was higher than 100 pounds of nitrogen alone. One hundred pounds nitrogen alone was significantly higher than phosphorus alone. There was no significant difference between phosphorus alone, 50 pounds nitrogen alone, or the check.

The "non-sod-bound" sod from the fence row gave a yield significantly higher than any other soil. The "sod-bound" soil from Neosho County was significantly lower than any other in all treatments.

The April 24 clipping produced a higher yield than the June 1 clipping. This would be expected in view of the fact that the first mentioned clipping had a 49-day growing period compared with 37 days for the latter.

The three treatments: 50 pounds nitrogen alone, 100 pounds nitrogen alone, and phosphorus alone gave the greatest yields on the "non-sod-bound" soil. One hundred pounds nitrogen with phosphorus gave the greatest yields on the cultivated soil and "non-sod-bound" soil, followed by the local "sod-bound" soil, with the Neosho County "sod-bound" soil lowest with that treatment.

The yield of the "sod-bound" sod from Neosho County increased slightly at the last clipping. The plants were also more vigorous in appearance at that time, which might indicate that the depressing effect of the "sod-bound" condition was diminishing. At the first clipping of tops, February 2, many of the plants in the "sod-bound" sod from Neosho County were in such a weakened condition that they did not survive. This fewer number of plants, then, would not give a true relation between the soils in later clippings.

The number of culms per pot were 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 nitrogen alone and the check.

Between soil means 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 number of culms produced by the different soils and treatments followed the same order at the March 6 clipping with the exception of the "sod-bound" soil from Neosho County, which was considerably lower than any other because of the number of plants which failed to survive the first clipping. An average of five and one-fifth of the original eight plants in this soil had not recovered following the first clipping.

The percent protein of the tops at the first two clippings is shown in Table 13. The highest protein percentage was produced by treatments of nitrogen alone. Phosphorus alone produced a significantly lower percent of protein than any other treatment. Differences between the check and combinations of nitrogen and phosphorus were not significant.

Table 13. Percent protein in bromegrass tops clipped February 2 and March 6 in the greenhouse following applications of nitrogen and phosphorus on different soils.

Treatment	"Sod-bound" soil, Neosho Co.		Cultivated soil, Neosho Co.		"Sod-bound" soil, local		Cultivated soil, local		"Non-sod-bound" soil, local		Average		Av.
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	
50 lbs. N	25.1	31.4	26.2	28.3	24.8	25.5	26.4	28.6	26.3	26.2	25.8	28.0	26.9
100 lbs. N	21.9	30.3*	28.0	29.8	26.0	29.5	28.6	29.8	28.1	26.2	26.5	29.1	27.8
50 lbs. N + 80 lbs. P_2O_5	22.5	29.2	25.0	24.5	23.6	25.5	23.6	25.3	26.1	25.3	24.2	26.0	25.1
100 lbs. N + 80 lbs. P_2O_5	21.8	25.0	25.9	26.9	25.9	26.7	24.3	27.9	26.3	23.0	24.8	25.9	25.4
80 lbs. P_2O_5	19.6	23.3*	19.1	23.1	21.4	23.1	19.3	20.0	21.9	22.4	20.3	22.4	21.3
Check	16.7	27.3*	23.7	27.4	24.8	27.4	25.0	27.6	21.6	26.2	22.4	27.2	24.8
Average	21.3	27.8	24.7	26.7	24.4	26.3	24.5	26.5	25.1	24.9	24.0	26.4	25.2
Average	24.5		25.7		25.4		25.5		25.0		25.2		

* Calculated value (Paterson, p. 181, 1939).

Among the means of soils the protein percent of the tops on the cultivated soil from Neosho County was significantly higher than on the adjacent "sod-bound" soil. Other differences were not significant. The clipping made March 6 was significantly higher in protein percentage than the earlier clipping made February 2.

The total production of protein per pot is shown in Table 14. The analysis of variance table is shown in Table 15. The greatest amount of protein was produced by the combination of nitrogen and phosphorus. Fifty pounds of nitrogen alone was barely significant over the check. Among the soils the highest yield of protein was made by the "non-sod-bound" soil and the Neosho County cultivated soil. The latter was significantly higher than the local cultivated soil, which, in turn, was higher than the Neosho County "sod-bound" soil.

