THE RESPONSE OF SORGHUM TO APPLIED PHOSPHORUS AS AFFECTED BY SOIL MOISTURE AND DEPTH OF PLACEMENT

By

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INTRODUCTION

The question of fertilizer placement is as old as the use of fertilizers in agriculture. The primary objective of fertilizer placement is to place the fertilizer where the plant may receive maximum benefits and the user may realize the greatest economic return from the quantity applied. The search for more effective placement of fertilizers for crops has shown that different areas, crops, and soils differ in placement requirements.

Plant and soil characteristics plus climatic factors must be carefully considered when determining where fertilizers are to be placed. Plant characteristics that may determine placement requirements are such factors as rate of root and top growth, rooting depth and ramification through the soil, and the growth stage in which the nutrients are most needed. Soil factors to consider are texture, bulk density, presence or absence of soil layers that impede root extension, water holding capacity, and native fertility. The amount and distribution of rainfall during the growing season is a very important factor. Of the soil factors mentioned, soil moisture deserves close consideration. Woodhouse (44)[1] reasoned that subsurface placement locates phosphorus fertilizers in a more continously moist zone and therefore in contact with active roots during a greater part of the growing season.

A classic question in fertilizer placement is how does varying soil moisture affect fertilizer absorption? If fertilizer elements

[1]Figures in parenthesis refer to Literature Cited.

are applied to the topsoil and the topsoil moisture is depleted after the plant is established, can the plant effectively absorb nutrients from the dry topsoil when the subsoil contains moisture at low tension?

This study was undertaken in order to investigate the effects of placement of fertilizer phosphorus in relation to soil moisture conditions.

REVIEW OF LITERATURE

The plant source of phosphorus is the soil, the medium is the soil solution, and the agent of uptake is the plant. The rate of uptake of phosphorus may be limited by the source, the medium or plant (15).

Changes in soil moisture content probably influence uptake (11). Lipps (29) obtained results that indicate that phosphorus absorption is influenced by soil moisture, but does not parallel water absorption. The ability of the soil to supply phosphorus to plants changes as the moisture content of the soil is changed (42). In an excised root technique, roots that were conditioned at high moisture stress absorbed phosphorus at a reduced rate as compared to roots preconditioned at low moisture stress. The moisture stress apparently tended to reduce the absorbing capacity of the roots. This suggested that a reduced phosphate absorption by roots in contact with dry soil may occur as a result of alterations in the physiology of the roots (11). Roots tend to become suberized in dry soils. Areas of roots that are suberized absorb nutrients and water slower than parts that are not suberized (28).

The question of availability of plant nutrients under varying soil moisture conditions was investigated as early as 1930 by Breazeale (4). Hunter and Kelly (23,24), Volk (41), and Hendrix and Veihmeyer (20), conducted experiments with plants which had a portion of their root system in a zone of soil with adequate moisture and the other portion in a zone of soil below the wilting point. The roots were either divided or were allowed to pass through a wax moisture barrier from a moist zone of soil to a dry zone. Results from these experiments indicate that the growth of roots into soil drier than the wilting point is very limited. The amount of nutrient ions absorbed from the dry soils ranged from none to very small amounts. In all cases, amount of uptake was relatively small compared to nutrient entry from moist soil. Hobbs and Bertramson (21) found that fast growing tomato plants did not obtain enough boron from dry surface soil to maintain normal growth even though adequate moisture was available in the subsoil.

Field experiments with potatoes by Jordan and associates (27) and an excised root technique by Dean and Glendhill (11) with rye roots indicate that more phosphorus is absorbed from soil at low moisture tension than at high moisture tension. Danielson and Russell (9) found the same tendency true for the uptake of rubidium by corn seedlings.

Results from five years of fertilizer placement with 100 pounds of 12-24-12 per acre on the same plots at the Sandy Land Research Station, Mangum, Oklahoma indicate that placement of fertilizer at 12 and 16 inches deep increased yields of cotton over the check, conventional (side and below seed), and eight inch placement (8).

Subsoil fertilization has resulted in a greater root concentration in that area (5, 15, 22, 25, 34, 38) and resulted in plant growth rate equal to or greater than that of more shallow placement (2). A greater resistance to drought by plants (12, 25, 31, 37, 38) and increased yields are reported by several investigators when fertilizers are placed deep (7, 22, 32, 34, 35, 38). Many workers reported no advantage to deep fertilization when soil moisture was adequate (18, 31, 32, 37).

Cook and Hulburt (6) stated that "nutrients are ineffective in dry soil." Therefore they should be placed rather deeply in the soil and in places where roots penetrate. From a practical standpoint, it is important that adequate moisture be present in the zone of fertilizer incorporation (37).

Although there is some evidence that plants may absorb small quantities of nutrients from dry soils, this source appears to be inadequate for a thriving plant. When most of the fertility is in a surface horizon that has become dry, the plant may suffer from inadequate mineral nutrients (42).

Controlled experiments dealing with the influence of soil moisture on the uptake of phosphorus have employed split root techniques and partitions of wax mixtures to separate the moist soil from the dry soil. There is need for a controlled study that more nearly simulates field conditions.

METHODS AND MATERIALS

A greenhouse experiment was established to determine the effect of phosphorus placement on the uptake of phosphorus and the yield of forage sorghum; to ascertain the influence of soil moisture on uptake of phosphorus and yield of forage sorghum; and to study the moisture-phosphorus placement interaction on the uptake of phosphorus and yield of forage sorghum.

