TEXAS AGRICULTURAL EXPERIMENT STATION

C. H. McDOWELL, Acting Director
College Station, Texas

BULLETIN NO. 672 JULY, 1945

THE VALUE OF DIFFERENT PHOSPHATES FOR VARIOUS TEXAS SOILS AND GRASSES, AS INDICATED BY POT EXPERIMENTS

J. F. FUDGE AND G. S. FRAPS

Division of Chemistry

AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS

GIBB GILCHRIST, President

E72-745-3500-L180

[Blank Page in Original Bulletin]

The effects of kind and amount of phosphates, kind of soil, and kind of grass upon the yield and phosphoric acid content of several grasses were studied by means of pot experiments in the greenhouse.

Superphosphate greatly increased either the yield or the percentage of phosphoric acid in the dry matter or both yield and percentage. The increases in yield were greater where the soils were more deficient in active phosphoric acid. Small applications of superphosphate often produced large increases in yield accompanied by only small increases in percentage of phosphoric acid in the dry matter. Larger applications produced large increases both in yield and in percentage of phosphoric acid, raising the percentage well above the minimum required for range animals. Different species of grasses differed in their capacity to utilize soil phosphates; differences among the grasses were reduced by the application of superphosphate. A large part of the phosphoric acid added in superphosphate was recovered in the crops.

Ground rock phosphate increased yields in a few cases but had little effect upon the percentage of phosphoric acid in the dry matter. Increasing the amount of rock phosphate, the period of contact with the soil, or the fineness of grinding did not cause any further increases in yield or percentage. Ground rock phosphate is not to be recommended for use on pastures.

CONTENTS

THE VALUE OF DIFFERENT PHOSPHATES FOR VARIOUS TEXAS SOILS AND GRASSES, AS INDICATED BY POT EXPERIMENTS

J. F. Fudge, Chemist, and G. S. Fraps, Chief,
Division of Chemistry

The importance of phosphatic fertilization of pastures has been shown by many investigators in recent years, following work which showed that the percentage of phosphoric acid in forage is an important limiting factor for satisfactory animal production in many areas (3, 5, 15, 16, 29, 40, 42). Studies in Texas have shown that many soils are deficient in phosphoric acid (19), that many grasses produced on these soils are deficient in phosphoric acid (20, 21, 26, 27), and that the percentage of phosphoric acid in young forage is closely related to the supply of phosphoric acid in the soils (22, 24, 25, 26, 27).

The question of the phosphatic fertilization of pastures in Texas is of immedate practical importance. It was therefore considered desirable to secure further information concerning the effect of different phosphates on grasses on different kinds of soils. In order to secure more complete control over various factors which affect plant growth than is possible under field conditions, this study was made by means of pot experiments in the greenhouse.

Several carriers of phosphoric acid are available for use as fertilizers. Superphosphate is the most important and widely used of these carriers. Phosphoric acid in superphosphate has a high availability. Rock phosphate is also obtainable in large quantities, but many investigators have shown that phosphoric acid in rock phosphate is not nearly as available to most plants as that in superphosphate. Calcium metaphosphate and ammonium phosphate may come on the market. Limited amounts of defluorinated rock phosphate are now being used on pastures.

Previous Work

The application of superphosphate to pastures often results in increased yields of forage, but even where increases in yield are small, the percentage of phosphoric acid in the forage may be increased sufficiently to warrant the use of the fertilizer. Increases in yield and phosphoric acid content following the use of superphosphate may differ widely on different soils and with different plants. Data presented in Table 1, taken from several publications, illustrate these points.

Superphosphate not only increases the phosphoric acid in the species already present in the pasture, but often promotes the growth of more desirable species of forage, particularly legumes, which are relatively high in protein and phosphoric acid.

Table 1. Effect of superphosphate upon yield and percentage of phosphoric acid in forage in field experiments

State	Crop	Soil series	Yield of Dry matter Tons per acre		Phosphoric acid in dry matter		Reported in literature cited No.
			Not fertilized	Fertilized	Not fertilized %	Fertilized %	
Alabama	Herbage	Houston			.41	.69	31
	Herbage	Eutaw			.23	.44	31
	Herbage	Norfolk	0.63	1.04	.24	.43	32
	Herbage	Houston	1.27	2.64	.37	.72	32
	Herbage	Decatur	0.54	0.93	.67	.82	32
Connecticut	Herbage	Charlton			.48	.73	10
West Virginia	Herbage	Dekalb			.38	.77	37
	Herbage	Huntington			.64	.83	37
	Herbage	Crowley	1.31	2.70	.26	.41	20
Washington	Alfalfa	Ritzville	1.52	2.10	.70	.80	43
	Alfalfa	Puget	1.69	2.17	.64	.70	43
	Alfalfa	Dungeness	2.14	3.27	.54	.78	43
	Alfalfa	Winchester	2.67	2.57	.52	.55	43
Wisconsin	Alfalfa	Miami			.46	.53	28
	Alfalfa	Gilford			.38	.59	28
New Mexico	Alfalfa	Gila	5.04	7.79	.37	.47	30
Florida	Carpet grass	Bladen	0.19	0.40	.27	.44	6
	Carpet grass	Bladen	0.20	0.43	.25	.42	7
	Carpet grass	Leon	0.27	0.37	.39	.50	7
	Carpet grass	Plummer	0.23	0.47	.44	.48	7
South Carolina	Carpet grass				.28	.40	13
Texas	Carpet grass	Crowley			.24	.36	24
Connecticut	Kentucky bluegrass				.49	.71	9
Maryland	Kentucky bluegrass				.89	1.12	44
	Kentucky bluegrass				.82	1.00	47
West Virginia	Kentucky bluegrass	Dekalb			.37	.68	37
Wisconsin	Kentucky bluegrass		0.84	1.40			1
Maryland	White clover				1.03	1.26	44
	White clover				.84	1.02	47
Connecticut	Sweet vernal				.34	.54	9
West Virginia	Poverty grass	Dekalb			.24	.60	37
	Broomsedge	Dekalb			.29	.52	37
	Kentucky bluegrass	Dekalb			.37	.68	37
Texas	Angleton grass	Lufkin	1.72	2.19	.26	.34	8
	Rhodes grass	Lufkin	3.05	4.71	.23	.38	8
	Bermuda grass	Lufkin	0.25	0.52	.30	.41	8

Lespedeza occurred in appreciable amounts on plats of a Crowley clay loam at Beaumont, Texas (22), which had received superphosphate but was not important on unfertilized plats. On a Connecticut pasture (9), white clover amounted to less than 1% of the total forage on unfertilized plats but contributed up to 55% of the total forage on plats which had received superphosphate. On another area (10), Kentucky bluegrass provided 1% of the forage on unfertilized plats, 50% on plats which had received superphosphate, and 75% on those which had received both superphosphate and a nitrogen fertilizer. During a 6-year experimental period on pastures in West Virginia (37), weeds and bare space increased markedly on unfertilized plats, while Kentucky bluegrass and white clover largely replaced less desirable grasses and weeds on plats which had received superphosphate. Many other similar results have been reported.