The average yield of protein at the second clipping was significantly higher than the first clipping. It should be noted that both the yield and percentage of protein was higher at the March 6 clipping.

Considering the check pots, the "sod-bound" soils produced significantly lower yields of protein than the others. Nitrogen alone increased the protein production of the "non-sod-bound" soil significantly greater than any other. Nitrogen plus phosphorus increased the production of all soils in about the same proportion.

Nitrate determinations were made on all soils on December 2, May 4, and June 7. Samples were taken from check pots

Table 14. Yield of protein (grams per pot) of bromegrass tops following applications of nitrogen and phosphorus on different soils in the greenhouse. (Data from two clippings made February 2 and March 6 as in Table 13).

Treatment	"Sod-bound" soil, Neosho Co.		Cultivated soil, Neosho Co.		"Sod-bound" soil, local		Cultivated soil, local		"Non-sod-bound" soil, local		Average		Av.
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	
50 lbs. N	.12	.20	.14	.21	.06	.07	.09	.13	.25	.38	.13	.20	.17
100 lbs. N	.07	--	.15	.20	.08	.18	.12	.09	.27	.46	.14	.19	.16
50 lbs. N + 80 lbs. P_2O_5	.14	.04	.37	.54	.19	.38	.27	.44	.28	.43	.25	.37	.31
100 lbs. N + 80 lbs. P_2O_5	.14	.08	.30	.57	.23	.47	.30	.58	.32	.51	.26	.44	.35
80 lbs. P_2O_5	.08	--	.23	.27	.07	.15	.13	.18	.17	.29	.14	.18	.16
Check	.03	--	.14	.24	.06	.10	.11	.15	.13	.27	.09	.15	.12
Average	.10	.05	.22	.34	.12	.23	.17	.26	.23	.39	.17	.25	.21
Average	.08		.28		.17		.22		.31		.21		

Table 15. Analysis of variance of yield of protein of bromegrass tops following applications of nitrogen and phosphorus on five soils in the greenhouse (two clippings).

Sources of variation	DF	SS	V
Total	59	1.3063	
Between soils	4	0.4252	.1063 **
Between treatments	5	0.4391	.0878 **
Between clippings	1	0.1101	.1101 **
Interaction S x T	20	0.1799	.0090 **
Interaction S x C	4	0.0685	.0171 **
Interaction T x C	5	0.0377	.0075 *
Interaction S x T x C	20	0.0458	.00229

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

which had been watered the same as the other pots but in which nothing was planted. The determinations are given in Table 16. Determinations were made in duplicate.

Table 16. Parts per million of nitrates in untreated soil in the greenhouse.

Source of soil	Dec. 2	May 4	June 7
"Sod-bound" bromegrass soil, Neosho County	51	209	245
Cultivated soil, Neosho County	49	164	80
"Sod-bound" bromegrass soil, local	41	77	101
Cultivated soil, local	40	63	54
"Non-sod-bound" bromegrass soil, local	78	119	152

The weight of roots produced per pot at each of the three dates of sampling is given in Table 17. The root growth at the first clipping is shown in Plates IV, V, and VI. One hundred pounds of nitrogen with phosphorus produced the greatest yield of roots at the last sampling date, June 3. Next in order was 50 pounds nitrogen with phosphorus, followed by phosphorus alone. The latter was significantly higher than 50 pounds nitrogen alone and checks.

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

Table 17. Yield of roots of bromegrass seedlings at three different dates following applications of nitrogen and phosphorus to pots in the greenhouse. Samples taken February 2 (1), March 6 (2), and June 3 (3), 1946. Yields expressed as dry weight (grams) per pot.

