RATES AND METHODS OF PHOSPHATE APPLICATION ON WHEAT

By

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1954

Submitted to the faculty of the Graduate School
of the Oklahoma State University in partial
fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 1960

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APPLICATION ON WHEAT

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ACKNOWLEDGEMENT

The author wishes to express gratitude to the following persons: Dr. Billy B. Tucker, thesis advisor, for supervision, advice and encouragement throughout the course of this study. Drs. Robert Reed, L. W. Reed, B. C. Curtis and R. D. Morrison for helpful suggestions and information concerning this study. F. Puente and S. Murdock for their help and cooperation during the investigation. Special graditude goes to the Rockefeller Foundation for financial assistance during the graduate program.

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INTRODUCTION

Many plant and soil factors are involved in the production of a given crop. Factors such as soil fertility level, ability of the soil to release nutrient elements from the soil solution to the plant roots, soil moisture content, the ease of penetrability of the roots into the soil, content of salts, and others, can be cited and are recognized as factors of great importance because they favor or limit plant growth and subsequent yields.

It is very common to find an inadequate total amount or low availability of one or more of the essential plant food nutrients. In general, phosphorus has been found to be a limiting plant nutrient for crop production in Oklahoma (7, 17).

Phosphorus availability and plant response to phosphorus have been studied by soil investigators for many years, but there still exists many controversies related to soil phosphorus and plant nutrition. Probably the principal problem is the phosphorus retention in difficultly available forms and it has been recognized that fixation or reversion of applied phosphorus varies from soil to soil.

Phosphorus absorption by plants is influenced by the method of application. Some experimental work shows that when phosphorus is applied at different depths the phosphorus uptake and plant growth is increased, but other experiments do not support these findings.

Soil moisture content is another factor closely related to plant growth and phosphate response of plants. It influences the soil solution which is one of the sources of the plant nutrients and supplies the plant water needs. Water often becomes the limiting production factor of any crop grown under dryland conditions and vast agricultural areas produce only limited yields of crops because of water deficiency. The effect on final yield produced by a temporary water deficiency in the soil depends on the time during the growth cycle of the plant at which the deficiency occurs. Black (3) states that a drought during the fruiting stage causes shorter stems and barrenness of fruit than a drought during other stages.

Taking into consideration previous investigations and the great importance of the foregoing factors, a study was initiated with the objective to observe and to measure the effect of different rates of phosphorus applied in bands with the seed and plowed down to a 6 inch depth, on yield and chemical composition of winter wheat growing under dryland conditions.

LITERATURE REVIEW

It is well known that phosphorus is essential to plant growth. This element performs functions in plant metabolism, structure, and reproduction that cannot be performed by any other element. Black (3) points out that arsenic, the element most similar to phosphorus with regard to chemical properties in aqueous systems, is toxic to plants. The concentration of phosphorus in plants is usually considerably lower than that of nitrogen, potassium, or calcium. However, as a limiting factor, phosphorus is more important than calcium, and probably is second in importance only to nitrogen.

The content of phosphorus in soils is relatively small. Lipman and Conybeare (22), in a study of the crop land of the United States, obtained an average of 0.064 per cent of phosphorus in the surface 6 2/3 inches (assuming 2,000,000 lbs. of soil surface per acre), a value considerably smaller than the corresponding figures of 0.14 per cent for nitrogen and 0.83 per cent for potassium.

In studies concerning the readily available phosphate in soils, crops often fail to respond when soluble phosphate is applied, or fail to show phosphate deficiencies when phosphate is not applied. Coleman (10) reported that the failure of crops to respond to applied phosphate has often been attributed to its rapid fixation by the soil and that the ability of plants to grow normally in soils with a limited amount of readily available phosphate suggests that many plants can obtain sufficient phosphorus from the difficulty available sources already present in the soil. In 1939 Dorman and Coleman (12) stated that cotton grew well on soils low in readily available phosphate and that it failed to respond to applied phosphate on many soils even though the readily available phosphate level of the soil was increased. They also found that by utilizing large amounts of adsorbed phosphate already present in the soil, cotton and oats may be able to grow well on many soils that contain very little readily available phosphate as determined by the common analytical methods.

Similar data were obtained by Ulrich et al. (38) who reported that grape vines which were exceedingly low in phosphorus (as shown by the soluble phosphate concentration of the leaves) failed to show consistent gains in phosphate concentration of the leaves or in grape yields after application of 400 to 620 pounds of P_2O_5 per acre. They concluded, (a) even though the vines were exceptionally low in phosphorus the amounts found still might have been adequate so that phosphate was not a limiting factor in vine growth or, (b) the amounts of P_2O_5 applied were inadequate to permit plants to compete successfully with a soil which has a high fixing capacity for phosphate.

The foregoing findings were not supported by Rich, Obenshain and McVickar (28) who obtained an increase in the yields of wheat from 9.8 bushels per acre with no phosphorus application to 15.5 bushels per acre when 70 pounds of P_2O_5 per acre were applied to a soil low in readily soluble phosphorus.

Smith (34) found a significant increase in the yield of wheat when 25 pounds each of N and P_2O_5 per acre were applied to a silt loam soil but no significant increase from 25 to 50 pounds per acre of N or P_2O_5 alone.

The methods of fertilizer application have been intensively studied, and it has been found that the position in the soil where the fertilizer is placed, affects root developemnt. Plant roots will ramify in properly fertilized soil. Thus placing the fertilizer in the subsoil will usually give a greater development of roots than if it is placed in the soil surface (24, 39).

Some investigators have worked with applications of different fertilizer rates at different depths, or the same rate applied at different depths or several rates placed at the same depth, while others have investigated the effect of broadcasting against banded or mixing the fertilizer with the soil (1, 20, 29, 36).