The beneficial effects of superphosphate may persist on pastures for several years after applications have been discontinued. Robinson and Pierre (38), found beneficial effects from the use of superphosphate four and one-half years after the last treatment. Brown (10) found that vegetation from fertilized plats contained 40% more phosphoric acid than vegetation from unfertilized plats 14 years after an application of 320 lbs. of phosphoric acid in superphosphate. Ahlgren (1) found that the yield of mature Kentucky bluegrass from plats which had received 20% superphosphate at the rate of 400 pounds per acre five years previously was nearly four times as great as that from the unphosphated plats.

Rock phosphate has usually been found to be less available than superphosphate. Mooers (33) reported that rock phosphate gave much lower returns than superphosphate for oats and hay, that fineness of grinding beyond that usually employed did not increase availability, and that availability of rock phosphate did not noticeably increase on long contact with the soil. Noll and Bechdel (34) reported that applications of rock phosphate carrying twice as much phosphoric acid as applications of superphosphate gave lower yields than superphosphate in every one of 58 comparisons conducted on pastures in Pennsylvania. Volk (45) reported that increases in yield of hairy vetch from the use of superphosphate on different soils were from twice to 18 times those from rock phosphate. Fraps (17, 18) reported that the phosphoric acid in rock phosphate was much less available than that from superphosphate. O'Brien (36) reported that superphosphate was much more effective than rock phosphate in increasing the percentage of phosphoric acid in Kentucky bluegrass and white clover. DeTurk (14) states that phosphoric acid in rock phosphate is not available to the plant during the critical early stage of growth, while that in superphosphate is readily available. Brown and Jacob (12) reported that superphosphate was superior to rock phosphate in all of their work. Increasing the rate of application of rock phosphate often has very little, if any, effect upon the yield secured (17, 45, 46). Soft rock phosphate with colloidal clay (also called waste pond phosphate) is no better than ordinary rock phosphate (18, 45, 46) and contains only about two-thirds as much phosphoric acid.

Several other phosphates are or may become obtainable for use as fertilizers. Calcium metaphosphate is made by burning phosphorus and passing the combustion products into rock phosphate at high temperature. Defluorinated rock phosphate is made by fusing rock phosphate with silica and quenching the melt. In both of these processes, much of the fluorine in the rock phosphate is removed. Phosphoric acid in these two phosphates may have practically the same availability on noncalcareous soils as that in superphosphate (2, 30, 11, 39), but they cannot, at present, be recommended on calcareous soils. Ammonium phosphate is a soluble phosphate in which the phosphoric acid probably has a high availability. Basic slag, a by-product from the manufacture of steel, has been used in many areas with variable results, but it contains only about 8 to 12 per cent of total phosphoric acid and is a low-grade fertilizer. Phosphoric acid in some basic slags may be nearly as available on some soils as that in superphosphate (33, 35, 39).

Methods

In all of the work reported in this bulletin, 5 kilograms of soil were weighed into galvanized iron pots, nitrogen and potash (1 gram each of ammonium nitrate and potassium sulphate per pot) were added to all pots at the start of the work in March and, in most experiments, again in August. Quantities of the various phosphates calculated from the analyses to contain the desired amounts of phosphoric acid were weighed out and mixed with the soil. When superphosphate was compared with rock phosphate, the amount of phosphoric acid applied in rock phosphate was usually twice that applied in superphosphate. A parallel series of pots to which no phosphoric acid was added was included in all experiments. All treatments were made in triplicate. After the fertilizer had been mixed with the soil, weighed quantities of seed (or, in a few cases, plants) were planted. Water equivalent to 50% of the water-holding

Table 2. Composition of soils

Soil No.	Soil type	Nitrogen %	Total phosphoric acid %	Active phosphoric acid p.p.m.	Basicity as $CaCO_3$ %	pH
49075	Lufkin fine sandy loam	.042	....	61	0.3	5.5
49663	Houston black clay	.127	.070	213	3.6	7.8
50300	Wilson clay loam	.083	.040	49	1.0	6.7
50301	Wilson clay loam	.065	.030	14	1.1	5.4
50304	Houston clay	.180	.111	26	31.3	8.2
50306	Reinach silt loam	0.76	0.94	458	20.0	8.2
52320	Houston black clay	.102	.106	34	10+	8.2
53798	Nimrod fine sand	.024	.015	64	0.5	8.6
53801	Abilene clay	.110	.052	59	10+	8.4
53802	Frio clay loam	.270	.136	449	5.0	7.7
53804	Windthorst fine sandy loan	.031	.018	35	0.4	7.9
53810	Blanket clay loan	.187	.057	60	15.1	7.7
54289	Norfolk fine sand	.044	....	52	0.3	5.8
65031	Lufkin fine sandy loam	.059	.025	19	0.3	5.8
66401	Lufkin fine sandy loam	....	.021	19	0.4	6.2

Table 3. Common and botanical names of grasses used

Common name	Botanical name
Angleton grass	*Andropogon annulatus*
Bermuds grass	*Cynodon dactylon*
Black fingergrass	*Chloris cucullata*
Buffalo grass	*Buchloe dactyloides*
Carpet grass	*Axonopus affinis*
Curly mesquite grass	*Hilaria Belangeri*
Dallis grass	*Paspalum dilatatum*
Feather finger grass	*Chloris virgata*
Georgia grass	*Paspalum plicatulum*
Johnson grass	*Sorghum halepense*
Little bluestem grass	*Andropogon scoparius*
Rhodes grass	*Chloris gayana*
Ribbed paspalum grass	*Paspalum malacophyllum*
Sideoats grama grass	*Bouteloua curtipendula*
Weeping love grass	*Eragrostis curvula*
Yellow beard grass	*Andropogon ischaemum*

capacity of the soil was added. This moisture content was maintained by weighing the pots every two or three days, making allowance for the estimated weight of the crops, and adding the amount of water required to bring the pots to the original weight.

The grass was usually clipped at intervals of about 6 weeks; several crops were cut from the same pot. At all but the final harvest, the grasses were cut back to about 2 inches in height. The final harvest included all plant material above the ground. The material harvested was dried at about 45°C., ground in a Wiley mill, and analyzed for phosphoric acid by the volumetric molybdate method (4).

Analyses of the soils used are shown in Table 2. The common and botanical names of the grasses used are given in Table 3.

Effect of Kind of Soil

In order to study the effect of the kind of soil upon the response to phosphatic fertilizers, 12 soils were selected which differed widely in physical and chemical characteristics. Black finger grass was grown the first year on all these soils; Bermuda grass was grown the following year on ten of the same soils. Both grasses were grown at the same time on two soils (65031 and 66401) used in other experiments. On black finger grass, superphosphate (100 mgm. P_2O_5) or rock phosphate (200 mgm. P_2O_5) was mixed with the soil in March at the start of the work and a second application broadcast on the surface in August. On Bermuda grass the following year, all of the phosphate (200 or 400 mgm. P_2O_5) was mixed with the soil before planting. The Bermuda grass on ten soils also had the benefit of the residue of the phosphate applied to black finger grass. Both grasses were clipped 5 times during the growing season, ending in November. The total yield of dry matter, the percentage of phosphoric acid in the dry matter, and the percentage recovery of the phosphoric acid added are shown in Table 4.