Treatment		Source of soil* I	II	III	IV	V	Average
50 lbs. nitrogen	(1)	0.13	1.07	0.89	0.41	1.99	0.90
	(2)	1.22	0.74	0.69	0.54	1.19	0.88
	(3)	0.57	1.70	0.60	1.53	4.98	1.88
100 lbs. nitrogen	(1)	0.16	0.81	0.64	1.19	1.07	0.73
	(2)	0.17	0.62	0.58	0.35	1.84	0.71
	(3)	0.52	1.69	2.37	1.07	6.81	2.49
50 lbs. nitrogen + 80 lbs. P_2O_5	(1)	0.73	2.15	1.69	1.64	1.91	1.62
	(2)	0.44	2.36	1.96	2.56	1.95	1.85
	(3)	2.21	7.54	4.41	5.33	6.71	5.24
100 lbs. nitrogen + 80 lbs. P_2O_5	(1)	0.74	1.76	1.69	1.49	1.58	1.45
	(2)	0.20	2.64	2.95	2.15	1.97	1.98
	(3)	2.24	10.01	4.95	10.25	9.38	7.37
80 lbs. P_2O_5	(1)	0.41	2.13	1.36	1.29	1.34	1.31
	(2)	0.23	2.09	1.68	1.26	2.34	1.52
	(3)	0.10	3.02	3.66	2.97	5.29	3.01
Check	(1)	0.07	1.01	0.74	0.80	1.34	0.79
	(2)	0.02	0.90	0.74	0.37	1.75	0.76
	(3)	0.51	0.56	0.53	3.03	3.15	1.56
Feb. 2 Average		0.37	1.49	1.17	1.14	1.54	1.14
Mar. 6 Average		0.38	1.56	1.43	1.21	1.84	1.28
June 3 Average		1.03	4.09	2.75	4.03	6.05	3.59

* 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.

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

Nitrogen alone stimulated root development in the "non-sod-bound" soil significantly more than in any other soil. The combinations of nitrogen and phosphorus and phosphorus alone produced about the same increases in root yield in all soils.

Response of Seedlings to
Nitrogen and Phosphorus in the Field

Field plots were established in March, 1946, to determine the response of seedlings under field conditions. The yields of grasses and weeds from these plots are given in Tables 18 and 19. Analysis of variance showed a significant difference between means of phosphorus rates only. The 40-pound rate of P_2O_5 produced a significantly lower yield than did the 80-pound rate or check. The 60-pound rate of nitrogen produced the greatest yield among nitrogen rates but it was not significantly greater.

Analysis of variance of the yield of weeds showed a highly significant difference between the means of the nitrogen rates. With a least significant difference of 93.5, the 100-pound and 60-pound rates of nitrogen produced significantly greater yields of weeds than did the 20-pound rate or check.

Analysis of covariance of grass and weeds showed a

Table 18. Yield of top growth of bromegrass seedlings following applications of nitrogen and phosphorus fertilizers in the field. Yields expressed as dry weight (lbs.) per acre.

Pounds nitrogen per acre		Pounds P_2O_5 per acre 0	40	80	Average
0		794	312	587	
		793	324	750	
		548	323	414	
		464	317	564	
		775	785	820	
		519	1107	867	
	Average	649	528	667	615
20		1054	342	741	
		809	666	529	
		674	386	751	
		766	318	535	
		435	902	514	
		678	762	435	
	Average	736	563	584	628
60		656	440	598	
		512	543	1055	
		658	464	923	
		384	408	1270	
		857	1172	985	
		1127	822	988	
	Average	699	642	970	770
100		1132	464	599	
		1234	590	606	
		390	411	751	
		657	561	836	
		265	413	897	
		573	746	914	
	Average	709	531	767	669
	Grand Average	698	566	747	

Table 19. Yield of weeds (lbs. per A.) from plots of bromegrass seedlings fertilized with nitrogen and phosphorus (see Table 18).

Pounds nitrogen per acre		Pounds P2O5 per acre 0	40	80	Average
0		199	103	207	
		112	76	162	
		215	206	393	
		235	114	237	
		284	335	431	
		125	310	397	
	Average	195	191	305	230
20		280	99	178	
		310	181	157	
		109	186	168	
		263	193	276	
		146	280	271	
		147	288	710	
	Average	209	205	293	236
60		339	357	318	
		709	387	373	
		230	175	149	
		644	478	122	
		236	662	302	
		181	511	613	
	Average	390	428	313	377
100		217	109	338	
		246	190	387	
		327	142	417	
		755	246	202	
		422	432	386	
		528	402	309	
	Average	416	254	340	336
Grand Average		302	269	313	295

significant positive correlation coefficient (r = .9198 with three degrees of freedom) for the means of nitrogen rates, and a highly significant positive correlation coefficient (r = .9993 with two degrees of freedom) for the means of the phosphorus rates. The correlation coefficient for error (r = -.138 with 58 degrees of freedom) was not significant. This negative correlation for error would indicate, however, that within treatments an increased growth of bromegrass would result in decreased growth of weeds, but applications of nitrogen or phosphorus fertilizers will increase both weeds and grass proportionately.