Jacob, et al. (20) found a considerable increase in the potato yields following the application of various rates of P_2O_5 at a depth of 2 inches below seed-level in a silt loam soil in North Carolina. They also observed that potato plants contained a higher proportion of fertilizer phosphorus when grown on soils low in native phosphorus than when they were grown on soils high in phosphorus. The percentage of phosphorus in the plant derived from fertilizer increased as the rate of application increased. Stanford and Nelson (36) applied 30 pounds of P_2O_5 per acre at 1/2, 2 and 5 inches in depth and were unable to find consistent differences in the yields of corn due to these placements. Contrary to the expected, Robertson, Hutton and Thompson (29) found a decrease in corn yields after an application of 30 pounds of P_2O_5 per acre at 2, 8, 14 and 20 inches and stated that evidently there was not enough available phosphorus in the surface soil to promote growth to the deep-placed fertilizer.

Allen et al. (1) in a study with wheat and vetch pointed out that, in general, surface application was a relatively unsatisfactory method and that banded fertilizer was most efficiently used by wheat when placed at a depth of 8 inches, and placement at depths of 2 to 4 inches gave the best results with vetch. Hervey, et al. (19) also found that sweet clover made better growth when the phosphate fertilizer was placed below the soil surface than when it was broadcast on the surface.

Soil water content has an important influence on ion uptake by plants, but ion uptake and water uptake are not necessarily related. It has been concluded by Veihmeyer and Hendrickson (40) that water either is available or is not available to plants, and that it is equally available over the entire range from field capacity to the wilting point. However many studies have indicated that water is not equally available over the entire range down to the wilting percentage. For instance, Magness (23) found that the growth rate of apples was reduced when the driest part of the root zone approached the wilting percentage, even though much of the root zone was considerably wetter. Furr and Taylor (15) observed that lemons grown on a shallow soil underlain by a dense subsoil suffered a reduction in fruit size before the moisture content of the first foot of soil was reduced to the permanent wilting point.

Soil water content, besides supplying the plant water needs, is closely associated with the processes involved in nutrient absorption and accumulation from soils by plant roots. Wadleigh and Richards (42) pointed out that soil moisture conditions may influence the growth and physiological activity of root systems and subsequently the utilization of mineral nutrients. Also changes in soil moisture content and thus thickness of the moisture film probably also influences nutrient availability *per se*. Breazeale (6), in work related to nutrition of plants at and below the wilting percentage, found that plants were absorbing potassium from a soil which was never above the wilting percentage and concluded that low percentages of moisture interferred with the absorption of nutrients. Volk (41) was able to show an increase in both percentage and total amounts of potassium and nitrogen absorbed by plants grown in dry Clyde silt loam of high fertility below the wilting point, but he did not obtain evidence for absorption of phosphorus.

Dean and Gledhill (11), by the use of an excised root technique, pointed out that a reduced phosphate absorption by roots in contact with dry soil may occur as a result of alteration in the physiology of roots. They also observed changes in the power of the soil to supply phosphorus. These findings are in agreement with Kramer (21) who concluded that there would seem to be a reasonable doubt that roots in contact with dry soil for protracted periods of time will absorb important quantities of phosphorus.

EXPERIMENTAL PROCEDURES

Location of Soil Used in the Experiment

The field experiment was conducted during the 1958-59 wheat season, and was located at the Agronomy Research Farm, Perkins, Oklahoma on a Norge sandy loam soil. This alluvial soil is deep and permeable. The profile is described in the appendix. The experiment was established between two terraces with a slope from 1 to 3 percent on a well prepared seedbed. In this particular area, no fertilizer had previously been applied.

The cropping system of the field during the last 20 years is indicated in Table I.

TABLE I.

CROPPING HISTORY OF THE EXPERIMENTAL SITE

Year	1938-45	1945-55	1955-57	1957-58
Crop	Cotton	Sorghum	Oats	Wheat

Soil Characteristics

Prior to the fertilizer applications, soil samples were taken from the 0 to 6 inch layer, designated as the soil surface, and from the 6 to 12 inch layer, considered as the subsoil. These samples were taken to the chemical laboratory, dried and prepared for the different soil analyses. In addition a bulk soil sample was taken from the arable layer, (0 to 6 inches in depth) for the greenhouse study.

The percentages of the various soil separates were determined by the use of the Bouyoucos hydrometer procedure (4). Soil reaction was measured by the glass electrode (32). The method proposed by Schollenberger (33) was used in the organic matter determination. Total nitrogen was obtained by the use of the Kjeldhal method (2). Available phosphorus was measured by the method suggested by Bray and Kurtz (5). The Bray and Kurtz method used in the available phosphorus determination was chosen because of its high correlation between the field and laboratory data in an experiment which included the soil used in this study. Available potassium content was determined by the methods as proposed by Peech, et al. (27). Cation exchange capacity determination was made by using the A.O.A.C. method (2).

Results of the chemical and physical analyses of the soil are given in Table II.

TABLE II

SOME PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE NORGE SOIL USED IN THE FIELD AND GREENHOUSE EXPERIMENTS

Depth	Percentage of			pH	% O.M.	% Total N	Avail. P (lb/acre)	Avail. K (lb/acre)	C.E.C. m.e./100g. of soil
	Sand	Silt	Clay						
0-6"	54.12	32.37	13.51	5.4	0.85	0.06	10.82	272	7.90
6-12"	48.00	32.06	19.94	5.8	1.24	0.08	4.40	152	11.93

Other physical characteristics of the same soil such as percentages of moisture retained against tensions of 1/10 atmosphere and 15 atmospheres plus bulk density for a six foot profile are listed in Table III.