Because nitrogen and potash were added, the yields without phosphate were due chiefly to the phosphoric acid of the soil. If the conditions for

Table 4. Effect of superphosphate (200 mgm. P_2O_5) and rock phosphate (400 mgm. P_2O_5) on total yield of dry matter and phosphoric acid in black finger and Bermuda grasses grown on different soils

		Total yield of dry matter			Weighted average percentage of phosphoric acid in dry matter			Recovery of phosphoric acid added	
		None gm.	Super gm.	Rock gm.	None %	Super %	Rock %	Super %	Rock %
	Black finger grass								
65031	Lufkin fine sandy loam	7.8	39.5	20.9	.23	.27	.23	43.4	7.7
53804	Windthorst fine sandy loam	8.3	22.5	11.1	.26	.28	.24	20.3	1.2
50304	Houston clay	14.1	48.3	18.3	.25	.27	.26	47.3	3.0
50301	Wilson clay loam	16.5	43.4	29.9	.18	.28	.21	47.0	8.6
66401	Lufkin fine sandy loam	20.7	68.0	38.9	.22	.24	.23	60.8	13.1
50306	Reinach silt loam	22.7	35.6	25.1	.32	.36	.30	27.6	1.0
53798	Nimrod fine sand	23.6	29.8	25.1	.23	.33	.26	22.6	2.0
52320	Houston black clay	26.4	50.5	41.3	.21	.24	.23	33.0	10.8
53801	Abilene clay	27.9	49.3	32.0	.23	.29	.23	39.7	2.4
54289	Norfolk fine sand	30.6	33.7	27.0	.27	.40	.28	26.4	0
49663	Houston black clay	44.4	48.8	42.0	.25	.30	.25	16.1	0
50300	Wilson clay loam	45.3	47.4	42.7	.34	.41	.38	19.6	1.3
53802	Frio clay loam	57.5	69.1	63.1	.27	.30	.28	27.7	5.0
53810	Blanket clay loam	57.7	67.6	60.6	.23	.31	.23	38.0	1.2
	Average	28.8	46.7	34.1	.25	.31	.26	33.5	4.1
	Bermuda grass								
65031	Lufkin fine sandy loam	12.5	34.3	17.4	.24	.26	.27	29.2	4.1
53801	Abilene clay	22.2	67.9	22.4	.14	.18	.14	41.0	0
66401	Lufkin fine sandy loam	22.9	69.3	55.7	.19	.23	.21	60.8	18.7
53804	Windthorst fine sandy loam	23.7	54.9	18.3	.15	.25	.16	51.3	0
50301	Wilson clay loam	24.0	57.9	34.9	.15	.17	.14	32.4	1.7
49663	Houston black clay	48.3	86.4	49.8	.16	.21	.14	53.4	0
50304	Houston clay	52.0	77.0	52.0	.14	.19	.15	37.6	1.1
50306	Reinach silt loam	54.1	81.2	54.3	.17	.26	.17	58.3	0
53810	Blanket clay loam	54.6	83.1	57.1	.17	.22	.13	44.2	0
52320	Houston black clay	64.4	86.5	62.4	.18	.23	.17	44.5	0
50300	Wilson clay loam	77.5	89.8	79.2	.19	.27	.20	47.0	2.9
53802	Frio clay loam	100.4	11.4	97.5	.21	.28	.23	48.7	4.4
	Average	47.2	75.0	50.1	.17	.23	.18	45.1	2.7

plant growth were entirely equalized, the yields in the pots fertilized with superphosphate would be equal in the different soils on which the same grass was grown under the same environmental conditions. Yields were not equal, but ranged from 22.5 to 69.1 grams per pot, with an average of 46.6 grams for the black finger grass, and from 34.3 to 111.1 grams with an average of 75.0 grams for Bermuda. The differences in yields show that the conditions for plant growth were not entirely equalized by the addition of the superphosphate. Some of the soils were much more favorable to the growth of the grasses than others. Bermuda failed entirely on two soils, though planted several times. These two soils were a Nimrod fine sand (53798) and a Norfolk fine sand (54289), on which superphosphate the previous year caused small increases in yield and considerable increases in the percentage of phosphoric acid in black finger grass. Bermuda grass seldom grows well on very sandy soils in the field. The relative growth on the soils was not always the same with the two grasses.

The difference in yield between finger grass and Bermuda grass indicates that Bermuda grass may have a greater growth capacity. However, the differences in yield cannot be assigned entirely to differences in the grasses. They may be due partly to differences between the seasons of 1942 and 1943, partly to the fact that the superphosphate was added in two applications to finger grass and in one application to Bermuda, and partly to residual phosphates available to the Bermuda grass.

The effect of superphosphate in increasing yields on most soils decreased as the yields of grass grown without phosphate increased. That is, as a rule, the greater the deficiency of the soil in phosphate for the growth of the grass, the greater was the relative effect of the superphosphate upon yields. Other factors interfered with this relation, as pointed out above.

The quantity of superphosphate used considerably affected the yield of the grasses and only slightly increased the percentage of phosphoric acid. The application of superphosphate increased the production of grass without increasing the phosphoric acid content sufficiently to meet the requirements of grazing beef animals (0.33%) in 22 of the 26 tests. In 4 of the tests, the percentage of phosphoric acid was increased sufficiently for this purpose. The black finger grass grown on the Reinach silt loam, Nimrod fine sand, Wilson clay loam and the Norfolk fine sand contained sufficient percentages of phosphoric acid (over .33%) but Bermuda grass on all soils did not. Yields of Bermuda grass were much greater than yields of black finger grass. The application of a limited amount of superphosphate, although increasing the yield, may not greatly increase the percentage of phosphoric acid in the grasses. Other work presented later shows that this increase may be secured when sufficient quantities of superphosphate are applied.

Rock phosphate produced much smaller increases in yield and percentage of phosphoric acid in the grasses than those produced by superphosphate.