The yields of roots from the same plots as above are given in Table 20. Analysis of these data showed no significance between the means of either nitrogen or phosphorus. The highest yield among the nitrogen means was in the 20-pound rate and the lowest in the 100-pound rate (Plate I, Figure 3). Among the phosphorus means the highest yield was in the 80-pound rate and lowest in the 40-pound rates.

Analysis of covariance of tops (grass) and roots revealed a highly significant positive correlation coefficient (r = .996 with two degrees of freedom) for the means of phosphorus rates. The correlation coefficient of the nitrogen means was negative (-.396) but not significant.

It is interesting to note that those nitrogen rates which gave the largest yield of tops gave the smallest root yield, and vice versa, as shown in Table 21.

Table 20. Yield of roots, dry weight (lbs.) per acre, of bromegrass seedlings following applications of nitrogen and phosphorus in the field (six replications).

Pounds nitrogen per acre		Pounds P_2O_5 per acre			
		0	40	80	Average
0		1860	1330	2540	
		1670	1740	1660	
		1860	1690	2090	
		1420	1480	2160	
		3020	1860	2230	
		1860	2140	2710	
	Average	1948	1707	2232	1962
20		2090	1480	2140	
		2610	2830	2110	
		2050	1450	2240	
		2090	1930	2550	
		1760	2690	1830	
		2040	1880	2190	
	Average	2107	2043	2177	2109
60		2240	2380	3090	
		2000	1290	2350	
		1830	1230	2210	
		1900	1780	1610	
		2170	2400	1450	
		1590	1240	1990	
	Average	1955	1720	2117	1931
100		2870	1520	1520	
		2810	2190	2400	
		2110	2110	1860	
		1160	1240	2520	
		1850	1640	1360	
		980	1330	1710	
	Average	1963	1672	1895	1843
Grand Average		1993	1785	2105	1961

Table 21. Production of roots and tops (lbs. per A.) of bromegrass seedlings under varying rates of nitrogen (means of 18 samples).

Pounds nitrogen per acre	Root yield	Top yield
0	1962	615
20	2109	628
60	1931	770
100	1843	669

No significant differences in density of stand were obtained on the above plots. Slight increases in density of grasses with increased amounts of nitrogen were observed but they were not large enough to be significant. Among the phosphorus levels the 40-pound rate produced the lowest density.

Yields were not obtained on the series of plots planted March 22, 1946, on the cultivated area because of the poor stand obtained and the large proportion of weeds. Density counts on this area did not provide significant increases in the density of the bromegrass as a result of nitrogen or phosphorus applications. Analysis of the data showed, however, a highly significant difference in density of weeds, the greatest number of weeds being produced by low rates of nitrogen. The 60-pound rate of nitrogen was significantly lower than the check, and the 100-pound rate was significantly lower than either the 20-pound rate or check.

DISCUSSION

Response of Roots of Bromegrass to Nitrogen and Phosphorus

Observations were made on the effect of nitrogen and phosphorus fertilizers on root development in bromegrass. The response was noted under greenhouse conditions with seedlings and in the field with established stands and with seedlings.

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. The field tests with seedlings gave no significant differences in root yields with phosphorus applications.

However, significant increases were shown in yield of both tops and roots resulting from phosphorus applications to bromegrass seedlings in the greenhouse. There was little difference between the "sod-bound" and cultivated soils in response to phosphorus. The greatest yield of roots was produced by a combination of nitrogen and phosphorus. All soils responded equally well to this treatment.

