THE RESPONSE OF WHEAT TO PHOSPHORUS PLACEMENT AS AFFECTED BY SOIL MOISTURE CONDITIONS

By

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MOISTURE CONDITIONS

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I INTRODUCTION

Fertilizer placement for most efficient returns has been a question of considerable interest for many years. This has been especially true in areas of low rainfall where the moisture content of the topsoil remains below the permanent wilting point for long periods of the growing season.

There are many acres of soils with sandy surfaces in western Oklahoma that receive relatively small amounts of rainfall during the growing season. Therefore, crops must largely depend on previously stored subsoil moisture for growth. Many of these soils are also low in fertility.

In conditions such as these, special questions of fertilizer placement arise. Should fertilizer be placed near the soil surface where soil moisture is below the permanent wilting point during much of the growing season, or should the placement be deeper in the profile where moisture is more abundant?

The objective of this study was to determine the effectiveness of phosphorus fertilizer uptake by wheat at different depths of fertilizer placement and varying levels of soil moisture.

II LITERATURE REVIEW

There must be an adequate supply of inorganic nutrient ions, water, and oxygen present at all times in the root zone for optimum plant growth. An inadequate supply of any one of these growth substances will usually result in a reduction of plant growth that cannot be compensated for later (31)[1]. Wadleigh and Richards (44) state:

> The mineral nutrition of plants within the available range of soil moisture is conditioned by (a) the extent to which growth and, consequently, mineral utilization might be limited by water supply, (b) the effect of change in thickness of the moisture films on nutrient availability, and (c) the effect of variations in soil moisture tension upon microbiological activity.

Effects of Moisture

According to Fried et al. (17) phosphorus absorption by plants is controlled by the concentration of phosphorus in solution. In soils well supplied with native and/or applied phosphorus, the removal rate will be dependent upon a solubility product that will continually provide an adequate quantity of phosphate in the root environment. Danielson and Russell (7) state that high soil moisture tensions would reduce the movement of water to the absorbing surface, thus reducing the ion concentration near the root surface. Fawcett and Quirk (13) found that available soil phosphorus was predominately present in those fine pores

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[1]Figures in parenthesis refer to Literature Cited.

of the soil which remain filled with water after the soil moisture content has been reduced to, or below, the wilting point. Several workers have concluded that fertilizers added to soil at or near the wilting point are ineffective and of very little value in plant nutrition (6, 10, 16, 18, 20, 43). However, it has been reported that many plants have the ability to remove nutrients from soil at moisture levels approaching the permanent wilting point, providing a portion of the plant roots are in soil above the permanent wilting point (2, 3, 4, 7, 21, 27, 43).

Dean and Gledhill (9) showed that excised rye roots were able to absorb phosphorus from a dry soil. Roots conditioned at low moisture stress absorbed phosphorus rapidly from the soil and roots conditioned at high moisture stress absorbed phosphorus at a reduced rate. Moisture movement from the roots to the soil was obtained during the absorption period.

Fawcett and Quirk (13) found that increasing water stress did not affect the rate of phosphorus uptake by young plants, provided the plants were not damaged by wilting. Haddock (18) found that the phosphorus content of sugar beets decreased as the soil moisture tension increased. Jordan et al. (23) reported that uptake of fertilizer phosphorus was greater at low moisture tensions than at high moisture tensions, although yields of potato vines and tubers were unaffected.

According to Lipps et al. (27) alfalfa absorbed very little fertilizer phosphorus from a subsoil during the early part of the growing season when surface moisture was adequate. During the latter part of the season, after the surface soil became dry, phosphorus adsorption from the surface remained relatively high but an increased uptake of fertilizer phosphorus from the subsoil was obtained. Bickford[2] found that less fertilizer phosphorus was taken up by forage sorghum when applied in dry soil than when applied in moist soil. Yields were greatest when phosphorus was applied in a moist zone. Studies by Mitchell (29) showed an increase in the proportion of fertilizer phosphorus contained in spring wheat under drought conditions.

Bertrand and Kohnke (2) obtained values indicating a greater uptake of nitrogen and potassium from a compacted subsoil having a low moisture content than one having a high moisture content. Moisture levels had no effect on the uptake of nitrogen and potassium from a subsoil that had not been compacted. Phosphorus uptake was not affected by differences in soil moisture. Volk (43) presented evidence that phosphorus was not assimulated from a dry soil as readily as nitrogen and potassium.

Breazeale (3) and Breazeale and Crider (4) concluded that some plants could absorb nutrients from a soil when the moisture content was maintained at the permanent wilting point provided a portion of the roots were in soil having a moisture content above the wilting point. Millar (28) found that alfalfa roots could absorb moisture from the subsoil at a sufficient rate to prevent wilting when the upper 15 inches of roots were placed in dry quartz sand.

Davis (8) found that corn roots were able to extract soil moisture below the wilting point near the plant while a portion of the roots were in soil above the wilting point. He also found that growth was stopped before the soil moisture of the root zone was lowered to the permanent wilting point. Guayule and alfalfa were found to extract

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[2]Bickford, C. P. The response of forage sorghum to applied phosphorus as affected by soil moisture and depth of placement. (unpub. M.S. thesis, Oklahoma State University, 1960), pp. 18-36.

moisture from the topsoil at tension near the wilting point even though moisture was held at less tension at lower depths (21).

Kmoch et al. (24) reported root extension of winter wheat into soil with a moisture tension in excess of 15 atmospheres and the removal of moisture at a tension greater than 15 atmospheres. Breazeale (3), Breaszeale and Crider (4), and Hunter and Kelley (22) all reported root extension into soil below the wilting point and a buildup of moisture in the dry soil. However, Hunter and Kelley (22) found that in no case was the moisture content increased to the permanent wilting percentage as reported by Breazeale (3) and Breazeale and Crider (4).

Hendrickson and Veihmeyer (19) found that sunflowers and beans were unable to extend their root systems into a soil where the soil moisture content was below the permanent wilting point.

According to Hobbs and Bertramson (20) tomato plants were unable to take up enough boron from a dry soil to prevent deficiencies when part of the root system was in a moist soil. Hunter and Kelley (21) obtained some indications that alfalfa would absorb phosphate from soil at the wilting point when a portion of the roots were in moist soil.

Depth of Placement

Yield increases due to subsoil fertilization have been reported for alfalfa and corn (2, 10, 12, 14, 25, 34, 37). Robertson (37) also reported a decrease in corn yields due to subsoil placement of fertilizer as compared to surface application. However, most of the work indicates that yield differences are not obtained for a majority of crops when surface (upper six inches) and subsurface fertilizer placements are compared (5, 12, 15, 25, 32, 33, 35, 36, 41, 45, 46, 47).