TABLE III

MOISTURE RETENTIONS AT TENSIONS OF 1/10 AND 15 ATMOSPHERES CONSIDERED IN THE SOIL USED AS THE FIELD CAPACITY AND PERMANENT WILTING PERCENTAGE RESPECTIVELY, PLUS BULK DENSITY IN A SIX FOOT PROFILE

Depth	Moisture Percentages		% Available	Bulk
	1/10 atm.	15 atms.	Water	Density
0-12"	31.29	9.17	22.12	1.78
12-24"	32.45	11.27	21.18	1.79
24-36"	26.68	8.14	18.54	1.80
36-48"	19.36	4.84	14.52	1.81
48-60"	17.04	4.25	12.79	1.82
60-72"	19.82	5.12	14.70	1.80

Treatments Used in the Field Experiment

As was indicated in the introduction the objective of the present experimental work was to study the plant responses to different rates of phosphorus applied in bands at seeding depth and plowed down to a six inch depth. A randomized complete block design with four replications and ten treatments was used. Levels of phosphorus added were 0, 18, 36, 72 and 144 pounds of P_2O_5 per acre. Forty pounds each of N and K_2O per acre were added to all the treatments to avoid any deficiency of these elements in the soil. Table IV shows in detail the treatments used in the field.

TABLE IV

TREATMENTS AND FERTILIZER PLACEMENT METHOD USED IN THE FIELD EXPERIMENT AT THE AGRONOMY RESEARCH FARM AT PERKINS, OKLAHOMA

Phosphate Placement Method		Treatments N	P	K
Application in Bands at Seeding Depth	1.	40	0	40
	2.	40	18	40
	3.	40	36	40
	4.	40	72	40
	5.	40	144	40
Plowdown Application (6 inches)	6.	40	0	40
	7.	40	18	40
	8.	40	36	40
	9.	40	72	40
	10.	40	144	40

The fertilizer sources used were:

Superphosphate	20.0% of P_2O_5
Ammonium Nitrate	33.0% of N
Muriate Potash	60.0% of K_2O

Each plot was 50 feet long and 10 feet wide. After the plots were staked (a few weeks prior to planting) those plots which were to receive the plowdown application were fertilized with the various phosphate rates. A calibrated grain drill was used to place the fertilizer on the surface in bands 7 inches apart. The entire area was then moldboarded to a 6 inch depth, thus placing the phosphate fertilizer at the bottom of the furrow. The plots designated to receive the surface application were fertilized with the same applicator, but the phosphate was placed from 1 to 2 inches deep. Both surface and deep applied application were made on the same day. Ponca wheat was planted at the rate of 30 pounds per acre.

Soil Moisture Determinations

Soil moisture at 1 foot intervals to a depth of 6 feet were taken with Veihmeyer tubes at monthly intervals during the growing season. The soil moisture percentages were determined by the gravimetric procedure in order to assess the prevalent moisture conditions at the different stages of growth of the plant.

Harvest

An area of 35 x 1.67 feet was harvested. The wheat was threshed with a portable Pullman Thresher. After the grain was threshed it was cleaned and weighed. Representative grain samples from the 40 plots were taken to the chemical laboratory and determinations of nitrogen and phosphorus content of the grain were made.

Greenhouse Experiment

The greenhouse experiment consisted of a randomized complete block design with three replications and five treatments. The fertility levels utilized were: 0, 18, 36, 72, and 144 pounds of P_2O_5 per acre, one rate of each nitrogen and potassium, 40 pounds of N and 40 pounds of K_2O per acre, respectively. The fertilizer sources were the same as those used in the field experiment (Table IV). Two gallon glazed pots were used in the experiment. Each pot contained ten pounds of air-dry soil which had been previously dried and screened. The fertilizer of the five treatments in the study was placed 1 inch below the seed level a day prior to planting. A stand of ten wheat plants per pot was grown for a two month period. After this growing period was completed the forage was then harvested and the yields on a dry weight basis were determined.

Statistical Analyses

Grain yields from the field experiment, dry-matter yields from the greenhouse experiment and the results of the determinations of the nitrogen and phosphorus contents in the grain were analyzed statistically as indicated by Snedecor (35). When the "F" test gave significant values for treatments, the Duncan (13) multiple range test was computed.

RESULTS AND DISCUSSION

Field Experiment

The application of 18 pounds of P_2O_5 per acre yielded an average of 6.6 bushels of grain more than wheat grown without the application of phosphorus. The yield differences between levels of phosphorus above 18 pounds per acre were generally small and not significant. However, the 72 pound rate of P_2O_5 averaged 2.4 bushels per acre more than the 36 pound per acre rate when plowed down and this was significant between the 5 and 10 per cent level of confidence. There were no differences in the yields of wheat due to method of application as shown by Tables V and VI and Fig. 1.

The lack of yield increases for rates of application larger than 18 pounds of P_2O_5 per acre could be due to one of the following reasons:

1. Factors other than phosphate may have been limiting yields. It is suggested that probably the 40 pounds of nitrogen per acre may have been insufficient to promote increases in the yields of grain when the phosphorus rate was above 18 pounds per acre. Van der Merwe (39) observed that a deficiency of available phosphorus was a most important factor limiting the fertility of subsoils and that correction of this deficiency frequently permitted a response to nitrogen additions. Other experiments on the same kind of soil on which the present study was conducted showed that nitrogen rates higher than 40 pounds per

TABLE V

YIELDS OF GRAIN OBTAINED IN THE FIELD EXPERIMENT, PLUS PROTEIN AND PHOSPHORUS PERCENTAGES OF THE GRAIN DUE TO THE EFFECT OF THE PHOSPHORUS RATES AND PLACEMENT METHODS