Table 5. Relation of chemical composition of soils to response of black finger grass to application of superphosphate

Level of constituent in soils	Total yield in dry matter		Increase in yield due to phosphate gm.	Phosphoric acid in dry matter		Phosphoric acid in dry matter		Increase in phosphoric acid due to phosphate mgm.
	None gm.	Super gm.		None %	Super %	None mgm.	Super mgm.	
Active phosphoric acid								
0 to 30 p.p.m.	14.8	49.8	35.0	.20	.26	29.6	128.8	99.2
31 to 100 p.p.m.	31.4	43.0	11.6	.26	.32	81.4	138.4	57.0
Over 100 p.p.m.	41.5	51.1	9.6	.28	.32	116.4	154.0	37.6
Total phosphoric acid								
0 to .050%	26.3	44.1	17.8	.25	.31	66.6	136.1	69.5
.051 to .100%	31.7	44.6	12.9	.26	.32	83.0	138.5	55.5
Over .100%	32.7	56.0	23.3	.25	.27	81.8	153.5	71.9
Basicity								
Under 2%	26.3	44.1	17.8	.25	.31	66.6	136.1	69.5
Over 2%	32.2	50.3	18.1	.26	.29	82.4	146.1	63.7

The increases due to rock phosphate are so low that the use of rock phosphate is not justified.

The percentage of the added phosphoric acid recovered from superphosphate averaged 33.5% with black finger grass and 45.2% with Bermuda grass. The apparently higher recovery by Bermuda grass may be due in part to phosphate residues from the preceding year. Recovery of phosphoric acid from rock phosphate averaged 4.1% and 2.7%, but the average would be much lower than this, if the 3 tests in which recovery was high were excluded.

The average relation between the composition of the soils and the effect of the superphosphate on black finger grass is shown in Table 5. Averages for the unfertilized soils show a close relation between active phosphoric acid in the soil and yield and percentage of phosphoric acid in the grass grown on them, but not between the total phosphoric acid in the soil and the response. As the active phosphoric acid in the soil increased, the yield of grass, percentage of phosphoric acid, and weight of phosphoric acid in the crops from the unfertilized soils markedly increased, and the increases due to superphosphate decreased. Although the yields and the phosphoric acid in the crops from the unfertilized soils differed widely, differences among the fertilized soils were much smaller. The addition of phosphoric acid in the superphosphate had offset considerably the differences in available phosphoric acid in the unfertilized soils. Total phosphoric acid and basicity in the soils were of minor importance in determining the response to superphosphate.

Effect of Phosphates on Different Species of Grasses

The effect of differences in species of grasses upon the response to phosphates was studied by growing several species on two samples of Lufkin fine sandy loam. In the first set, one-half of the phosphate was mixed with soil 65031 at the start of the work in April, 1942, and the second half was broadcast on the pots in August. Plants of Dallis, Georgia, and Johnson grasses were set out and seeds of 11 other species were planted on April 29. In the second set, all of the phosphate was mixed with soil 66401 at the start of the work in March, 1943, and seeds of seven species were planted on March 10. Results secured in this experiment are given in Table 6.

Yields on the soils without phosphate averaged nearly the same (16.3 and 20.8 grams) on the two soils, but ranged from 7.8 to 26.4 grams on soil 65031, and from 12.2 to 31.1 grams on soil 66401. The wide differences indicate that some of the grasses were lower than others in their capacity to utilize soil phosphates. With superphosphate, yield ranged from 33.9 to 51.2 grams on soil 65031 and from 51.6 to 82.7 grams on soil 66401; average yields for the two soils were 40.5 grams and 75.2 grams, respectively. The differences between the two soils may be due partly to difference in season, including period of growth, partly to differences in the two soils, and partly to the difference in the method of application

Table 6. Effect of superphosphate (200 mgm. P_2O_5) and rock phosphate (400 mgm. P_2O_5) on total yield of dry matter and phosphoric acid in different species of grasses

Kind of grass	Total yield of dry matter			Weighted average percentage of phosphoric acid in dry matter			Recovery of phosphoric acid added	
	None gm.	Super gm.	Rock gm.	None %	Super %	Rock %	Super %	Rock %
Lufkin fine sandy loam 65031								
Black finger grass	7.8	39.5	20.9	.23	.27	.23	43.4	7.7
Rhodes grass	9.5	48.4	27.8	.24	.26	.21	50.5	8.5
Bermuda grass	12.5	34.3	17.4	.24	.24	.27	29.2	4.1
Yellow beard grass	13.3	35.0	22.9	.22	.29	.25	35.1	6.8
Johnson grass	13.5	36.3	26.4	.23	.24	.21	24.1	6.0
Angleton grass	16.0	33.9	21.0	.21	.24	.23	23.2	3.7
Curly mesquite grass	16.7	34.6	22.5	.21	.24	.22	24.7	3.8
Feather finger grass	18.0	45.6	28.5	.20	.26	.23	41.6	7.3
Carpet grass	18.8	37.1	24.0	.21	.28	.26	32.1	6.0
Ribbed paspalum grass	21.4	51.2	30.1	.17	.29	.23	55.0	8.2
Sideoats grama grass	21.5	49.6	33.5	.20	.21	.22	31.4	7.4
Georgia grass	26.4	41.2	30.1	.21	.28	.23	29.4	3.2
Dallis grass*	8.5	17.5	12.2	.22	.30	.27	34.2	7.0
Weeping love grass*	10.1	18.7	14.2	.23	.29	.25	29.6	5.8
Lufkin fine sandy loam 66401								
Sideoats grama grass	12.2	55.3	40.7	.17	.23	.24	54.1	19.2
Buffalo grass	13.9	51.6	42.9	.19	.27	.25	56.3	19.7
Black finger grass	20.7	68.0	38.9	.17	.23	.23	60.8	13.1
Ribbed paspalum grass	20.9	80.8	71.6	.15	.22	.19	71.9	25.7
Bermuda grass	22.9	69.3	55.7	.18	.23	.21	60.8	18.7
Yellow beard grass	23.7	78.7	53.2	.14	.20	.19	64.2	17.7
Rhodes grass	31.1	82.7	60.3	.14	.19	.14	57.0	21.6

*Plants died before Aug. 4, when second one-half of phosphate was applied.

of the phosphates. The higher yields were obtained on soil 66401, which received all of the phosphate in a single application. Both superphosphate and rock phosphate increased the percentage of phosphoric acid in the grasses, but in no case up to .33% needed to prevent the grasses from being deficient in phosphoric acid for range animals. The percentage of phosphoric acid was usually higher with superphosphate than with rock phosphate. The differences appear to be due chiefly to differences in the ability of the plants to utilize soil phosphates. Superphosphate on soil 65031 increased the weighted average percentage of phosphoric acid by more than .04% in ribbed paspalum, Dallis, yellow beard, carpet, Georgia, feather finger, and weeping love grasses, and by .02% or less in Rhodes, Bermuda, sideoats grama, and Johnson grasses. Superphosphates on soil 66401 increased the percentage of phosphoric acid in all grasses, but the increases were small in Rhodes and Bermuda grasses. Percentages were lower and increases in percentage caused by superphosphate were greater on soil 66401 than on soil 65031.

The percentage of the added phosphoric acid recovered from superphosphate ranged from 23.2 to 55.0, average 35.0, with soil 66401, and with soil 65031, from 54.1 to 71.9, average 60.7. Recovery from rock phosphate was also higher on soil 66401 than on soil 65031. Recovery was much greater when all of the phosphate was applied in one application mixed with soil 66401 than in two applications carrying the same total amount of phosphoric acid, half of which was mixed with soil 65031 and the other half broadcast later.