The application of nitrogenous fertilizers to established stands of bromegrass has generally resulted in significant increases in yield of roots. The only exception was the series fertilized April 24, 1946, in which nitrogen rates of 200, 140, and 100 pounds per acre brought about a decrease in root growth. Willard (1932) found that heavy applications of nitrogen brought about a temporary reduction in the amount of roots of bluegrass, but toward the end of the season there was no difference between the treated and untreated plots. In the present study, however, the ultimate effect was an increase in quantity of root material. Considering all of the data, 100 pounds of nitrogen per acre produced the greatest amount of roots, followed closely by 60 pounds per acre. Increasing or decreasing the rate of nitrogen from these amounts resulted in smaller increases in yield of roots. All rates of nitrogen ultimately produced more root growth than the checks.

The April 24 series mentioned above gave a greater forage yield than any other series. There was a significant negative correlation between root production and top growth. Graber (1931) noted that heavy nitrogenous fertilization of bluegrass made possible the stimulation of top growth at the expense of root growth. He also noted that this stimulation may accelerate the accumulation of the reserve carbohydrates when the plant is given an opportunity for such storage. Sprague (1932) also noted that liberal supplies of nitrogen stimulated top growth at the expense of the carbohydrate reserves and the development of the root system. In the April 24 series the 200-, 140-, and 100-pound nitrogen rates definitely stimulated top growth at the expense of root growth. However, as the other series in this study show, and as was suggested by Graber above, this first depressing effect was followed by increased root growth after a sufficient time had elapsed and the plants were given an opportunity for storage.

With the limited rainfall received during the spring of this study (1946) the bromegrass did not give so great a vegetative response as would be expected in a period of normal rainfall. However, with the previously mentioned exception in series M7, the root yields increased with applications of nitrogen. It seems probable that in those series which made very little top growth the root system was increased without the preliminary depressing effect.

The correlation of yield of roots at various nitrogen levels with the number of growing days between fertilization and sampling was positive and highly significant. However, there seemed to be a certain length of time after which no further increases occurred. It was not determined in this study how long the effects of one application would be apparent in the root system. In the fall sampled series which had been fertilized September 30, 1944, the differences were not consistent, which might suggest about one year as the limit of measurable differences.

Response of Seedlings

Greenhouse tests showed significant responses of bromegrass seedlings to phosphorus, but only limited response to nitrogen alone. The greatest response was obtained from a combination of nitrogen and phosphorus. The first clipping of tops showed no difference between 50- and 100-pound rates of nitrogen. At the last two clippings there were slight differences in favor of the 100-pound rates.

Field tests showed significant differences between phosphorus means but no significant increases as a result of nitrogen. The 80-pound P_2O_5 rate and check were significantly higher in yield of tops and roots than the 40-pound rate. No explanation can be offered for this response of 40 pounds of P_2O_5.

In the greenhouse the two "sod-bound" soils produced a significantly lower yield than the other three soils. These "sod-bound" soils gave only limited response to either nitrogen or phosphorus alone, these treatments at the first clipping producing a lower yield than the corresponding cultivated soil checks. Combinations of nitrogen and phosphorus increased the yields above that level. Within the same treatment, however, the yield of the "sod-bound" soils was always lower.

These results show that the immediate productive capacity of the "sod-bound" soils is definitely lower than the corresponding cultivated soils. Although the yields of the "sod-bound" soils were increased by applications of nitrogen and phosphorus in combination, the yields of the cultivated soils were increased even greater by that treatment. This suggests that there are other nutritional deficiencies besides nitrogen and phosphorus connected with this "sod-bound" condition.

Considering the last two clippings of tops in the greenhouse, both 100 pounds of nitrogen alone and phosphorus alone increased the yield of the local "sod-bound" soil to the level of the untreated cultivated soil. Phosphorus alone caused a slight increase over the corresponding cultivated soil. The ratio of the average yield of the local "sod-bound" to cultivated soil at the last clipping was 0.78 compared to 0.58 at the first clipping. This suggests that further tests should be made to determine the persistancy of this suppressing effect of the "sod-bound" condition. The effects of this condition were becoming less apparent at the close of this experiment.

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

The results of the protein percentage analysis followed the same trends as have been noted under field conditions. The highest protein percentage was produced by nitrogen alone. Phosphorus alone produced the lowest percentage. Tyson (1939) noted that applications of phosphate had a slight tendency to decrease the percent of nitrogen in the grass.