Fertilizer Placement Method	Treatment N P K	Grain Yields (Bushels/Acre)	Per cent Protein	Per cent Phosphorus
Seeding Depth Application in Bands	1. - 40 - 0 - 40	15.8	14.22	0.245
	2. - 40 - 18 - 40	22.4	10.81	0.332
	3. - 40 - 36 - 40	23.1	10.57	0.338
	4. - 40 - 72 - 40	22.0	10.39	0.424
	5. - 40 - 144 - 40	22.7	10.41	0.453
Plowed Down to Six Inch Depth	6. - 40 - 0 - 40	16.1	14.63	0.252
	7. - 40 - 18 - 40	23.3	10.63	0.291
	8. - 40 - 36 - 40	22.6	10.59	0.345
	9. - 40 - 72 - 40	25.0	10.38	0.381
	10. - 40 - 144 - 40	23.4	10.50	0.432

TABLE VI

ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF THE GRAIN YIELDS OBTAINED IN THE FIELD EXPERIMENT

Source of Variation	d.f.	S.S	M.S.	F
Total	39	0.905		
Blocks	3	0.241		
Methods	(1)	0.0105	0.0105	1.44
Levels	(4)	0.4369		
None vs Fert.	(1)	0.4333	0.4333	59.36**
Among Fert.	(3)	0.0026	0.0009	
Methods x Levels	(4)	0.0185	0.0046	
Error	27	0.198	0.0073	

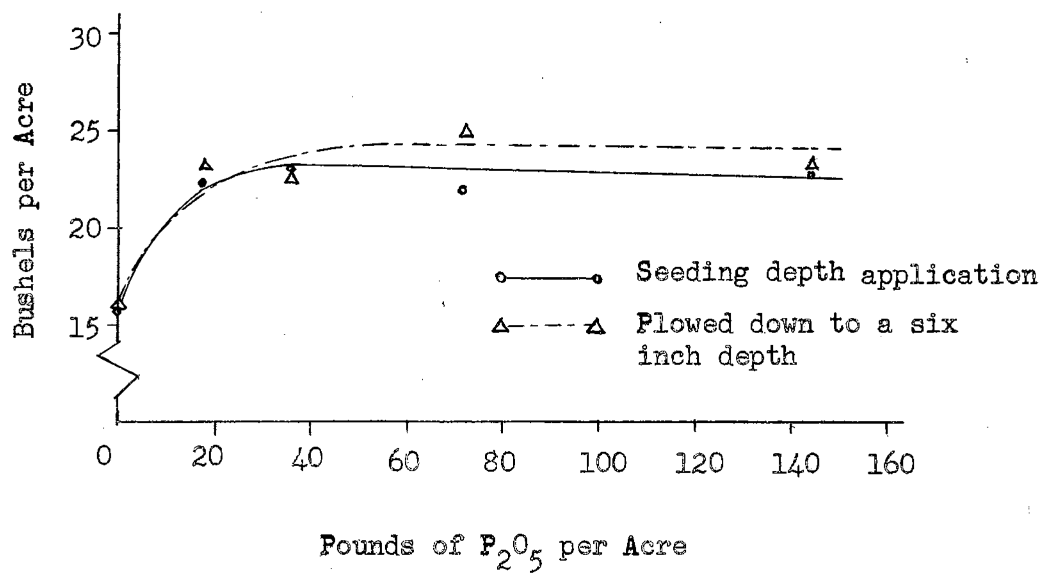
** Significant at 1 per cent level

Multiple range test, 5 per cent level of confidence

Treat. No.	1	6	4	2	8	5	3	7	10	9
Rp		0.124	0.130	0.134	0.137	0.139	0.141	0.142	0.143	0.144
Mean	0.577	0.589	0.805	0.818	0.825	0.831	0.845	0.853	0.859	0.915

Any two means underscored by the same line are not significantly different

Fig. 1. Effect of rates of applied phosphorus on grain yield



were necessary for optimum yields during the 1958-59 wheat season.

2. Soil moisture condition during the second part of the growth period of the plant, either at the heading time or at the grain formation stage, cannot be discounted as another possible limiting factor or probably these two limiting factors were interacting. In earlier studies it was concluded that the amount of moisture in the soil can affect the availability of phosphorus (18). Neidig and Snyder (26) found that the wheat yield decreased when the soil moisture content was low at the fruiting period. Robins and Domingo (30) reported that soil moisture depletion to the wilting percentage for periods of 1 to 2 days during the tasseling or pollination period in corn resulted in as much as a 22 per cent yield reduction.

3. The small differences in yields obtained from additions of P_2O_5 above 18 pounds per acre could possibly be attributed to a lack of availability of the higher phosphate rates due to some form of phosphate fixation. As shown in Table II, the soil on which this experiment was conducted has an acid reaction and phosphate availability is usually decreased in acid soils. It is not likely that phosphate fixation could occur without reducing the availability of the 18 pound per acre rate of phosphate fertilizer to such an extent that no response would have been obtained from the first increment. Investigations by Moser (25) reported that only one-tenth to

one-half of the phosphorus added to the soil was used by plants while the remainder was fixed by the soil. Studies on the phosphorus availability have demonstrated that the applied phosphorus is fixed by the soil by reacting with the aluminum and iron oxides, forming aluminum and iron phosphates which are highly insoluble phosphates (8, 9, 31, 37). Aluminum determinations in the soil used in the present experimental work indicated the presence of this element in substantial quantities. No test for iron content was made.

4. Probably only small amounts of phosphate are needed in this soil for high yields of wheat. Experiments conducted at several locations in the Great Plains states have shown that only small amounts of applied phosphate were necessary for maximum yields.

In Table V the protein data show that in every case phosphorus applications decreased the protein content of the grain compared with the protein content of the grain from plants grown on unphosphated plots. However, protein percentages were similar among phosphorus rates above 18 pounds of P_2O_5 and for methods of application (Table VII).

Total protein production per acre is approximately the same for phosphate and unphosphated plots.

The decrease in protein percentages of the grain was a result of the needs for more nitrogen in the plants which received phosphate because they had greater plant development and higher grain yields. Plants on the check plots had larger amount of nitrogen per head (or per grain) than those plants which received phosphate, consequently those plants on the phosphated plots had less nitrogen for protein synthesis. If the grain yields increased proportionally to the phosphorus applications, the protein content of the grain should tend to decrease with increasing increments of applied phosphorus, instead of giving almost constant percentages after the first increment of phosphorus as observed in Table V and in Figure 2.