The high recovery in some grasses was due to large increases in yield, and in other grasses, to smaller increases in yield plus considerable increases in percentage of phosphoric acid. For example, superphosphate increased the yield of Rhodes grass on 65031 from 9.5 to 48.4 grams but increased the percentage of phosphoric acid only from .24% to .26%, while the yield of ribbed paspalum grass was increased from 21.4 to 51.2 grams and the percentage of phosphoric acid from .17% to .29%. The recovery of phosphoric acid was considerably higher in ribbed paspalum than in any other grass. Results on both soils indicate that ribbed paspalum is a heavy feeder on phosphoric acid in the soil; this is also shown by the large increase in yield of this species due to rock phosphate. Recoveries in black finger and Rhodes grasses were relatively high on both soils. Recoveries in Bermuda and yellow beard grasses were high on 66401 but considerably lower on 65031. The average recovery by all species was considerably higher on 66401 than on 65031; part of this difference is due to higher yields caused by the earlier date of planting (March 10 as compared with April 29), and part to the fact that only one-half of the phosphate had been added to 65031 throughout the early part of the growing season.

Results of this experiment furnish information concerning several important practical points. Although superphosphate applied to these phosphorus-deficient soils greatly increased the total amount of phosphoric

Table 7. Effect of superphosphate (200 mgm. P_2O_5) and rock phosphate (400 mgm. P_2O_5) on yield and phosphoric acid in grasses at different dates

Date of clipping	Total yield of dry matter			Weighted average percentage of phosphoric acid in dry matter			Recovery of added phosphoric acid	
	None gm.	Super gm.	Rock gm.	None %	Super %	Rock %	Super %	Rock %
Soil 65031*								
6/ 5/42	1.7	7.7	3.2	.26	.27	.29	7.9	1.2
6/24/42	2.1	4.6	4.5	.22	.29	.24	4.3	1.5
8/ 3/42	4.5	8.2	6.6	.21	.26	.23	5.7	1.5
9/16/42*	2.6	10.5	3.7	.23	.28	.24	12.0	0.8
11/ 3/42	4.2	10.2	6.3	.20	.25	.21	8.6	1.2
Total	15.1	41.2	24.3	.22	.27	.24	38.5	6.2
Soil 66401**								
5/26/43	1.0	12.3	5.0	.25	.30	.30	16.9	3.1
6/30/43	5.4	16.1	12.0	.15	.25	.18	15.7	3.4
8/ 4/43	3.9	13.3	11.4	.17	.24	.22	12.5	4.5
9/15/43	4.0	8.6	7.8	.15	.22	.19	6.3	2.1
11/ 2/43	6.6	17.8	15.7	.14	.16	.18	9.3	4.8
Total	20.9	68.1	51.9	.16	.23	.20	60.7	17.9

*One-half of phosphate added to 65031 at start and one-half on Aug. 4. Recovery calculated from total quantity added.
**All of phosphate added at start.

acid in the clippings, the increase in some species was due almost entirely to increases in yield, and in other species was due to a considerable increase in both yield and percentage of phosphoric acid. The botanical composition of a pasture may influence to a considerable degree the nature and degree of the response to applications of superphosphate. One large application of superphosphate caused greater increases in both yield and percentage of phosphoric acid than did two small applications carrying the same total amount of phosphoric acid. The relative order of different species of grasses in their response to superphosphate may differ considerably on different soils.

Effect of Phosphates on Yield and Composition at Different Dates

The previous discussion was based on the total yields from 5 clippings secured throughout the growing season. The results averaged according to date of clipping are presented in Table 7. Averages for soil 65031 were calculated for only eight grasses of which clippings were secured at all dates shown in Table 7; all grasses on soil 66401 were clipped at all dates.

Superphosphate greatly increased the yields at all dates. At the first clipping, good yields were secured from superphosphate pots, but yields from unfertilized pots were very small. The first clipping on unfertilized pots represented about 10% of the total yield on soil 65031 and 5% on soil 66401, compared with about 25% from superphosphate pots. At the first clipping, increases due to superphosphate were several times those due to rock phosphate. This is in agreement with the work of DeTurk (14), who stated that phosphoric acid in superphosphate is available to young seedlings but that in rock phosphate is not available. At later clippings, differences between superphosphate, rock phosphate, and no phosphate were smaller. Following the broadcast application of the second one-half of the phosphates to soil 65031, superphosphate again greatly increased the yield, but rock phosphate had little effect. During the first part of the growing season (April, May, June, July), the grasses on soil 66401 had twice as much phosphoric acid in superphosphate as those on soil 65031, and this resulted in much greater relative increases in yield in the first 3 clippings. The beneficial effect of the greater amount of phosphoric acid available during the early part of the growing season is also shown by the increases in total yield. Superphosphate increased the average yield on soil 65031 by 2.7 times, and on soil 66401 by 3.3 times.

The average precentage of phosphoric acid in the first clipping was not significantly increased by superphosphate on soil 65031, but was increased on soil 66401. All of the phosphoric acid taken up by the young plants from the smaller amount of phosphate on 65031 was used in producing additional plant material, whereas, when twice the amount of superphosphate was applied on soil 66401, the additional phosphoric acid not only caused a much greater relative increase in yield of the young plants, but also caused a significant increase in percentage of phosphoric

Table 8. Summary of percentage recovery of phosphoric acid added in superphosphate and rock phosphate

Experiment	Number of pairs	Mean percentage recovered		Standard deviation		Coefficient of variation	
		Super	Rock	Super	Rock	Super	Rock
Different soils (32% rock)							
Black finger grass	11	30.8	3.3	11.0	3.6	.35	1.09
Bermuda grass	10	46.3	0.6	7.5	2.3	.16	3.93
Different grasses							
Soil 65031 (32% rock)	14	31.4	6.1	12.9	3.1	.41	.51
Soil 66401 (34% rock)	7	60.7	17.9	6.1	4.8	.10	.27
All experiments	42	39.7	6.0	15.1	4.4	.38	.73

acid in the dry matter. The percentage of phosphoric acid in the grasses was much lower in the later clippings than in the first one, and differences in the percentage of phosphoric acid caused by the fertilizers were greater. Recovery of phosphoric acid from superphosphate applied in one application to soil 66401 decreased with each succeeding clipping except the last, chiefly because of the decreases in yield.

Recovery of Phosphoric Acid in Superphosphate Compared with that in Rock Phosphate

Data secured in 42 paired comparisons made in this work are summarized in Table 8. The average percentage of recovery of phosphoric acid added in superphosphate in the different experiments ranged from 30.8 to 60.7, and in rock phosphate, from 0.6 to 17.9. Recovery of phosphoric acid in superphosphate applied to different soils and grasses varied considerably, but the coefficient of variation for superphosphate was always much smaller than that for rock phosphate. A considerable percentage of the phosphoric acid added in superphosphate was recovered in every comparison; none of that added in rock phosphate was recovered on a number of the soils with Bermuda grass, and only small percentages of the phosphoric acid added in rock phosphate were recovered in any comparison. The average recovery of phosphoric acid from one rock phosphate (17.8%) was about three times that recovered from another rock phosphate (6.1%) on the same soil; companion averages for superphosphate were 60.7% and 31.4%. The averages given in Table 8 show that the recovery of phosphoric acid from superphosphate was always several times that from rock phosphate.