The total production of protein followed closely the total yield of tops, except that phosphorus produced no greater amount of protein than nitrogen alone.

Nitrate determinations on the bromegrass sods showed increased nitrification until the close of the experiment. The cultivated soils had begun to decrease at that time. The high rate of nitrification of the Neosho County "sod-bound" soil should be noted. Newton (1939), using growing crops as indicators of soil nitrification rates, found that bromegrass was distinctly poorer than other grasses studied in its aftereffects on wheat.

These higher rates of nitrification on the "sod-bound" soils suggests that under conditions of this experiment the amount of nitrates present in the soil was not a limiting factor in the production of bromegrass seedlings on the "sod-bound" soils.

Bromegrass seedlings in the field responded to nitrogen in a similar manner as established stands. With the seedlings 20 pounds of nitrogen produced the greatest root development with larger amounts of nitrogen causing smaller root yields. (Figure 3). The 60- and 100-pound rates of nitrogen gave lower root yields than the check, although not significantly lower. These results are in close agreement with the April 24 series on established stands of bromegrass described earlier.

In the field tests, no significant differences in density of stand of bromegrass were obtained as a result of applications of nitrogen or phosphorus. On one series of plots a highly significant difference was obtained in density of weeds between nitrogen rates. The greatest number of weeds was produced by low rates of nitrogen and the lowest density by high rates of nitrogen.

SUMMARY

1. The effect of varying rates of nitrogen and phosphorus fertilizers on the root development and on seedling growth in bromegrass (Bromus inermis Leyss) is reported. Rates of nitrogen used in the field were 200, 140, 100, 60, 20, and 0 pounds

elemental nitrogen per acre. Root yields are expressed as pounds of oven dry root material in the top five inches of soil.

2. The immediate effect of applications of readily available nitrogenous fertilizer at the rate of 100 pounds nitrogen or more per acre to established stands of bromegrass has been a reduction in the amount of roots below the level of unfertilized plots.

3. The end result of application of nitrogen has been an increase in the amount of roots by all rates of nitrogen.

4. The maximum yield of roots was produced by 100 pounds of nitrogen, followed closely by 60 pounds. Rates of nitrogen above or below these rates produced smaller increases in yield.

5. Application of phosphorus had no effect on root development in the field.

6. Bromegrass seedlings have made significant responses to applications of phosphorus and greater response to combinations of nitrogen and phosphorus in the greenhouse. Field plantings made in March, 1946, did not give comparable results.

7. Soil from "sod-bound" bromegrass fields gave significantly lower yields of roots and tops of bromegrass seedlings than cultivated soil or "non-sod-bound" bromegrass sod. This depressing effect of "sod-bound" bromegrass sod persisted throughout this experiment.

8. Increased yields resulting from fertilization of greenhouse seedlings were accompanied by significant increases

in number of culms.

9. Application of nitrogen alone produced a significant increase in percentage of protein in bromegrass seedlings (tops) in the greenhouse. Application of phosphorus alone produced a significantly lower percentage of protein than any other treatment.

10. The total production of protein followed essentially the same order as the total yield of tops, except that phosphorus alone produced no more protein than did nitrogen alone.

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EXPLANATION OF PLATE II

Fig. 4. The effect of application of 80 pounds of P_2O_5 per acre on the growth of bromegrass seedlings on five 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. 5. The effect of application of 50 pounds of nitrogen plus 80 pounds of P_2O_5 per acre on the growth of bromegrass seedlings in the greenhouse. (Order of soils the same as in Figure 4).

PLATE II

Figure 4

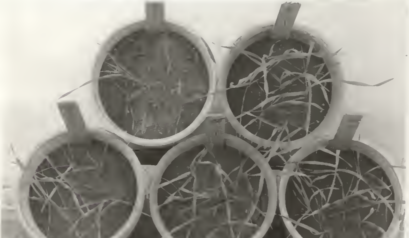

Figure 5

EXPLANATION OF PLATE III

Fig. 6. 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. 7. The effect of application of 50 pounds of nitrogen per acre on the growth of bromegrass seedlings on five soils in the greenhouse. (Order of soils the same as in Figure 6).