TABLE VII

ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF THE PROTEIN PERCENTAGES CONTAINED IN THE GRAIN

Source of Variation	d.f	S.S	M.S.	F
Total	39	105.257		
Blocks	3	1.033		
Methods	(1)	0.043	0.043	
Levels	(4)	97.409		
None vs Fert.	(1)	96.892	96.892	427.51**
Among Fert.	(3)	0.517	0.172	
Methods x Levels	(4)	0.387	0.097	
Error	27	6.385	0.236	

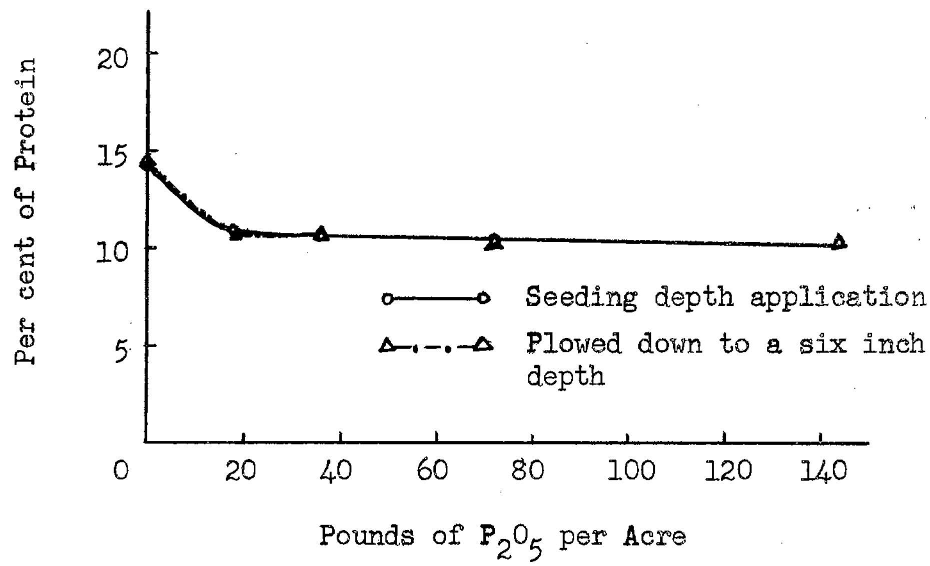
** Significant at 1 per cent level.

Multiple range test 5 per cent level of confidence.

Treat. No.	9	4	5	10	3	8	7	2	1	6
Rp		0.71	0.74	0.76	0.78	0.79	0.80	0.81	0.81	0.82
Mean	10.38	10.39	10.41	10.50	10.57	10.59	10.63	10.81	14.22	14.63

Any two means not underscored by the same line are significantly different.

Fig. 2. Effect of rates of applied phosphorus on the protein content of the grain



The uptake of phosphorus (Table V) by the plants was directly proportional to the amount of phosphorus added to the soil. Thus, plant absorption of phosphorus increased as the applied phosphorus increased, although, the phosphorus content of the grain is not proportional to the grain yields above the level of 18 pounds of P_2O_5 per acre. It is suggested that most of the phosphorus was taken up by the plants in the earlier stages of growth and that the lack of significant differences among phosphate levels in the final yield may be due to some other limiting factors in the later stages of plant growth.

Generally, the phosphorus uptake by plants was greater in plants which received the phosphorus application at seeding depth than those where the phosphorus was plowed down at the 6 inch depth (Table VIII and Fig. 3). A probable reason for these uptake differences of phosphorus was the fertilizer placement method. Phosphorus placement at a

TABLE VIII

ANALYSIS OF VARIANCE AND MULTIPLE RANGE TEST OF THE PERCENTAGES OF PHOSPHORUS CONTAINED IN THE GRAIN

Source of Variation	d.f.		S.S	M.S.	F
Total	39		0.228		
Blocks	3		0.013		
Methods		(1)	0.0080	0.0080	12.69
Levels	(1)	(4)	0.1862		
None vs Fert.	(1)		0.1117	0.1117	177.30**
Among Fert.	(3)		0.0745	0.0248	39.36**
Methods x Levels		(4)	0.0040	0.0010	1.59
Error	27		0.017	0.00063	

** Significant at 1 per cent level.

Multiple range test, 5 per cent level of confidence.