Mixing high rates of fertilizer completely within the soil at depths of 18, 27, and 36 inches increased corn yields when equivalent amounts were mixed with the surface nine inches (14). Pitner (33) was able to increase corn yields by placing nitrogen eight to 10 inches below the seed. In only one of three years was a yield increase obtained that could be attributed to phosphorus.

A Red Bay fine sandy loam that had been cultivated for several years responded more to phosphorus placed at 14 and 20 inches than at two and eight inches, whereas yields of corn on a virgin Red Bay fine sandy loam were greatest for the two inch placement and decreased with descending placements (37). Scarseth (38) found that corn yielded better during a prolonged drought when phosphorus was plowed down than when banded in the row. Tissue tests showed a phosphorus deficiency when phosphorus fertilizer was banded in the row with the seed.

Drake and Stewart (10) obtained increases in yield and phosphorus content of alfalfa when phosphorus was banded at eight inches as compared to more shallow depths. A split application at three and eight inch depths produced better results than the three inch placement alone. Lawton et al. (26) found that the percent of plant phosphorus derived from fertilizer by alfalfa and bromegrass decreased with depth of placement from the surface to 36 inches. Murdock and Engelbert (30) found that uptake of fertilizer phosphorus decreased with depth of placement for two of the four soils tested. Phosphorus fertilizer uptake was greatest at 24-30 inches for Parr silt loam and 6-12 inches for Kewaunee silty clay loam. Stanford and Nelson (41) found that more phosphorus was recovered from fertilizer placed at seed level than when placed either above or below. Bickford[3] obtained greater uptake of fertilizer phosphorus from placement at four and eight inches than from placement at 16 inches or a split placement at four and 16 inches.

Working with a Texas Blackland soil, Allen et al. (1) found that the phosphorus content of wheat was higher when phosphorus was mixed into the surface eight inches than when the material was banded at two, four, and eight inches. The eight inch bands increased total phosphorus more than the two and four inch bands. When vetch was used as the experimental crop, phosphorus mixed with the surface eight inches and the two and four inch bands gave similar results. Each of three treatments increased the total phosphorus content when compared to the eight inch band placement. Haddock (18) found a greater concentration of phosphorus in sugar beet leaves when phosphorus was banded at four inches than when broadcast on the surface.

Root proliferation of potatoes was obtained by Bushnell (5) when fertilizer was added to the subsoil. However, tuber yields were not always increased. Engelbert and Troug (12) reported that deep placement of lime and fertilizer promoted root penetration to the depth of placement. Fehrenbacker et al. (14) found increased root activity of corn with placement of fertilizer to 36 inches. Depth of root penetration was depressed when high rates of fertilizer was applied to the upper nine inches as compared to equivalent amounts distributed to depths of 18, 27 and 36 inches. According to Ferrant and Sprague (15), deep placement of fertilizer increased the root formation for red clover but did not increase yields.

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[3]Ibid.

Duncan and Ohlrogge (11), Ferrant and Sprague (15), Millar (28), and Pohlman (34) found that subsoil placement of fertilizer increased root activity in the zone of placement. Younts and York (47) reported that when a complete fertilizer was concentrated in the upper six inches of a soil deeper root penetration was obtained, but there was very little evidence that deep placement stimulated root activity in the subsoil. Banding nitrogen and phosphorus together increased root activity in the zone of fertilizer placement, whereas banding nitrogen and phosphorus separately did not affect root development, and phosphorus banded alone decreased root development (11).

Wheat that had received a broadcast application of nitrogen fertilizer extracted more water from the soil than did unfertilized wheat (24). Surface applied nitrogen did not limit root penetration. Younts and York (47) found that concentrating a complete fertilizer in the upper six inches of soil increased the moisture removal by corn from 15 and 21 inch depths as compared to mixing to a depth of 24 inches. No difference was found in the total amount of water removed between deep and shallow placement of fertilizer. Alfalfa wilted less during hot dry weather where phosphorus was banded at eight inches as compared to three inch placement (10).

Fox and Lipps (16), working with sub-irrigated soils, showed that root penetration into phosphorus deficient subsoil was limited. When the subsoils were not deficient in phosphorus, root penetration was not limited. This indicates that a shift from surface to sub-surface moisture would necessitate a shift from surface to sub-surface nutrition. It was concluded that it was possible for plants to absorb water without absorbing phosphorus, or vice versa.

III METHODS AND MATERIALS

A greenhouse experiment with hard red winter wheat was initiated. The objectives were to determine the effect of phosphorus fertilizer placement and various soil moisture conditions upon the uptake of phosphorus and forage yield. The moisture - phosphorus interaction on the uptake of phosphorus and yield of forage was also studied.

Description of Soil Used

A Brownfield loamy fine sand was used in this experiment. The Brownfield soils occur in the Reddish Chestnut and Reddish Brown soil zones of the High Plains. The parent materials are very sandy earths that appear to be aeolian. The principle associated series are Amarillo, Dalhart, Travoli, and Springer. This soil is found extensively in southwestern Oklahoma, northwestern Texas, and eastern New Mexico.

The Brownfield Soil is developed on undulating to hummocky upland bordering rivers. The principle native vegetation is shinnery oak and coarse grasses, largely sand dropseed and little bluestem, with some scattered yucca and sage.

The gently sloping Brownfield soils are cultivated to cotton and grain sorghum. The more sloping soils are used for grazing. The Brownfield soil is very susceptible to wind erosion and the fertility is depleted rather rapidly when cultivated.[4]

[4]Templin, E. H., Official description of Brownfield series. Rev. 5-17-46.

Experimental Procedure

The greenhouse experiment was set up in a 3 by 4 factorial with a randomized block design containing four replications. The treatments consisted of three moisture conditions: surface soil (0-12") wet - subsoil (12-25") wet; surface soil wet - subsoil dry; and surface soil dry - subsoil wet, and four zones of phosphorus placement at 4", 8", 16" and 4 and 16" depths. Treatments are given in Table I. 'Concho' (Triticum aestivum (L.), a variety of hard red winter wheat was grown during the experiment.

The containers used in this experiment and method of soil preparation were described by Bickford[5].

Water was added to all pots prior to planting, in quantities sufficient to bring the moisture level to approximately field capacity, as determined by electrodes placed in the containers. Electrodes sensed the presence of a wetted front upon addition of water to the pots. Wheat was planted on November 20, 1959. Both surface-soil and sub-soil were kept moist until roots were well established in the sub-soil. Root establishment was determined by periodic observations of a control container equipped with a removable wall to facilitate observations.