Effect of Different Amounts of Phosphates on Yields and Composition of Grasses

The phosphoric acid in superphosphate containing 200 mg. of phosphoric acid was used by the grasses for growth, if other conditions favored it, with little increase in the percentage of phosphoric acid in the grass. An experiment was also conducted in which different amounts of phosphoric acid in superphosphate (200, 400, 800, and 1,600 mgm.) and in rock phosphate (800 and 3,200 mgm.) were added to Lufkin fine sandy loam 66401. Each treatment was made in triplicate. Weighed amounts of Bermuda and Rhodes grass seed were planted on March 22, 1944. From this point, the procedure was the same is in previous experiments. Results secured are shown in Table 9.

The lowest amount of superphosphate (200 mg. phosphoric acid) greatly increased the yields. The percentage of phosphoric acid in the dry matter was increased in Rhodes grass, but was not increased in Bermuda grass. As the amount of superphosphate increased, both yields and percentages of phosphoric acid also increased, but the relative effect upon yield decreased while that upon percentage of phosphoric acid increased. Phosphoric acid in the dry matter reached a maximum of .47% in Bermuda

Table 9. Effect of different amounts of superphosphate and rock phosphate upon total yield and phosphoric acid in Bermuda and Rhodes grasses

	Total yield of dry matter gm.	Percentage of phosphoric acid in dry matter %	Recovery of phosphoric acid added %
Bermuda grass			
No phosphate	19.5	.18	....
Superphosphate (200 mg. P_2O_5)	52.5	.18	47.5
Superphosphate (400 mg. P_2O_5)	59.9	.24	27.9
Superphosphate (800 mg. P_2O_5)	72.8	.32	25.0
Superphosphate (1600 mg. P_2O_5)	76.4	.47	22.5
Rock phosphate (800 mg. P_2O_5)	25.0	.18	1.2
Rock phosphate (3200 mg. P_2O_5)	33.3	.18	0.8
Rhodes grass			
No phosphate	26.1	.17	....
Superphosphate (200 mg. P_2O_5)	59.4	.22	43.2
Superphosphate (400 mg. P_2O_5)	81.3	.24	38.6
Superphosphate (800 mg. P_2O_5)	91.9	.31	30.7
Superphosphate (1600 mg. P_2O_5)	95.0	.59	32.2
Rock phosphate (800 mg. P_2O_5)	32.8	.17	1.6
Rock phosphate (3200 mg. P_2O_5)	35.2	.18	0.6

grass and .59% in Rhodes grass: Sufficient applications of superphosphate increased the percentage of phosphoric acid appreciably above the minimum percentage (0.33%) required for the adequate nutrition of range cattle.

Rock phosphate even in large amounts, increased yields much less than did smaller amounts of superphosphate, and had almost no effect on the percentage of phosphoric acid in the grasses. Rock phosphate is not a suitable fertilizer for pasture land.

Value of Other Phosphates

In addition to superphosphate and rock phosphate used for the seven grasses grown on Lufkin fine sandy loam 66401 (Table 6), several other phosphates were used in order to estimate their relative value. Two hundred milligrams of phosphoric acid were added in ammonium phosphate and in calcium metaphosphate; 400 milligrams of phosphoric acid were added in finely ground rock phosphate (32% total P_2O_5), defluorinated rock phosphate (29.8% total P_2O_5), and basic slag (13.4% total P_2O_5). Average results with each of these phosphates are compared with those with superphosphate and rock phosphate to Table 10.

Results with ammonium phosphate and calcium metaphosphate were practically the same as those with superphosphate. Results with finely ground rock phosphate and soft rock phosphate with colloidal clay were similar to those with ordinary rock phosphate. Defluorinated rock phosphate and basic slag caused increases in yield and percentage of phosphoric acid considerably greater than those caused by superphosphate carrying one-half as much phosphoric acid. The phosphoric acid in defluorinated rock phosphate and basic slag was nearly as available as that in superphosphate and several times as available as that in the rock phosphate. The phosphates used may thus be divided into two groups based upon the

Table 10. Effect of different phosphates upon total yield and phosphoric acid in 7 grasses

	Phosphoric acid added mgm.	Total yield of dry matter gm.	Increase in yield due to phosphate gm.	Percentage of phosphoric acid in dry matter %	Recovery of phosphoric acid added %
No phosphate	0	20.9	....	.16	....
Superphosphate	200	68.1	47.2	.23	60.7
Ammonium phosphate	200	70.3	49.4	.22	60.1
Calcium metaphosphate	200	68.7	47.8	.22	58.9
Rock phosphate	400	52.0	31.1	.19	16.9
Finely ground rock phosphate	400	54.0	33.1	.20	19.5
Soft rock phosphate	400	50.4	29.5	.21	17.9
Defluorinated rock phosphate	400	83.9	63.0	.25	43.7
Basic slag	400	79.7	58.8	.26	43.8

Table 11. Effect of dicalcium phosphate (412 mgm. P_2O_5) upon total yield and phosphoric acid in four grasses

	Total yield of dry matter		Percentage of phosphoric acid in dry matter		Recovery of phosphoric acid added
	None gm.	Phosphate gm.	None %	Phosphate %	%
Buffalo grass	10.7	18.1	.30	.50	14.1
Little bluestem grass	22.8	24.0	.23	.44	12.3
Sideoats grama grass	24.7	33.9	.20	.37	18.3
Black finger grass	25.0	30.9	.29	.50	20.1

availability of their phosphoric acid. Phosphoric acid in superphosphate, ammonium phosphate, calcium metaphosphate, defluorinated rock phosphate and basic slag was highly available; that in ordinary rock phosphate, finely ground rock phosphate, and soft rock phosphate with colloidal clay was only slightly available even on this very favorable soil.

Dicalcium phosphate (1 gram of salt or 412 milligrams of phosphoric acid) was used in one experiment with a Lufkin fine sandy loam (49075, Table 2) on four grasses. The results are shown in Table 11, principally because they were considerably different from those secured on the other two Lufkin fine sandy loams (65031 and 66401). Yields and percentages of phosphoric acid in grasses grown on the unfertilized pots of this soil were very similar to those on the other two soils. On this soil, however, dicalcium phosphate caused comparatively small increases in yield and very large increases in the percentages of phosphoric acid in the dry matter. This experiment again provides evidence indicating that, where available phosphoric acid is added to a phosphorus-deficient soil under conditions where the increases in yield are relatively small, the additional phosphoric acid will be used by the plant to increase the percentage of phosphoric acid in the dry matter.