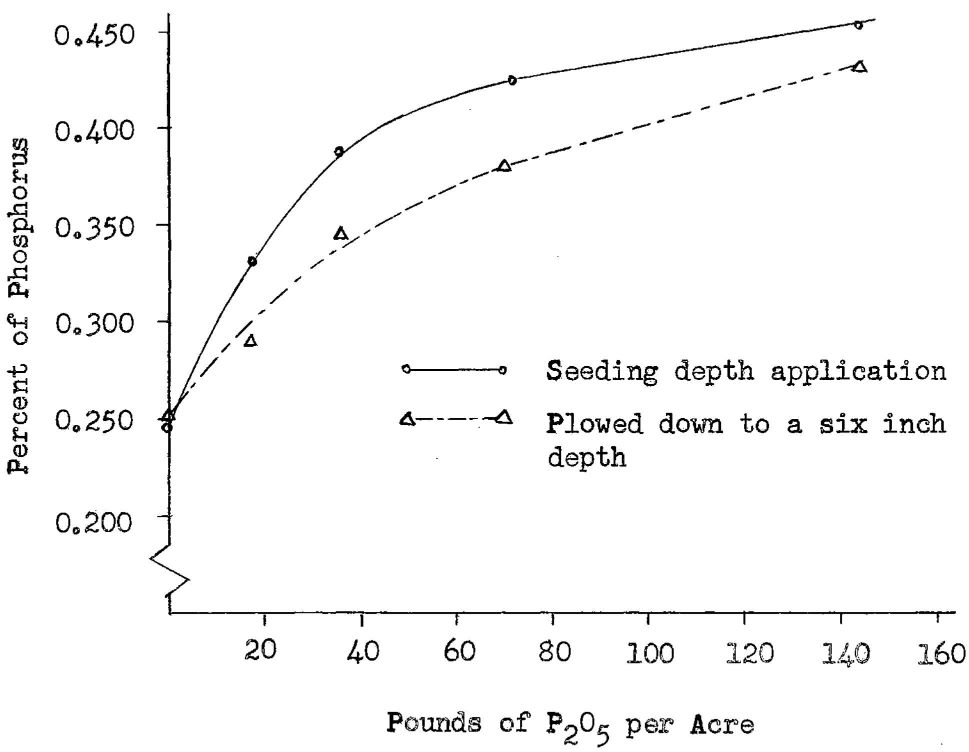
Treat No.	1	6	7	2	8	9	3	4	10	5
Rp		0.036	0.038	0.039	0.040	0.041	0.041	0.042	0.042	0.042
Mean	0.245	0.252	0.291	0.332	0.345	0.381	0.388	0.424	0.432	0.453

1 per cent level of confidence.

Treat. No.	1	6	7	2	8	9	3	4	10	5
Rp		0.049	0.051	0.052	0.054	0.054	0.055	0.056	0.056	0.057
Mean	0.245	0.252	0.291	0.332	0.345	0.381	0.388	0.424	0.432	0.453

Any two means not underlined by the same line are significantly different.

Fig. 3. Effect of rates of applied phosphorus on the phosphorus content of the grain



6 inch depth was farther away from the absorbing roots when most of the phosphorus uptake occurred.

Soil moisture content was determined (at six different depths) periodically throughout the wheat growing season. These moisture percentages obtained are reported in Tables IX and X. The available moisture percentages found at different dates during the whole plant cycle and the percentages of moisture retained against tensions of 1/10 atmosphere and 16 atmospheres for each of the six feet depth are graphically represented in Figure 4. The record of daily rainfall during the 1958-59 wheat season at the Agronomy Research Farm at Perkins, Oklahoma is reported in Table XI.

Possibly the soil moisture determinations were spaced at too wide a time interval, but the data obtained suggested that moisture may have been a limiting factor in wheat production. For instance on April 21 (Table IX) the moisture percentage in the 12 to 24 inch layer of soil reached the wilting point and it is logical to assume that the moisture percentage was around the wilting point for at least three or four days which would have reduced plant growth prior to the heading stage. Moisture content may also have reduced the grain yields about May 20 when the first foot of soil had the lowest moisture content of the entire wheat season and the second foot of soil profile reached the wilting point for a three or four day period. At this time the plant water needs were perhaps larger than at any other stage of development because it was the grain formation period. According to Table XI, the rainfall amount from May 10 to May 20 was low.

TABLE IX

PERCENTAGES OF AVAILABLE MOISTURE OCCURRING AT DIFFERENT DEPTHS AND AT VARIOUS TIMES DURING THE GROWING SEASON

	1958			1959					
Depth	Oct. 8*	Nov.14	Dec.19	Jan.15	Feb.18	Mar.25	Apr.21	May 20	June 8**
0-12"	24.09	10.98	15.05	13.70	11.44	15.96	20.03	8.72	29.97
12-24"	22.23	17.14	11.94	11.94	8.17	0.61	0.80	0.80	11.47
24-36"	22.44	25.13	22.44	29.99	24.59	14.89	18.66	8.41	7.33
36-48"	28.65	25.21	32.78	37.60	34.16	23.83	20.38	11.43	15.56
48-60"	37.13	32.45	36.36	37.92	37.14	37.14	29.32	-	24.63
60-72"	41.36	37.96	40.00	40.68	33.88	46.80	35.24	-	22.31

* Planting time date.

** Date of the harvest.

TABLE X

TABLE X

INCHES OF AVAILABLE WATER PER FOOT AT THE DIFFERENT DEPTHS
OF THE SOIL STUDIED IN THE FIELD EXPERIMENT

Depth	1958 Oct. 8*	1958 Nov. 14	1958 Dec. 19	1959 Jan. 15	1959 Feb. 18	1959 Mar. 25	1959 April 21	1959 May 20	1959 June 8**	Capacity of available water inches per foot
0-12"	1.14	0.52	0.71	0.65	0.54	0.75	0.94	0.41	1.42	4.72
12-24"	1.02	0.78	0.54	0.54	0.37	0.00	0.00	----	0.52	4.55
24-36"	0.90	1.01	0.90	1.20	0.98	0.60	0.75	0.34	0.29	4.01
36-48"	0.90	0.79	1.03	1.18	1.08	0.75	0.64	0.36	0.49	3.16
48-60"	1.04	0.91	1.01	1.06	1.04	1.04	0.82	----	0.69	2.80
60-72"	1.31	1.20	1.27	1.29	1.07	1.48	1.12	----	0.71	3.18
Total	6.31	5.21	5.46	5.92	5.08	4.62	4.27	1.11	4.12	22.42

* At planting time.