Eighty pounds of nitrogen per acre as ammonium nitrate was dissolved in water and applied to the surface of all plots on December 20, 1959. Plants were periodically removed until January 4, 1960, when thirty-five plants remained in each pot. Roots were observed in the sub-soil of the control pot at this time. All pots were kept moist until February 6, 1960, to insure good root development in the subsoil; the

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[5]Bickford, pp. 7-11.

TABLE I

TREATMENT DESIGNATION ACCORDING TO PHOSPHORUS PLACEMENT AND MOISTURE CONDITIONS

Treatment No.	Treatment Symbol		Phosphorus Placement	Moisture condition		P_2O_5
	Moisture	Placement		Topsoil	Subsoil	lbs./acre
1	W/D	P_1	4"	wet	dry	80
2	D/W	P_1	4"	dry	wet	80
3	W/W	P_1	4"	wet	wet	80
4	W/D	P_2	8"	wet	dry	80
5	D/W	P_2	8"	dry	wet	80
6	W/W	P_2	8"	wet	wet	80
7	W/D	P_3	16"	wet	dry	80
8	D/W	P_3	16"	dry	wet	80
9	W/W	P_3	16"	wet	wet	80
10	W/D	P_4	4" & 16"	wet	dry	20 & 60
11	D/W	P_4	4" & 16"	dry	wet	20 & 60
12	W/W	P_4	4" & 16"	wet	wet	20 & 60

moisture treatments were started at this time.

Those areas of the pots designated as dry did not receive water during the rest of the experiment. Those zones of the soil designated as wet were checked periodically by use of electrodes and were watered to maintain the moisture level between the permanent wilting point and field capacity.

Phosphorus fertilizer solution was made up for each pot to replace the amount removed by the previous crop of sugar drip sorghum grown by Bickford[6]. Three ml. of P^{32} solution containing 29.3 µc./ml. were added to the phosphorus solution for each pot and made up to eight ml.

On February 20, 1960, the wheat was harvested from all pots. Immediately following harvest, the phosphorus fertilizer solution was added to the pots. A 30 ml. medical syringe with Luer-lock fittings and a 14 gauge Lukens catheter were used for injection of the phosphorus solution into the pots. One ml. of the phosphorus solution was injected at one inch intervals, beginning one and one-half inches from the inside wall and continuing across the diameter of the pot. The procedure was repeated at the four, eight, and sixteen inch depths. The split application was made by applying 0.25 ml. of solution at one inch intervals beginning one and one-half inches from the inside wall at the four inch depth and 0.75 ml. of solution at one inch intervals beginning one and one-half inches from the inside wall at the 16 inch depths.

After P^{32} injection, the plants were grown for 35 days. At the end of the growth period the plants were harvested, dried at 105°C for 18 hours and ground in an intermediate Wiley mill, using a 20-mesh sieve.

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[6]Bickford, p. 26.

A one gram sample of forage was digested and analyzed for total phosphorus using a modified procedure of Sheldon and Harper (39). A 2 ml. aliquot of the digested sample was transferred to a glass planchet and dried under an infrared lamp on a 16 rpm sample spinner for determination of P^{32}. The counting equipment consisted of a Nuclear-Chicago model 186 scaler and a model DS 5-lP (Scintillation) detector probe equipped with a XTB anthracene crystal 3/16 inch thick by $1\frac{1}{2}$ inches in diameter. The detector was housed in a Nuclear-Chicago model 3053 aluminum veneered lead shield.

Yield, total phosphorus uptake, phosphorus removed, and fertilizer phosphorus uptake were all subjected to statistical analysis according to Snedecor (40) and Steele and Torie (42).

IV RESULTS AND DISCUSSION

Results were concerned with the yield and phosphorus content of wheat forage as affected by the various treatments. Four phosphorus fertilizer placements at a uniform level of phosphorus under three moisture regimes were studied.

Plant Growth

Apparently, roots were not well established in the subsoil of all pots when the moisture regimes were started. Some of the plants growing in the dry surface soil treatment began to die within a few days after watering of the surface ceased. All of the plants receiving treatments five and eight of replication III died within 10 days. Many of the plants from the other placement depths having the dry surface soil died before harvest. There was evidence of roots in the subsoil where phosphorus was placed at the 16 inch depth as indicated by the uptake of P^{32}.

Yields

Forage yields are presented in Table II and Figure 1. Yields are reported in grams of oven dry forage per pot. Analysis of variance is given in Table III, and Tukey's hsd in Table IV. Significant yield increase was obtained from a moist topsoil when compared to a dry topsoil. There was no significant difference in yield between a moist and dry subsoil when the surface soil was moist.

TABLE II

OVEN DRY YIELD OF WHEAT GROWN IN THE GREENHOUSE UNDER THREE MOISTURE LEVELS WITH FOUR DEPTHS OF PHOSPHORUS FERTILIZER PLACEMENT

Treatment No.	Treatment Symbol	Replications I	II	III	IV	Mean
		Grams per pot				
1	W/D P_1	5.4077	4.6444	5.0604	3.8272	4.7349
2	D/W P_1	0.2405	1.8249	1.9876	0.6693	1.1806
3	W/W P_1	3.8012	5.3679	4.0570	4.5598	4.4465
4	W/D P_2	4.9429	5.4374	5.2787	4.2131	4.9680
5	D/W P_2	1.3446	0.9715	0.0044	1.4613	0.9455
6	W/W P_2	5.3935	5.0064	2.9177	4.8776	4.5488
7	W/D P_3	4.6842	3.2768	5.3105	3.7056	4.2443
8	D/W P_3	3.0944	0.2958	0.0417	0.6347	1.0167
9	W/W P_3	6.0180	4.5145	3.9962	4.6336	4.7906
10	W/D P_4	4.1768	2.6978	4.5384	4.1595	3.8931
11	D/W P_4	1.2291	0.7746	0.1829	1.2345	0.8553
12	W/W P_4	4.2022	4.2871	4.0947	5.8472	4.6078