PLATE III

Figure 6

Figure 7

EXPLANATION OF PLATE IV

Fig. 8. The effect of nitrogen and phosphorus fertilizers on root development of bromegrass seedlings in the greenhouse on Neosho County cultivated soil. Each mass of roots produced by eight plants. Left to right: check, 50 pounds of nitrogen per acre, 80 pounds of P_2O_5 per acre, and 50 pounds of nitrogen plus 80 pounds of P_2O_5 per acre.

Fig. 9. The effect of nitrogen and phosphorus fertilizers on root development of bromegrass seedlings in the greenhouse on soil from a "sod-bound" bromegrass field in Neosho County. (Order of treatments the same as in Figure 8).

PLATE IV

Figure 8

Figure 9

EXPLANATION OF PLATE V

Fig. 10. The effect of nitrogen and phosphorus fertilizers on root development of bromegrass seedlings in the greenhouse on local cultivated soil. Each mass of roots produced by eight plants. Left to right: check, 50 pounds of nitrogen per acre, 80 pounds of P_2O_5 per acre, and 50 pounds of nitrogen plus 80 pounds of P_2O_5 per acre.

Fig. 11. The effect of nitrogen and phosphorus fertilizers on root development of bromegrass seedlings in the greenhouse on soil from a local "sod-bound" bromegrass field. (Order of treatments the same as in Figure 11).

PLATE V

Figure 10

Figure 11

EXPLANATION OF PLATE VI

The effect of nitrogen and phosphorus fertilizers on root development of bromegrass seedlings in the greenhouse on soil from local "non-sod-bound" bromegrass sod. Each mass of roots produced by eight plants. Left to right: check, 50 pounds of nitrogen per acre, 80 pounds of P_2O_5 per acre, and 50 pounds of nitrogen plus 80 pounds of P_2O_5 per acre.

PLATE VI

LITERATURE CITED

Ahlgren, H. L., I. W. Rupel, G. Bohstedt and E. S. Graul. Eight years results on the effectiveness of fertilization and management in increasing the production of permanent pastures. Amer. Soc. Agron. Jour. 36: 301-315. 1944.

Benedict, H. M. The inhibiting effect of dead roots on the growth of bromegrass. Amer. Soc. Agron. Jour. 33: 1108-9. 1941.

Biswell, H. H. and J. E. Weaver. Effect of frequent clipping on the development of roots and tops of grasses in prairie sod. Ecology 14: 368-390. 1933.

Cardwell, A. B. and S. D. Flora Kansas weather and climate. Kans. Agr. Expt. Sta. Bul. 302. 1942.

Churchill, B. R. Smooth bromegrass seed production in Michigan. Mich. Agr. Expt. Sta. Cir. Bul. 192. 1944.

Cook, C. W. A study of the roots of Bromus inermis in relation to drouth resistance. Ecology 24: 169-82. 1943.

Dodd, D. R. The place of nitrogen fertilizers in a pasture fertilization program. Amer. Soc. Agron. Jour. 27: 853-62. 1935.

Eheart, J. F. and W. B. Ellett. The effect of certain nitrogenous fertilizers on the chemical and vegetative composition and yield of pasture plants. Va. Agr. Expt. Sta. Tech. Bul. 75. 1941.

Enlow, C. R. and J. M. Coleman. Increasing the protein content of pasture grasses by frequent light applications of nitrogen. Amer. Soc. Agron. Jour. 21: 845-53. 1929.

Frolick, A. L. and L. C. Newell. Bromegrass production in Nebraska. Nebr. Agr. Expt. Sta. Cir. 68. 1941.

Fuelleman, R. F. and W. L. Burlison. Pasture studies of bromegrass. Amer. Soc. Agron. Jour. 33: 883-92. 1941.

Fuelleman, R. F., W. L. Burlison and W. G. Kammlade.
Bromegrass and bromegrass mixtures. Ill. Agr. Expt. Sta. Bul. 496. 1943.

Gainey, P. L., M. C. Sewell and H. E. Myers.
Nitrogen--the major cause in the production of spotted wheat fields. Kans. Agr. Expt. Sta. Tech. Bul. 43. 1937.

Gardner, H. W.
The response of permanent grassland to nitrogen and the efficiency of its recovery. Jour. Agr. Sci. 29: 364-78. 1939.