** At harvesting time.

Fig. 4. Percentages of available moisture at different dates during the plant cycle, moisture retained against tensions of 1/10 and 15 atms. in a six foot profile

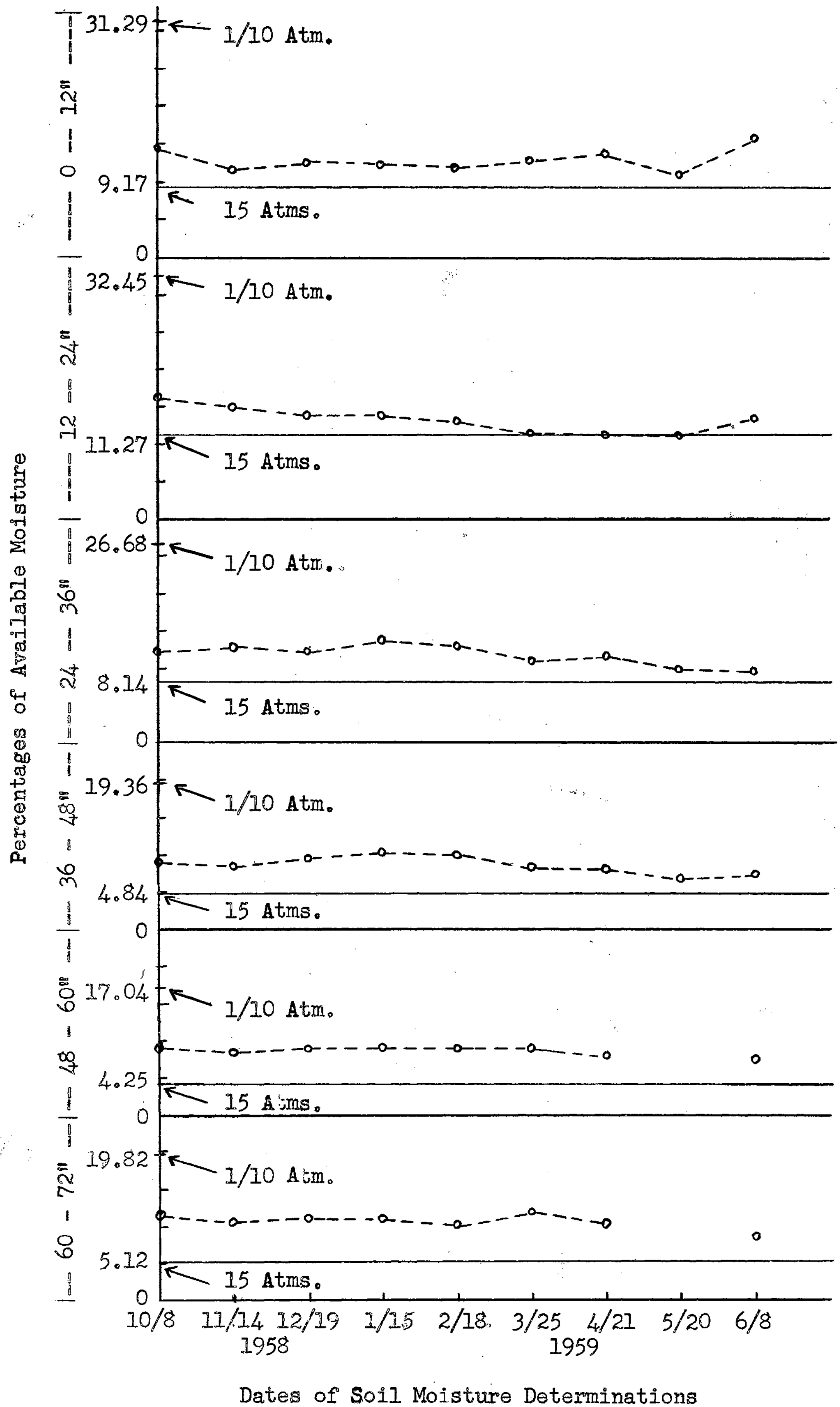


TABLE XI

RECORD OF DAILY RAINFALL DURING THE
1958-59 WHEAT SEASON AT THE
AGRONOMY RESEARCH FARM
AT PERKINS, OKLAHOMA

	1958						1959					
Day	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
1		0.49				0.01				0.03		0.89
2							0.01	0.06			0.07	
3												
4												0.44
5	T							0.01	0.08		0.96	
6	0.02		0.01									
7	0.16		0.01									
8		0.08					T			0.78	1.43	
9								0.40		0.02	0.17	
10		1.06	0.02								0.42	
11												0.26
12	1.88	0.10		0.44		0.47						
13					0.19		T					
14	0.13		0.12	T	T						0.01	
15			0.13	0.26			0.03				0.06	
16			2.49		0.37							
17		0.65			0.28					0.45		
18										1.13		
19												0.11
20		2.36	0.03				0.09		1.53			
21	0.11	0.02									0.65	
22	0.03							T			0.89	1.39
23		0.07	0.02									
24												
25									0.64		1.19	2.64
26	0.38			0.04		0.17						
27	1.42				0.23		T	0.52				
28								0.03	0.06			
29			0.16			0.10			0.03			
30			0.08			0.28						0.28
31							0.03		0.15			
Total	4.13	4.83	3.07	0.74	1.07	1.03	0.17	1.03	2.49	2.41	5.85	6.01

A total of 15.95 inches occurred during the wheat growing season (October 8, 1958 to June 8, 1959).

Greenhouse Experiment

Plant responses in dry matter yields to the application of available phosphorus are shown in Table XII and are statistically analyzed in Table XIII. A great increase in dry weight yield was observed when 18 pounds of P_2O_5 per acre were applied to the soil. Practically no yield differences were found among the rates of applied phosphorus above the level of 18 pounds of P_2O_5, but the yield from 72 pounds of available phosphorus was significant between 5 and 10 per cent level of confidence compared with yield produced by 36 pounds of P_2O_5.

As can be seen in Tables V and XII, a great similarity exists between the grain yields obtained in the field experiment and the dry weight forage yields obtained in the greenhouse. The latter yields are very similar to the grain yields when the phosphorus was plowed down to a depth of 6 inches. There was a great yield increase for the first increment of phosphorus and no differences in yields for the higher rates of applied phosphorus. A slight increase in yield was obtained when 72 pounds of P_2O_5 were applied. The highest phosphorus rate (144 pounds of P_2O_5) produced yields which were practically the same as those obtained from the use of either the 18 or 36 pound rates.