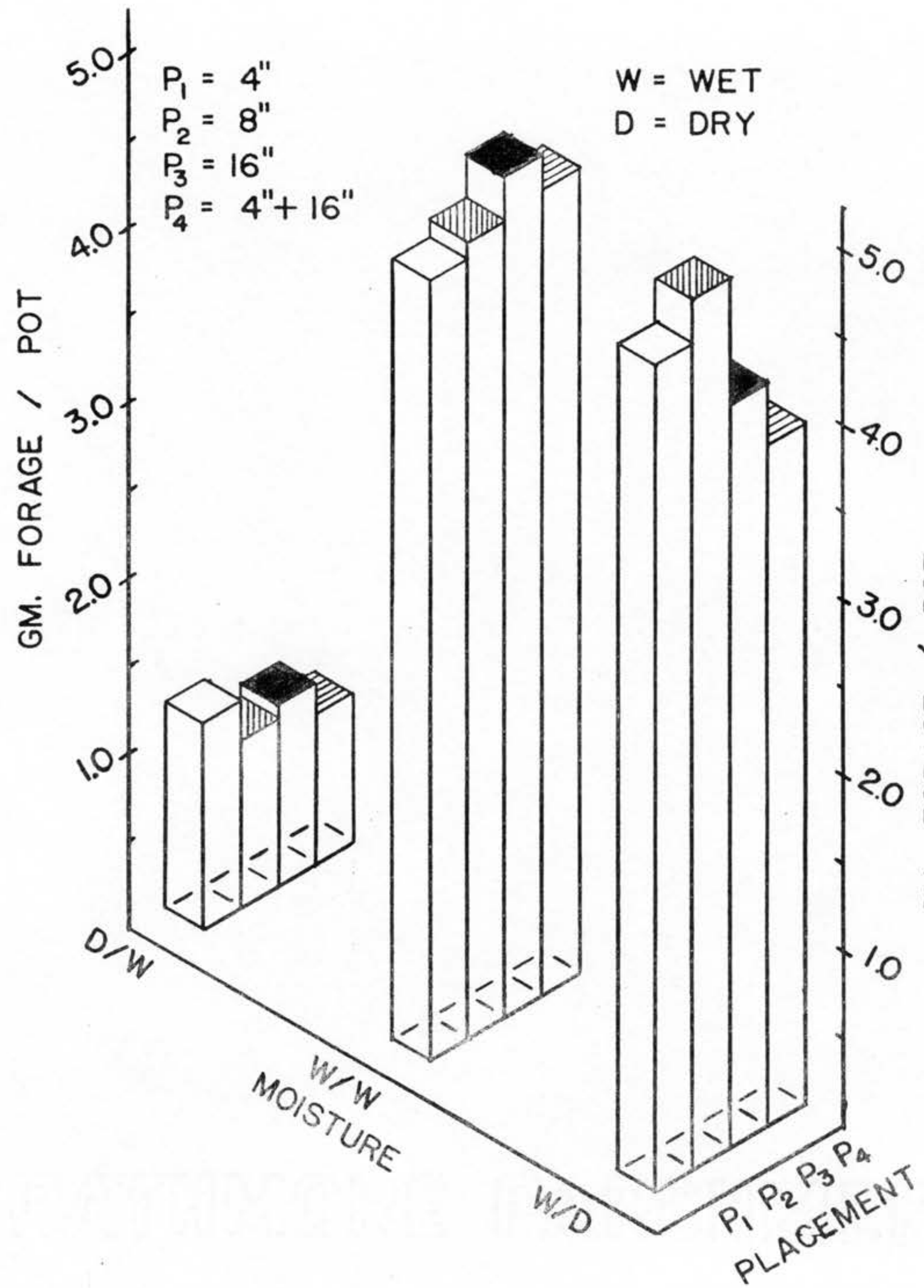

Figure 1. Yield of Forage as Affected by Moisture Levels and Phosphorus Placement.

TABLE III

ANALYSIS OF VARIANCE ON THE GRAMS OF FORAGE PRODUCED PER POT

Source	dF	MS	F	
Total	47			
Replications	3	0.7665	1.05	
Treatments	11	12.394	16.93	**
W/D ≁ D/W vs W/W@	(1)	37.2454	50.88@	**
W/D vs D/W@	(1)	95.8060	130.88	**
W/D ≁ D/W vs W/W (A)	(1)	24.4151	33.35	**
W/D vs D/W (B)	(1)	77.8255	106.32	**
P_4 vs P_1, P_2, & P_3	(1)	0.8756	1.20	
Among P_1, P_2, & P_3				
P Linear	(1)	0.0643	0.09	
P Quadratic	(1)	0.0580	0.08	
$P_L \times A$	(1)	0.6010	0.82	
$P_Q \times A$	(1)	0.0960	0.13	
$P_L \times B$	(1)	0.1068	0.15	
$P_Q \times B$	(1)	0.5319	0.73	
Error	33	0.7320		

@ Comparisons made with all placements. Other comparisons exclude P_4.

$s_m = 0.4278$ C.V. = 25.52%

TABLE IV

TUKEY'S HSD TEST ON YIELD OF FORAGE

Trt.	gm./pot	
W/D P_2	4.9680	a
W/W P_3	4.7096	a
W/D P_1	4.7349	a
W/W P_4	4.6078	a
W/W P_2	4.5488	a
W/W P_1	4.4465	a
W/D P_3	4.2443	a
W/D P_4	3.8931	a
D/W P_1	1.1806	b
D/W P_3	1.0167	b
D/W P_2	0.9455	b
D/W P_4	0.8553	b

Any two means not covered by the same letter are significantly different at the 1% probability level. Any two means covered by the same letter are not significantly different at the 1% probability level.

There was no significant difference due to phosphorus placement. The greatest yield was obtained when phosphorus was placed eight inches below the surface of a soil having a moist topsoil and a dry subsoil. Yields were lower when phosphorus was placed in a dry subsoil than when placement was in a moist surface soil, but the difference was not significant. Yields were not significantly different between subsoil and surface soil placement when the surface soil was dry.

Phosphorus Content of Forage

Phosphorus per gram of forage is shown in Table V and Figure 2. Analysis of variance is given in Table VI and Tukey's hsd in Table VII. Values for treatments five and eight of replication III were estimated using the missing plot technique found in Snedecor (40) as there was not enough forage produced for phosphorus analysis.

Significance at the 5 percent level was obtained between treatments. There was a significant difference in phosphorus uptake from a completely moist soil and from a soil that was dry either in the topsoil or subsoil when all levels of phosphorus placement were considered; however, there was no difference in phosphorus uptake between moisture levels at any one phosphorus placement.

Phosphorus uptake due to placements at four, eight, and 16 inches gave a highly significant linear response. Uptake decreased as depth of placement increased. Greatest uptake per unit of forage was obtained when the surface soil was dry. Least uptake of phosphorus per gram of forage occurred when the entire soil was moist.