Graber, L. F.
Food reserves in relation to other factors limiting the growth of grasses. Plant Physiol. 6: 43-71. 1931.

Harrison, C. M.
Effect of cutting and fertilizer applications on grass development. Plant Physiol. 6: 669-84. 1931.

______________ and W. N. Crawford.
Seed production of smooth bromegrass as influenced by applications of nitrogen. Amer. Soc. Agron. Jour. 33: 643-51. 1941.

Haynes, J. L.
Effects of pasture practices on root distribution. Amer. Soc. Agron. Jour. 35: 10-18. 1943.

Laird, A. S.
A study of the root systems of some important sod forming grasses. Fla. Agr. Expt. Sta. Bul. 211. 1930.

McClure, G. M.
Nitrogen on pasture grasses at Columbus. Ohio Agr. Expt. Sta. Ann. Rep. 1929: 47-8.

Myers, H. E. and K. L. Anderson.
Bromegrass toxicity vs nitrogen starvation. Amer. Soc. Agron. Jour. 34: 770-73. 1942.

Nedrow, W. W.
Studies on the ecology of roots. Ecology 18: 27-52. 1937.

Newell, L. C. and F. D. Keim.
Field performance of bromegrass strains from different regional seed sources. Amer. Soc. Agron. Jour. 35: 420-34. 1943.

Newton, R. and R. S. Young.
Nitrification under and after alfalfa, brome, timothy, and western rye grass. Canad. Jour. Res. 17: sec. c 212-231. 1939.

Paterson, D. D.
Statistical technique in agricultural research. New York. McGraw-Hill. 263 p. 1939.

Pavlychenko, Thomas.
Root systems of certain forage crops in relation to the management of agricultural soils. Nat. Res. Council of Canada and Dom. Dept. Agr. N. R. C. 1088. 1942.

Robinson, R. R. and W. H. Pierre.
The effect of nitrogen fertilization of permanent pastures on seasonal distribution of yields and on nitrogen recovery in the herbage. Amer. Soc. Agron. Jour. 34: 747-63. 1942.

Snedecor, G. W.
Statistical methods, Ames, Iowa. Iowa St. Col. Press. 422 p. 1940.

Sprague, H. B.
Root development of perennial grasses and its relation to soil conditions. Soil Sci. 36: 189-209. 1932.

Stevenson, T. M. and W. J. White.
Root fiber production of some perennial grasses. Sci. Agr. 22: 108-18. 1941.

Stoddard, L. A.
How long do roots of grass live? Science 81: 544. 1935.

Stuckey, Irene H.
Seasonal growth of grass roots. Amer. Jour. Bot. 28: 486-91. 1941.

Ten Eyck, A. M.
The roots of plants. Kans. Agr. Expt. Sta. Bul. 127. 1904.

Turner, T. W.
Studies of the mechanism of the physiological effects of certain mineral salts in altering the ratio of top growth to root growth in seed plants. Amer. Jour. Bot. 9: 415-46. 1922.

______________.
The effect of varying the nitrogen supply on the ratio between the tops and roots in flax. Soil Sci. 21: 303-6. 1926.

Tyson, James.
Use of fertilizer and lime on native pastures in Michigan. Mich. Agr. Expt. Sta. Tech. Bul. 167. 1939.

Weaver, J. E.
Carnegie Inst. Wash. Pub. 292: 132-3. 1920.

__________, F. C. Jean and J. W. Crist.
Development and activity of roots of crop plants. Carnegie Inst. Wash. Pub. 316. 1922.

__________ and G. W. Harmon.
Quantity of living plant material in prairie soil in relation to runoff and soil erosion. Nebr. Univ. Consv. Bul. 8. 1935.

__________ and Ellen Zink.
Annual increase of underground materials in three range grasses. Ecology 27: 115-27. 1946.

Whitman, Warren et al.
Grass. N. Dak. Agr. Expt. Sta. Bul. 300. 1941.

Willard, C. J. and G. M. McClure.
The quantitative development of tops and roots in bluegrass with an improved method of obtaining root yield. Amer. Soc. Agron. Jour. 24: 509-14. 1932.