DISCUSSION

While results of pot experiments in the greenhouse are not directly applicable to field work, they do give valuable information concerning certain general relations which are applicable. A due appraisal of the results secured in pot experiments is thus of practical value.

Superphosphate: The addition of a limited amount of superphosphate to soils which were deficient in active phosphoric acid resulted in very large increases in yields of dry matter. Where the application of superphosphate did not produce large increases in yield, the added phosphoric acid was used by the plants to increase the percentage of phosphoric acid in the dry matter. Where larger amounts of superphosphate were applied, the additional phosphoric acid was used to produce some additional dry matter, but most of it was used to raise the percentage of phosphoric acid in the dry matter. The phosphoric acid in superphosphate is used primarily to increase the yield of dry matter, and secondarily, to increase the percentage of phosphoric acid in the dry matter. Since percentage of phosphoric acid, rather than yield, is the principal factor in satisfactory animal production on many Texas pastures, the amount of superphosphate to be added should be sufficient not only to raise the yield to a satisfactory level, but also to raise the percentage of phosphoric acid in the dry matter to a level higher than the minimum requirements for range animals. The amount to be applied will also be influenced by the amount of active phosphoric acid in the unfertilized soil, and by the capacity of the soil to fix phosphoric acid in unavailable or slowly available compounds.

A single large application of superphosphate appears to be better than two small applications carrying the same amount of phosphoric acid. Superphosphate should be added at a time when the additional phosphoric acid will be available to stimulate the growth of seedlings and develop them into strong plants before the advancing season brings unfavorable growth conditions.

Superphosphate greatly increased bloom and seed production in nearly all species of grass. The stimulation of seed production following the application of superphosphate may be of practical importance, particularly on many of our over-grazed or depleted ranges. Superphosphate resulted in very greatly increased root systems; under range conditions this would be of value in increasing the capacity of the plant to secure food and water. Superphosphate considerably reduced the loss of seeedlings due to "damping off".

Rock phosphate: The availability of phosphoric acid in rock phosphate is much lower than in superphosphate. Rock phosphate significantly increased yields of black finger grass on only 4 out of 14 soils and on 5 out of 15 species of grass grown on a favorable soil. It increased the percentage of phosphoric acid in the grasses in only a few cases. Rock phosphate did not cause much increase in either yield or percentage of phosphoric acid in young grasses. Increasing the amount of rock phosphate or the period of contact with the soil did not result in any further increase. In all cases where increases due to rock phosphate were secured, they were much smaller than those produced by superphosphate carrying only half as much phosphoric acid. Rock phosphate cannot be recommended for increasing either the yield or the phosphoric acid content of range grasses.

ACKNOWLEDGEMENT

Chemical analyses and other work was done by Mr. T. L. Ogier, Waldo Walker, and other members of the staff.

SUMMARY

Yields of black finger grass and Bermuda grass grown in pot experiments without phosphate varied widely according to the soil, chiefly due to differences in the active phosphoric acid content of the soils. When superphosphate was added, the yields were more nearly uniform. The effect of the superphosphate depended on the soil, being greater where the soil was more deficient in active phosphoric acid. The application of limited amounts of superphosphate increased the yield to a greater extent than it increased the percentage of phosphoric acid in the grasses.

The yield and percentage of phosphoric acid in the grasses was closely related to the amount of active phosphoric acid in the soils.

When 14 species of grasses were grown on the same unphosphated soil, considerable differences occurred among the yields of grass. When superphosphate was added, the differences were much smaller. This indicates that the differences were chiefly due to differences in the capacity of the grasses to utilize soil phosphates.

One application of superphosphate at the beginning of the season produced larger yields with greater increases in percentage of phosphoric acid than the same amount of phosphoric acid added in two applications. Small applications of superphosphate usually produced large increases in yield but small increases in the percentage of phosphoric acid in the grasses. As the quantity of superphosphate was increased, the effect on the yield was less but the effect on the percentage of phosphoric acid in the grasses was greater. Liberal applications of superphosphate produced large yields of dry matter containing good percentages of phosphoric acid.

Superphosphate stimulated early growth and seed formation.

Applications of ground rock phosphate increased yields in a few cases, but the increases were not nearly as great as those for superphosphate. Ground rock phosphate, even when applied in large quantities, usually had little effect upon the percentage of phosphoric acid in the grasses.

Phosphoric acid in ammonium phosphate, calcium metaphosphate, defluorinated rock phosphate, and basic slag applied to a slightly acid,

phosphorus-deficient Lufkin fine sandy loam was nearly as available as that in 20% superphosphate. Phosphoric acid added in finely ground rock phosphate or in soft rock phosphate with colloidal clay was no more available than that in ordinary ground rock phosphate.

LITERATURE CITED

1. Ahlgren, H. L. 1938. Effect of fertilization, cutting treatments, and composition of the rhizomes of Kentucky bluegrass (*Poa pratensis* L.) Jour. Amer. Soc. Agron. 30: 683-691.

2. Alway, F. J., and Nesom, G. H. 1944. Effectiveness of calcium metaphosphate and fused rock phosphate on alfalfa. Jour. Amer. Soc. Agron. 36: 73-88.

3. Archibald, J. G., and Bennett, E. 1935. The phosphorus requirements of dairy heifers. Jour. Agr. Res. 51: 83-96.

4. Association of Official Agricultural Chemists. 1940. Official and tentative methods of analysis. Fifth Edition. Washington, D. C.

5. Becker, R. B., Neal, W. M., and Shealy, A. L. 1933. Stiffs or sweeny (phosphorus deficiency) in cattle. Fla. Agr. Exp. Sta. Bul. 264.

6. Blaser, R. E., and Stokes, W. E. 1942. The chemical composition, growth, and certain deficiency symptoms of carpet grass, *Axonopus affinis*, as affected by lime and fertilizer mixtures. Jour. Amer. Soc. Agron. 34: 765-768.

7. Blaser, R. E., and Stokes, W. E. 1943. Effect of fertilizer on growth and composition of carpet and other grasses. Fla. Agr. Exp. Sta. Bul. 390.

8. Brittingham, W. H., and Fudge, J. F. 1944. Yields, chemical analysis and fertilizer response of eleven forage grasses. Tex. Agr. Exp. Sta. Progress Report 875.

9. Brown, B. A. 1932. The effects of fertilization on the chemical composition of vegetation in pastures. Jour. Amer. Soc. Agron. 34: 129-145.

10. Brown, B. A. 1940. The chemical composition of pasture species of the Northeast region as influenced by fertilizers. Jour. Amer. Soc. Agron. 32: 256-264.

11. Brown, B. A., and Clark, K. G. 1943. An appraisal of calcium and potassium metaphosphates as sources of phosphorus in plants. American Fertilizer 98 (5): 10-11.

12. Brown, B. E., and Jacob, E. D. 1944. Greenhouse and field tests comparing colloidal phosphate, phosphate rock, and superphosphate as sources of phosphorus for various crop plants. American Fertilizer, 101 (13) 2.