TABLE V

PHOSPHORUS UPTAKE BY WHEAT AS AFFECTED BY MOISTURE LEVELS AND PHOSPHORUS PLACEMENT

Treatment		Replications				Mean
No.	Symbol	I	II	III	IV	
		Milligrams phosphorus per gram sample				
1	W/D P_1	3.38	4.55	4.75	5.40	4.52
2	D/W P_1	7.15	5.40	4.80	3.20	5.14
3	W/W P_1	3.74	4.55	3.44	3.84	3.89
4	W/D P_2	3.32	3.68	4.70	3.30	3.75
5	D/W P_2	3.56	5.09	4.18[a]	2.32	3.79
6	W/W P_2	3.16	3.70	3.84	3.18	3.47
7	W/D P_3	2.84	2.70	3.38	3.00	2.98
8	D/W P_3	2.40	3.38	3.74[a]	3.85	3.34
9	W/W P_3	2.48	2.78	3.28	2.04	2.65
10	W/D P_4	3.76	4.95	3.36	3.78	3.96
11	D/W P_4	2.86	4.52	6.34	2.80	4.13
12	W/W P_4	2.96	3.38	3.70	2.58	3.16

[a] Estimated by missing plot technique

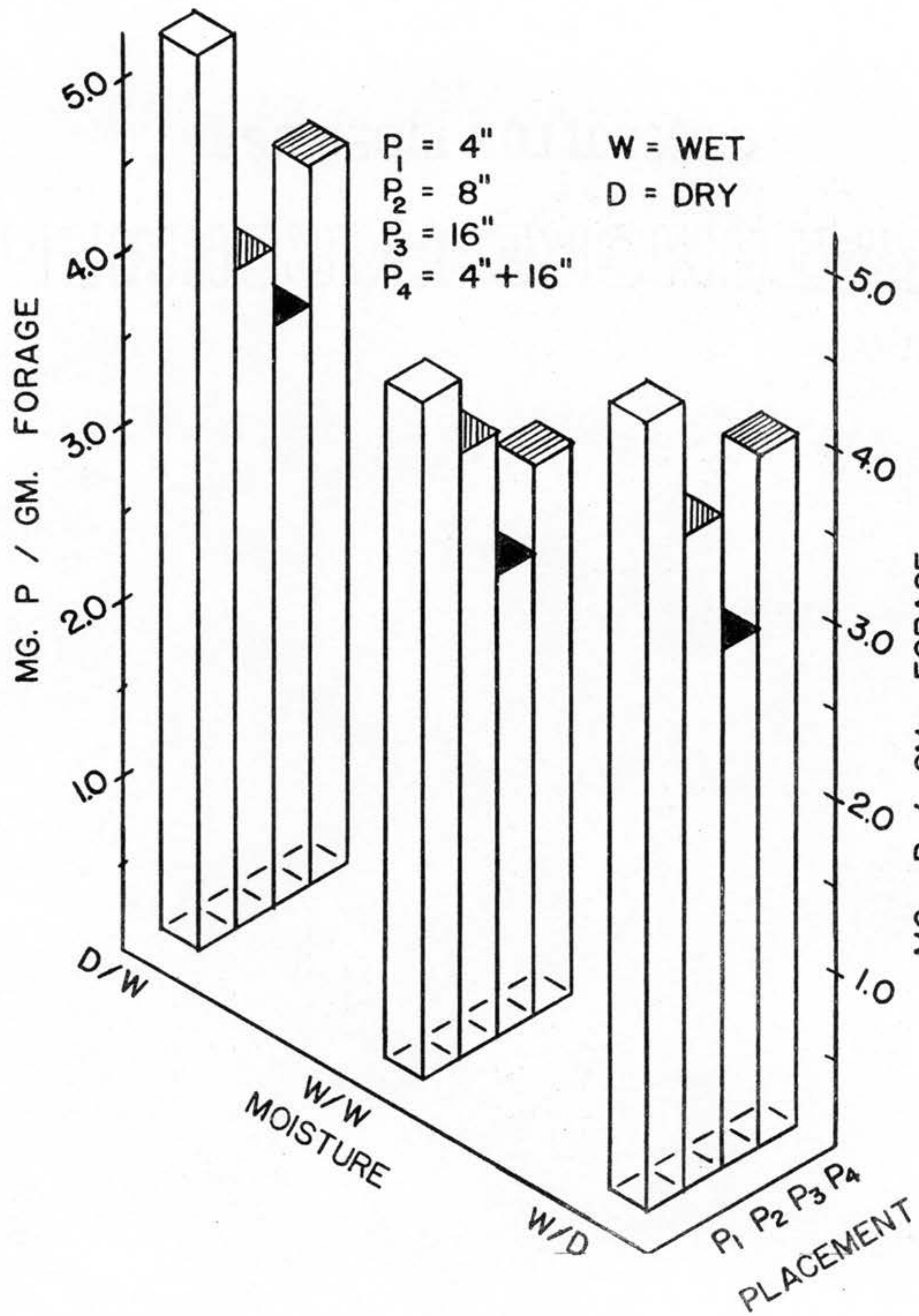

Figure 2. Phosphorus Uptake as Affected by Moisture Levels and Phosphorus Placement

TABLE VI

ANALYSIS OF VARIANCE ON PHOSPHORUS UPTAKE PER GRAM SAMPLE

Source	dF	MS	F	
Total	45			
Replications	3	2.15	2.91	*
Treatments	11	1.85	2.50	*
W/D ≠ D/W vs W/W@	(1)	4.66	6.30@	*
W/D vs D/W	(1)	0.70	0.95@	*
W/D ≠ D/W vs W/W (A)	(1)	2.73	3.69	
W/D vs D/W (B)	(1)	0.69	0.93	
P_4 vs P_1, P_2, & P_3	(1)	0.01	0.01	
Among P_1, P_2, & P_3				
P Linear	(1)	14.00	18.92	**
P Quadratic	(1)	0.06	0.08	
P_L x A	(1)	0.24	0.32	
P_Q x B	(1)	0.33	0.45	
P_L x B	(1)	0.07	0.09	
P_Q x B	(1)	0.27	0.36	
Error	31	0.74		

@ Comparisons made with all placements. Other comparisons exclude P_4.

s_m = 0.43 C.V. = 23.06%

TABLE VII

TUKEY'S HSD TEST ON PHOSPHORUS UPTAKE

Trt.	mg P/gm.	
D/W P_1	5.14	a
W/D P_1	4.52	ab
D/W P_4	4.13	abc
W/D P_4	3.96	abcd
W/W P_1	3.89	abcd
D/W P_2	3.79	abcd
W/D P_2	3.75	abcd
W/W P_2	3.47	bcd
D/W P_3	3.34	bcd
W/W P_4	3.16	bcd
W/D P_3	2.98	cd
W/W P_3	2.65	d

Any two means not covered by the same letter are significantly different at the 5% probability level. Any two means covered by the same letter are not significantly different at the 5% probability level.