TABLE XII

DRY MATTER YIELD IN THE GREENHOUSE EXPERIMENT DUE TO THE APPLICATION OF DIFFERENT RATES OF SOLUBLE PHOSPHORUS

Treatment	N	P	K	Dry Weight (grams)
1.	40	0	40	1.023
2.	40	18	40	2.870
3.	40	36	40	2.840
4.	40	72	40	3.242
5.	40	144	40	2.942

TABLE XIII

ANALYSIS OF VARIANCE OF THE GREENHOUSE RESULTS

Source of Variation	d.f.	S.S.	M.S.	F
Total	14	10.374	2.359	2
Block	2	0.299		
Treatments	4	9.436	2.359	29.49**
Error	8	0.639	0.080	

** Significant at 1 per cent level of confidence.

Multiple range test, 5 per cent level of confidence.

Treat. No.	1	3	2	5	4
Rp		0.532	0.553	0.567	0.575
Mean	1.023	2.840	2.870	2.942	3.242

Any two means not underscored by the same line are significantly different.

SUMMARY AND CONCLUSIONS

The influence of five phosphorus fertilizer levels applied at seeding depth and plowed down to a six-inch depth on the yield and chemical composition of dryland winter wheat was investigated. This field experiment was conducted during the 1958-59 wheat season on a Norge fine sandy loam soil located at the Agronomy Research Farm at Perkins, Oklahoma. In this experiment a randomized complete block design with four replications and ten treatments was used. None, 18 36, 72 and 144 pounds of P_2O_5 per acre applied at the two depths. Forty pounds each of N and K_2O per acre were added to all treatments in an attempt to avoid any deficiency of these elements and to have the phosphorus as the only variable.

Soil moisture contents were determined at monthly intervals throughout the growing season. Determinations were made in order to assess the soil moisture conditions at the different stages of plant development.

A greenhouse experiment was carried out which consisted of a randomized complete block design with three replications and five treatments. The fertility levels were the same as those used in the field experiment, but all fertilizer materials were placed only at seeding depth. Wheat plants were grown for a two month period, harvested, and dry matter production was determined.

From the field and greenhouse studies, the following conclusions seem justifiable:

1. On this soil the phosphorus response was evident; the yields of grain were increased significantly due to the application of 18 pounds of P_2O_5 per acre when placed either in bands at seeding depth or broadcast and plowed down to a 6-inch depth.
2. Amounts greater than 18 pounds of available P_2O_5 applied to the soil had little effect on yields. The yields may have been held down due to one or more other limiting factors.
3. The methods of phosphate placement did not influence the yields of wheat.
4. Increases in the rates of applied phosphorus increased the phosphorus percentages in the grain. The larger the application of phosphorus the higher the phosphorus percentages in the grain.
5. Phosphorus applications decreased the protein percentages of the grain, but grain yields were higher on phosphated plots. The nitrogen available for protein synthesis was diluted in the grain of plants grown on plots which received phosphate.
6. In the greenhouse experiment responses of the wheat forage from added phosphate were very similar to the grain responses in the field experiment.

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APPENDIX

Profile Description of the Norge Fine Sandy Loam Soil*

Profile

A_1 0-7" Brown (7.5 YR 5/3; 3.5/2, moist) fine sandy loam, weak medium granular, permeable, pH 5.4, a few fine pores, grades to the layer below.

B_1 7-12" Reddish-brown (5 YR 5/5; 4/5, moist) sandy loam, weak medium granular, permeable, pH 5.8, contains a few fine pores, grades to the layer below.

B_{2-1} 12-22" Yellowish-red (5 YR 4/6; 3/6, moist) light sandy clay loam, weak coarse prismatic and weak medium subangular blocky, firm, slightly hard when dry, moderately permeable, pH 6.2, occasional pores and worm holes, a few fine black concretions, grades to the layer below.

B_{2-2} 22-30" Yellowish-red (5 YR 5/6; 4/6, moist) light sandy clay much like the layer above, pH 6.2 contains a few fine red spots.

B_3 30-43" Yellowish-red (5 YR 5/6; 4/6, moist) sandy clay loam, weak angular breakage, firm, hard when dry, pH 6.5, a few fine pores, grades to the layer below.

C 42-50+" Reddish-yellow (5 YR 6/6; 5/6, moist) sandy clay loam like the layer above but slightly less compact, pH 6.5. This material appears to be old alluvium but definite stratification bands are not evident.

* (16)

AVAILABLE PHOSPHORUS DETERMINATIONS BY SIX DIFFERENT METHODS OF THE SOIL USED IN THE FIELD AND GREENHOUSE EXPERIMENTS. VALUES REPORTED IN POUNDS PER ACRE

Depth	0.2N H_2SO_4	.1NHCl + .03N NH_4F	Dist. H_2O	0.1 Acetic Acid	0.025N HCl + 0.03N NH_4F	0.025N HCl + 0.03N NH_4F
	(1)	(2)	(3)	(4)	(5)	(6)
0-6"	57.75	9.46	4.67	7.08	27.18	10.82
0-12"	26.78	9.25	4.06	3.62	17.97	4.40

Each value is the average of eight samples.

(1) 2.5 grams of soil, 30 ml extracting solution, 20 ml aliquot.
(2) 4.0 grams of soil, 28 ml extracting solution, 20 ml aliquot.
(3) 2.5 grams of soil, 30 ml extracting solution (Dist. H_2O), 25 ml aliquot.
(4) 5.0 grams of soil, 200 ml extracting solution, 25 ml aliquot.
(5) 1.0 gram of soil, 50 ml extracting solution, 20 ml aliquot.
(6) 4.0 grams of soil, 28 ml extracting solution, 20 ml aliquot.

VITA

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