13. Cooper, H. P., and Mitchell, J. H., Kyser, E. D., and Clyburn, T. M. 1937. Chemical composition of clippings of carpet grass from pasture plats receiving various fertilizer treatments. Soil Sci. Soc. Amer. Proc. 2: 353-358.

14. DeTurk, E. E. 1942. The problem of phosphate fertilizers. Ill. Agr. Exp. Sta. Bul. 484.

15. DuToit, P. J., and Bisschop, J. H. R. 1929. The breeding of cattle of phosphorus deficient veld. Union So. Africa. Dept. Agr. Rpt. Dir. Vet. Serv. and Animal Indus. 15: 1059-1166.

16. Eckles, C. H., Gullickson, T. W., and Palmer, L. S. 1932. Phosphorus deficiency in the rations of cattle. Minn. Agr. Exp. Sta. Tech. Bul. 91.

17. Fraps, G. S. 1922. The effect of rock phosphate upon the corn possibility of phosphoric acid of the soil. Texas Agr. Exp. Sta. Bul. 289.

18. Fraps, G. S. 1935. Availability of the phosphoric acid of finely divided rock phosphate. Texas Agr. Exp. Sta. Bul. 509.

19. Fraps, G. S., and Fudge, J. F. 1937. Chemical composition of soils of Texas. Tex. Agr. Exp. Sta. Bul. 549.

20. Fraps, G. S., and Fudge, J. F. 1937. Phosphoric acid, lime, and protein in forage grasses of the East Texas Timber Country. Soil Sci. Soc. Amer. Proc. 2: 347-351.

21. Fraps, G. S., and Fudge, J. F. 1940. The chemical composition of forage of the East Texas Timber Country. Tex. Agr. Exp. Sta. Bul. 582.

22. Fraps, G. S., Fudge, J. F. and Reynolds, E. B. 1937. Effect of fertilization on the composition of a Lufkin fine sandy loam and of oats grown on it. Jour. Amer. Soc. Agron. 29: 990-996.

23. Fraps, G. S., Fudge, J. F., and Reynolds, E. B. 1941. The effect of fertilization on nitrogen, active phosphoric acid, and active potash of a Lake Charles clay loam. Jour. Amer. Soc. Agron. 33: 130-134.

24. Fraps, G. S., Fudge, J. F., and Reynolds, E. B. 1943. The effect of fertilization of a Crowley clay loam on the chemical composition of forage and carpet grass. *Axonopus affinis*. Jour. Amer. Soc. Agron. 35: 560-566.

25. Fudge, J. F., and Fraps, G. S. 1938. The relation of nitrogen, phosphoric acid, and lime in the soils of East Texas to those constituents in Bermuda and little bluestem grasses. Soil Sci. Soc. Amer. Proc. 3: 189-194.

26. Fudge, J. F., and Fraps, G. S. 1944. The chemical composition of forage grasses from the Gulf Coast Prairie, as related to soils and to requirements of range cattle. Tex. Agr. Exp. Sta. Bul. 644.

27. Fudge, J. F., and Fraps, G. S. 1945. The chemical composition of forage grasses from Northwest Texas, as related to soils and to requirements of range cattle. Tex. Agr. Exp. Sta. Bul. 669.

28. Grizzard, A. L. 1935. Effects of soil type and soil treatments on the chemical composition of alfalfa plants. Jour. Amer. Soc. Agron. 27: 81-99.

29. Hart, G. H., Guilbert, H. R., and Goss, H. 1932. Seasonal changes in the chemical composition of range forage and their relation to nutrition of animals. Cal. Agr. Exp. Sta. Bul. 543.

30. Hinkle, D. A. 1942. Efficiency of various phosphate fertilizers on calcareous soil for alfalfa and sweet clover. Jour. Amer. Soc. Agron. 34: 913-918.

31. McClendon, J. W., and Mayton, E. L. 1941. The effect of lime and fertilizer on the composition and yield of pasture herbage in Alabama. Soil Sci. Soc. Amer. Proc. 6: 285-287.

32. McClendon, J. W., and Mayton, E. L. 1942. The effect of lime and fertilizer on the composition and yield of pasture herbage from different soil types. Assoc. Southern Agr. Workers. Proc. 43: 88-89.

33. Mooers, C. A. 1929. The comparative values of different phosphates. Tenn. Agr. Exp. Sta. Bul. 141.

34. Noll, N. F., and Bechdel, S. I. 1940. Science for the farmer. Pa. Agr. Exp. Sta. Bul. 399.

35. Noll, C. F., and Irvine, C. J. 1942. Field test of phosphate fertilizers. Pa. Agr. Exp. Sta. Bul. 423.

36. O'Brien, R. E. 1942. The effect of different phosphatic fertilizers on the chemical composition of pasture herbage. Assoc. Southern Agr. Workers Proc. 43: 35-36.

37. Pierre, W. H., and Robinson, R. R. 1937. The calcium and phosphorus contents of pasture herbage and of various pasture species as affected by fertilization and liming. Jour. Amer. Soc. Agron. 29: 477-497.

38. Robinson, R. R., and Pierre, W. H. 1938. Response of permanent pastures to lime and fertilizers (1930 to 1936). W. Va. Agr. Exp. Sta. Bul. 289.

39. Ross, W. H., and Jacob, K. D. 1937. Report on phosphoric acid. Availability of calcined phosphate and other new phosphatic materials as determined by chemical and vegetative tests. Jour. A.O.A.C. 20: 231-249.

40. Schmidt, H. 1924. Field and laboratory notes on a fatal disease of cattle appearing *on the coastal plains of Texas (Loin Disease). Tex. Agr. Exp. Sta. Bul. 319.*

41. Thomas, Walter. 1930. The feeding power of plants. Plant Physiology 5: 443-489.

42. Turner, W. A., Kelly, R. B., and Dann, A. T. 1935. Peg-leg in cattle in North Queensland. Jour. Council Sci. Ind. Research 8: 126-132.

43. Vandecaveye, S. C., and Bond, L. V. 1936. Yield and composition of alfalfa as affected by various fertilizers and soil types. Jour. Amer. Soc. Agron. 28: 491-505.

44. Vinall, H. N., and Wilkins, H. L. 1936. The effect of fertilizer applications on the composition of pasture grasses. Jour. Amer. Soc. Agron. 28: 562-569.

45. Volk, Garth W. 1942. Waste pond phosphate compared with rock phosphate and superphosphate as a fertilizer. Jour. Amer. Soc. Agron. 34: 823-829.

46. Volk, Garth W. 1944. Availability of rock and other phosphate fertilizer as influenced by lime and form of nitrogen fertilizer. Jour. Amer. Soc. Agron. 36: 46-56.

47. Wilkins, H. L., and Vinall, H. N. 1933. The effect of lime and of certain fertilizers constituents on the yield and composition of the herbage from pasture plats at Beltsville, Maryland. Jour. Amer. Soc. Agron. 25: 603-611.