Yield of Phosphorus

Milligrams phosphorus removed per pot is shown in Table VIII and Figure 3. Analysis of variance is given in Table IX and Tukey's hsd is given in Table X. Values for treatments five and eight of replication III were estimated using the missing plot technique found in Snedecor (40).

Significance at the 1 percent level was obtained for moisture levels. Treatments where all of the phosphorus was placed in moist surface soil removed more total phosphorus than treatments having a dry surface soil. There was no difference in phosphorus removal when all of the phosphorus was placed at a depth of four inches in a dry surface soil and when one-fourth of the phosphorus was placed at the same level in a moist surface soil. Phosphorus removal from the 16 inch placement was not significant for any moisture level. A dry surface soil did not show signigicance due to placement of phosphorus.

Phosphorus removal due to placement at depths at four, eight, and 16 inches gave a significant linear response at the 1 percent probability level. As depth of placement increased the phosphorus removal decreased.

Percent Fertilizer Phosphorus Removed

Percent fertilizer phosphorus removed is shown in Table XI and Figure 4. Analysis of variance and Tukey's hsd are given in Tables XII and XIII.

Moisture levels were significant at the 1 percent level when all depths of placement were considered. Greatest uptake of fertilizer phosphorus was obtained when the surface soil was moist. Uptake of fertilizer phosphorus applied at a depth of four inches in a moist

TABLE VIII

TOTAL PHOSPHORUS REMOVED BY WHEAT AS AFFECTED BY MOISTURE LEVELS AND PHOSPHORUS PLACEMENT

Treatment No.	Treatment Symbol	Replication I	Replication II	Replication III	Replication IV	Mean
		Milligrams phosphorus per pot				
1	W/D P_1	18.28	21.13	24.04	20.67	21.03
2	D/W P_1	1.72	9.85	9.54	2.14	5.81
3	W/W P_1	14.22	24.42	13.96	17.51	17.53
4	W/D P_2	16.41	20.01	24.81	13.91	18.78
5	D/W P_2	4.79	4.95	5.70[a]	3.39	4.71
6	W/W P_2	17.04	18.52	11.20	15.51	15.57
7	W/D P_3	13.30	8.85	17.95	11.12	12.80
8	D/W P_3	7.43	1.00	4.95[a]	2.44	3.96
9	W/W P_3	14.93	12.55	13.11	9.45	12.51
10	W/D P_4	15.71	13.35	15.25	15.72	15.01
11	D/W P_4	3.52	3.50	1.16	3.46	2.91
12	W/W P_4	12.44	14.49	15.15	15.09	14.29

[a] Estimated using missing plot technique

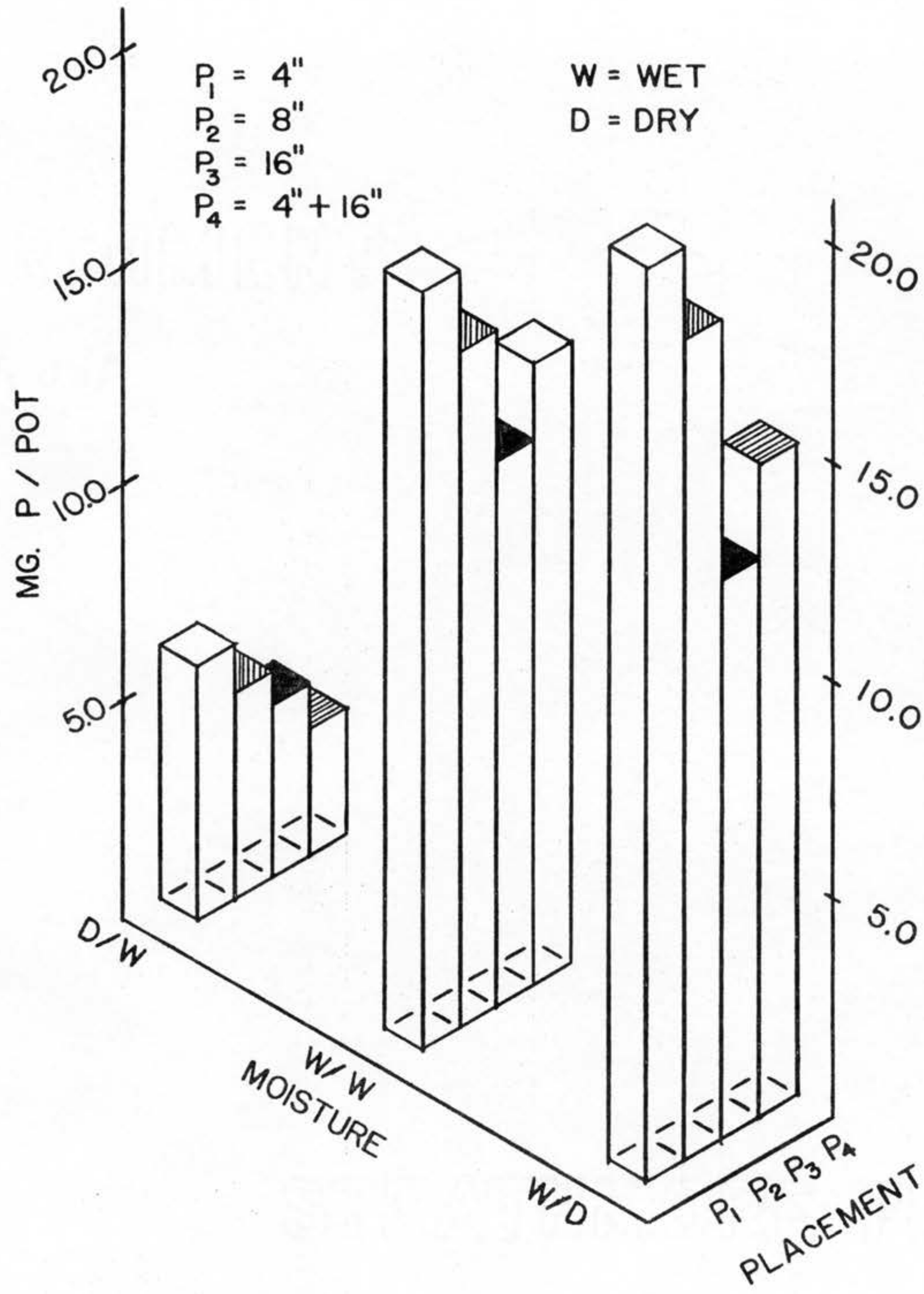

Figure 3. Phosphorus Yield as Affected by Moisture Levels and Phosphorus Placement.

TABLE IX

ANALYSIS OF VARIANCE ON PHOSPHORUS REMOVAL PER POT

Source	dF	MS	F	
Total	45			
Replications	3	28.43	2.85	
Treatments	11	141.36	14.16	**
W/D ≁ D/W vs W/W@	(1)	201.67	20.21@	**
W/D vs D/W@	(1)	1262.03	126.46@	**
W/D ≁ D/W vs W/W (A)	(1)	129.26	12.95	**
W/W vs D/W (B)	(1)	969.90	97.18	**
P_4 vs P_1, P_2 & P_3	(1)	28.68	2.87	
Among P_1, P_2, & P_3				
P Linear	(1)	152.01	15.23	**
P Quadratic	(1)	4.45	0.45	
$P_L \times A$	(1)	0.01	0.01	
$P_Q \times A$	(1)	0.16	0.02	
$P_L \times B$	(1)	40.55	4.06	
$P_Q \times B$	(1)	5.56	0.56	
Error	31	9.98		

@ Comparisons made with all placements. Other comparisons exclude P_4.

$s_m = 1.58$ C.V. = 26.62%

TABLE X

TUKEY'S HSD TEST ON PHOSPHORUS REMOVED

Trt.	mg. P/pot	
W/D P_1	21.03	a
W/D P_2	18.78	a
W/W P_1	17.53	a
W/W P_2	15.57	a
W/D P_4	15.01	ab
W/W P_4	14.29	ab
W/D P_3	12.81	abc
W/W P_3	12.51	abc
D/W P_1	5.81	bcd
D/W P_2	4.71	cd
D/W P_3	3.96	cd
D/W P_4	2.91	d

Any two means not covered by the same letter are significantly different at the 1% probability level. Any two means covered by the same letter are not significantly different at the 1% probability level.

TABLE XI

FERTILIZER PHOSPHORUS UPTAKE BY WHEAT AS AFFECTED BY MOISTURE LEVELS AND PHOSPHORUS PLACEMENT

Treatment No.	Treatment Symbol	Replications I	II	III	IV	Mean
		Percent fertilizer phosphorus absorbed				
1	W/D P_1	12.75	13.52	16.92	13.71	14.23
2	D/W P_1	0.10	1.72	6.82	0.73	2.34
3	W/W P_1	4.92	15.12	8.73	12.36	10.28
4	W/D P_2	4.05	11.43	10.48	8.78	8.68
5	D/W P_2	1.36	2.17	0.29	0.77	1.15
6	W/W P_2	7.81	10.46	5.89	5.61	7.44
7	W/D P_3	0.65	0.47	5.30	10.03	4.11
8	D/W P_3	0.99	0.22	0.74	0.35	0.58
9	W/W P_3	3.37	2.14	2.56	2.83	2.73
10	W/D P_4	10.90	9.07	10.80	14.42	11.30
11	D/W P_4	1.96	1.03	6.35	1.49	2.71
12	W/W P_4	8.65	11.27	12.16	15.07	11.79

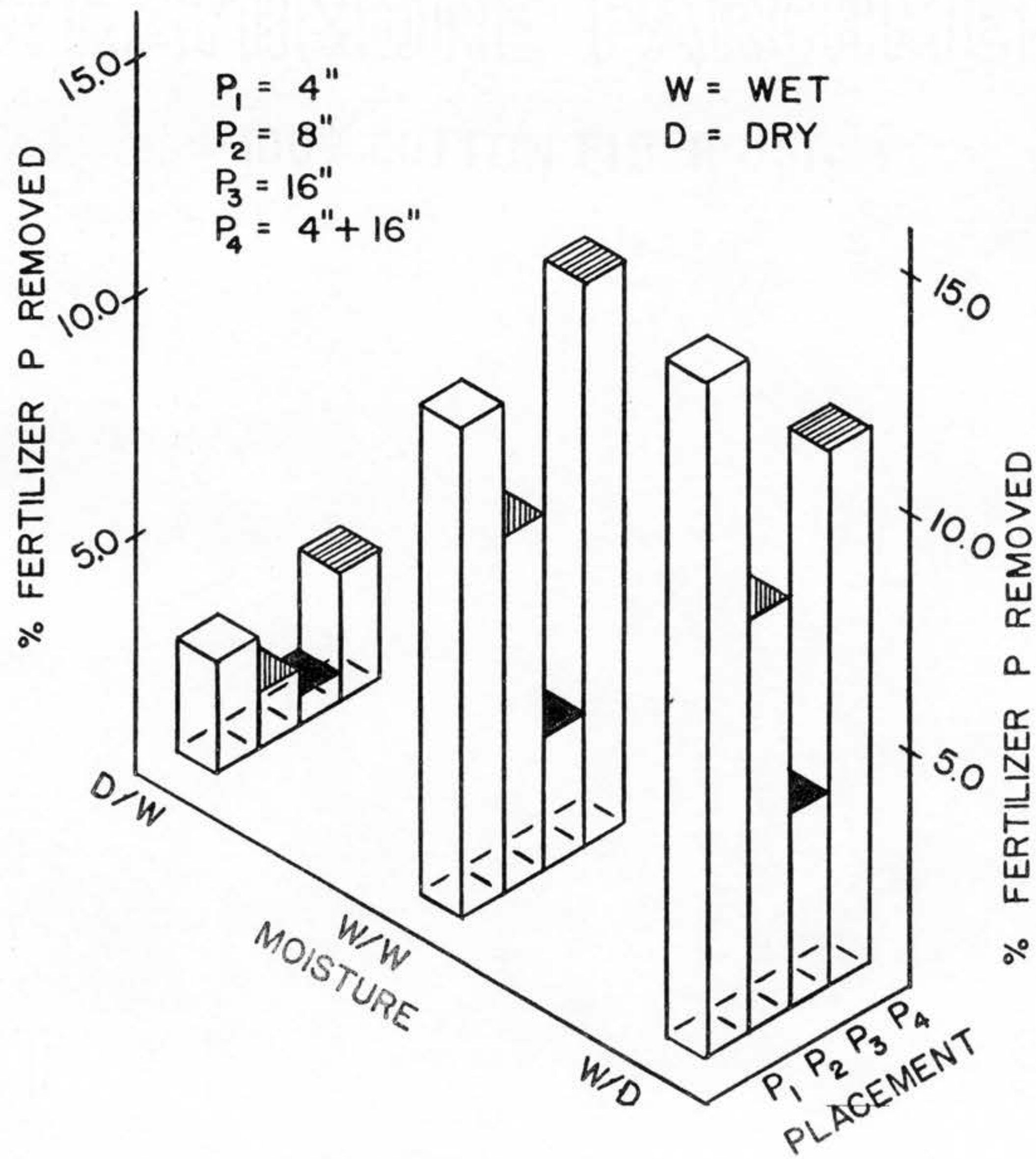

Figure 4. Fertilizer Phosphorus Uptake as Affected by Moisture Levels and Phosphorus Placement.

TABLE XII

ANALYSIS OF VARIANCE ON PHOSPHORUS ABSORPTION FROM FERTILIZER

Source	dF	MS	F	
Total	47			
Replications	3	15.72	2.40	
Treatments	11	89.42	13.63	**
W/D ≠ D/W vs W/W@	(1)	62.68	9.55@	**
W/D vs D/W@	(1)	497.31	75.81@	**
W/D ≠ D/W vs W/W (A)	(1)	14.48	2.21	
W/D vs D/W (B)	(1)	351.06	53.52	**
P_4 vs P_1, P_2, & P_3	(1)	74.25	11.32	**
Among P_1, P_2, & P_3				
P Linear	(1)	251.88	38.40	**
P Quadratic	(1)	0.02	0.01	
$P_L \times A$	(1)	3.49	0.53	
$P_Q \times A$	(1)	3.20	0.49	
$P_L \times B$	(1)	69.64	10.62	**
$P_Q \times B$	(1)	0.04	0.01	
Error	33	6.56		

@ Comparisons made with all placements. Other comparisons exclude P_4.

$s_m = 1.28$ C.V. = 39.75%

TABLE XIII

TUKEY'S HSD TEST ON PHOSPHORUS UPTAKE FROM FERTILIZER

Trt.	% Fert. Uptake	
W/D P_1	14.23	a
W/W P_4	11.79	a
W/D P_4	11.30	ab
W/W P_1	10.28	ab
W/D P_2	8.68	abc
W/W P_2	7.44	abcd
W/D P_3	4.11	bcd
W/W P_3	2.73	cd
D/W P_4	2.71	cd
D/W P_1	2.34	cd
D/W P_2	1.15	cd
D/W P_3	0.58	d

Any two means not covered by the same letter are significantly different at the 1% probability level. Any two means covered by the same letter are not significantly different at the 1% level.

surface soil was 14.23% where the subsoil was dry as compared to 10.28% for a moist subsoil. There was only o.49% more uptake of fertilizer phosphorus from a split application (four inches and sixteen inches) when the subsoil was moist than from a dry subsoil where the surface soil was moist in both cases. Least uptake of fertilizer phosphorus was obtained from the 16 inch placement in a dry subsoil. Greater uptake of fertilizer phosphorus was obtained from a moist surface and a dry subsoil than from a dry surface and moist subsoil at all placement depths.

A split application of phosphorus at four and 16 inches gave the greatest uptake of fertilizer phosphorus for two of the three moisture levels. Linear response was significant at the 1 percent probability level for placement at depths of four, eight, and 16 inches. Fertilizer phosphorus uptake decreased as the depth of placement increased.

V SUMMARY AND CONCLUSIONS

'Concho' wheat (*Triticum aestivum* (L.) was grown in the greenhouse at three different moisture levels and four different depths of phosphorus placement. P^{32} was used to study the uptake of fertilizer phosphorus due to moisture regimes and phosphorus placement on yield and phosphorus content of forage.

Yield of forage was drastically reduced when the surface 12 inches of soil was dry. Subsoil moisture did not affect yields when the surface was moist. Yields were not significantly affected by placement of phosphorus fertilizer.

Greatest phosphorus uptake per gram of forage was obtained from the four inch placement in a dry surface soil, although there was no significant difference in uptake of phosphorus when the treatment was split and a portion was placed in the upper 12 inches of soil. Least phosphorus uptake was obtained from placement at 16 inches. Uptake of phosphorus was less when the entire profile was moist than from placement at the same depth when only a portion of the profile was moist.

Total phosphorus removed from each treatment decreased with depth of placement for each moisture regime. For each depth of placement, the phosphorus removal was greatest from a moist surface - dry subsoil and least from a dry surface - moist subsoil with a moist surface - moist subsoil being intermediate.

The percent fertilizer phosphorus removed by plants growing in a moist surface - dry subsoil was greatest for the four inch placement, whereas the removal was greatest from a split application for the other moisture regimes. Fertilizer removal from the four inch placement was significantly greater than from the 16 inch placement for the moist surface - dry subsoil and the moist surface - moist subsoil treatments. Percent fertilizer removal decreased with the depth of placement when all fertilizer was placed at one depth.

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APPENDIX

TABLE XIV

PROFILE DESCRIPTION OF BROWNFIELD LOAMY FINE SAND

The following profile description was made near the location where soil was taken for the greenhouse experiment. The site was 700 feet south and 950 feet east of the north quarter corner of Section 8 by the field road. This area was deep plowed in 1951 or 1952. The land is level to slightly billowy and has a surface gradient of about ½ percent.

A_{1_p} 0-6"	Brown (7.5 YR 5/4; 4/3, when moist) loamy fine sand; structureless; slightly firm; hard when dry; permeable; pH 6.5; grades to the layer below.
A_1 or A_2 6-18"	Light brown (7.5 YR 6/3; 5/3, when moist) loamy fine sand; structureless; very friable; freely permeable; pH 6.5; rest with a short transition on the layer below.
B_2 18-38"	Reddish-brown (6YR 5/3; 4/3, when moist) sandy clay loam; weak medium subangular blocky; firm; porous and permeable; pH 6.5; contains a few, fine, reddish-yellow specks around the fine pores; grades to the layer below.
B_3C 38-46"	Light-brown (7.5 YR 6/4; 5/4, when moist) light sandy clay loam; weak medium subangular blocky; firm; porous and permeable; pH 6.5; grades to the layer below.
C_1 46-66"	Brown (7.5 YR 6/4; 5/4, when moist) light sandy clay loam with numerous medium to coarse, faint light-gray mottles and strong-brown specks; weak medium subangular block; firm to friable; pH 7.5; occasional soft fine black pellets and ferruginous films; grades to the layer below.

C_{ca} 66-86"

Light brown (7.5 YR 6/3; 5/3, when moist) loamy sand with considerable coarse quartz sand and seams of brown sandy clay loam; occasional concretions of $CaCO_3$; pH 8.0; calcareous in seams; occasional soft black concretions and ferruginous films; mass material averages fine sandy loam when crushed; grades to the layer below.

[1] Profile description by H. M. Galloway, formerly soil scientist with Oklahoma State University and Soil Conservation Service.

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