Description of Soil Used in the Greenhouse Experiment

A Brownfield loamy fine sand was selected for this experiment. It occurs within the Reddish Chestnut and Reddish Brown soils of the Southern High Plains. This soil is found extensively in southwestern Oklahoma, northwestern Texas, and eastern New Mexico. The soil for this study came from the Sandy Land Research Station near Mangum, Oklahoma. The area from which the soil was taken was in cultivation, but had not been deep plowed.

The Brownfield loamy fine sand was developed upon nearly level to billowy sandy plains of Quaternary age which overlay the Permian Red Beds. The soil has a brown loamy fine sand surface which becomes light brown below plow depth and rests on reddish-brown sandy clay loam at 16 to 20 inches. Shinnery oak is the predominate native plant species of the Brownfield soils. A complete profile description of this soil is given in the Apprendix.

Analyses of the Soil

Mechanical analysis of the soil was determined by the method suggested by Day (10), and "Calgon" plus sodium carbonate was used as a dispersing agent. The method of Richards (33) was used in determining the moisture tension data.

The Beckman zeromatic pH meter was used to measure the pH value of the soil from a soil water paste. Walkley's (43) procedure was used to determine the organic matter percentage. Total nitrogen was determined as recommended by the A.O.A.C. (1); total phosphorus was derived by the method outlined by Jackson (26); and procedures by Bray (3), Fried (15), Harper (19), and Jackson (26), with modifications, were used in the determination of soluble phosphorus. Exchange capacity and exchangeable cations were determined by the procedures outlined by the United States Salinity Laboratory Staff (39). Results of the chemical and physical determinations are presented in Table I.

Experimental Procedure

The greenhouse experiment was designed as a randomized block with a factorial arrangement of three moisture regimes and four placements of phosphorus fertilizer applied at a uniform rate. The treatments were replicated four times. Sugar Drip forage sorghum, Sorghum Vulgare var. Saccharatum (L.), was used as the indicator plant.

The soil containers for the greenhouse experiment were sections of transite pipe set into 14 x 14 x 4 inch metal pans fitted with drain plugs. The pipe sections were 26 inches high and 10 inches in inside diameter. Inspection and servicing ports were cut into the sides of the

TABLE I

SOME CHEMICAL AND PHYSICAL PROPERTIES OF BROWNFIELD LOAMY FINE SAND USED IN THE GREENHOUSE EXPERIMENT

Texture by Profile Layers

Layer	Sand	Coarse silt 50-20 Micron.	Fine silt 20-5 Micron.	Coarse clay 5-2 Micron.	Fine clay < 2 Micron.
A	84.01	8.0	3.9	0.0	5.0
B_2	58.0	10.0	6.0	1.0	25.0
C	75.5	6.0	0.5	0.0	18.0

Moisture Retention Data

Tension (atmospheres)	Percent Moisture Topsoil	Percent Moisture Subsoil
0.33	2.87	9.04
2.00	2.87	8.52
4.00	2.46	8.56
7.00	2.18	6.94
10.00	1.61	
15.00	1.69	6.28

Easily Soluble Phosphorus (Extracting Solution)	Parts Per Million Phosphorus Topsoil	Parts Per Million Phosphorus Subsoil
0.2 N H_2SO_4	8.25	7.65
0.5 M $NaHCO_3$	6.00	5.00
0.02 N H_2SO_4	5.70	4.50
0.1 N Acetic Acid	5.20	2.00
0.03 N NH_4F + 0.025 N HCl	4.28	4.38
0.03 N NH_4F + 0.1 N HCl	2.18	1.19
Water	1.70	0.10

	Topsoil	Subsoil
Total Phosphorus	84.00 lbs/acre	140.00 lbs/acre
Cation Exchange Capacity	1.64 meq/100 gm.	8.02 meq/100 gm.
Percent Nitrogen	0.017%	0.065%
Organic Matter	0.25%	0.78%
pH	6.60	6.20
Exchangeable Potassium	100.00 lbs/acre	
Percent Base Saturation	74.00%	

Exchangeable Cations	meq/100 gm.	Saturation (percent)
Calcium	0.950	57.99
Magnesium	0.083	5.04
Potassium	0.128	7.81
Sodium	0.044	1.56

pipe. The interior of the pots and pans were painted with water and acid resistant paint. Details of construction and phosphorus placement depths are illustrated in Figure 1.

The Brownfield loamy fine sand was taken from the field in depth increments of twelve inches. For convenience, the first twelve inch increment of soil was designated as topsoil and the second twelve inch increment was designated as subsoil. The subsoil and topsoil were kept separated. They were screened to pass a 4-mesh screen and throughly mixed. Twenty-two kilograms of air-dry subsoil was packed into the lower portion of the transite pipe section. This was followed with 1.8 kilograms of coarse phosphorus free sand that served as a barrier against upward capillary movement of water. The surface of the sand was smoothed and 330 grams of 20 mesh subsoil were placed evenly over it. Thirty grams of sodium saturated bentonite clay were spread evenly over the screened subsoil. The bentonite formed a layer about 1.5 millimeters thick and its purpose was to retard downward movement of excess water. The remainder of the pot was filled with 25.15 kilograms of air-dry topsoil.

Bare electrodes were placed in the soil one inch below the sand layer in the subsoil and one inch above the bentonite clay as illustrated in Figure 1. The purpose of the upper electrode was to indicate the presence of the wetting front when the topsoil was watered. The lower electrode was to detect overwetting of the topsoil after the moisture regimes were established. Electrodes were prepared by stripping two inches of the rubber insulation from one end of an eighteen inch length of number 18, stranded, copper lamp cord wire and one inch from the

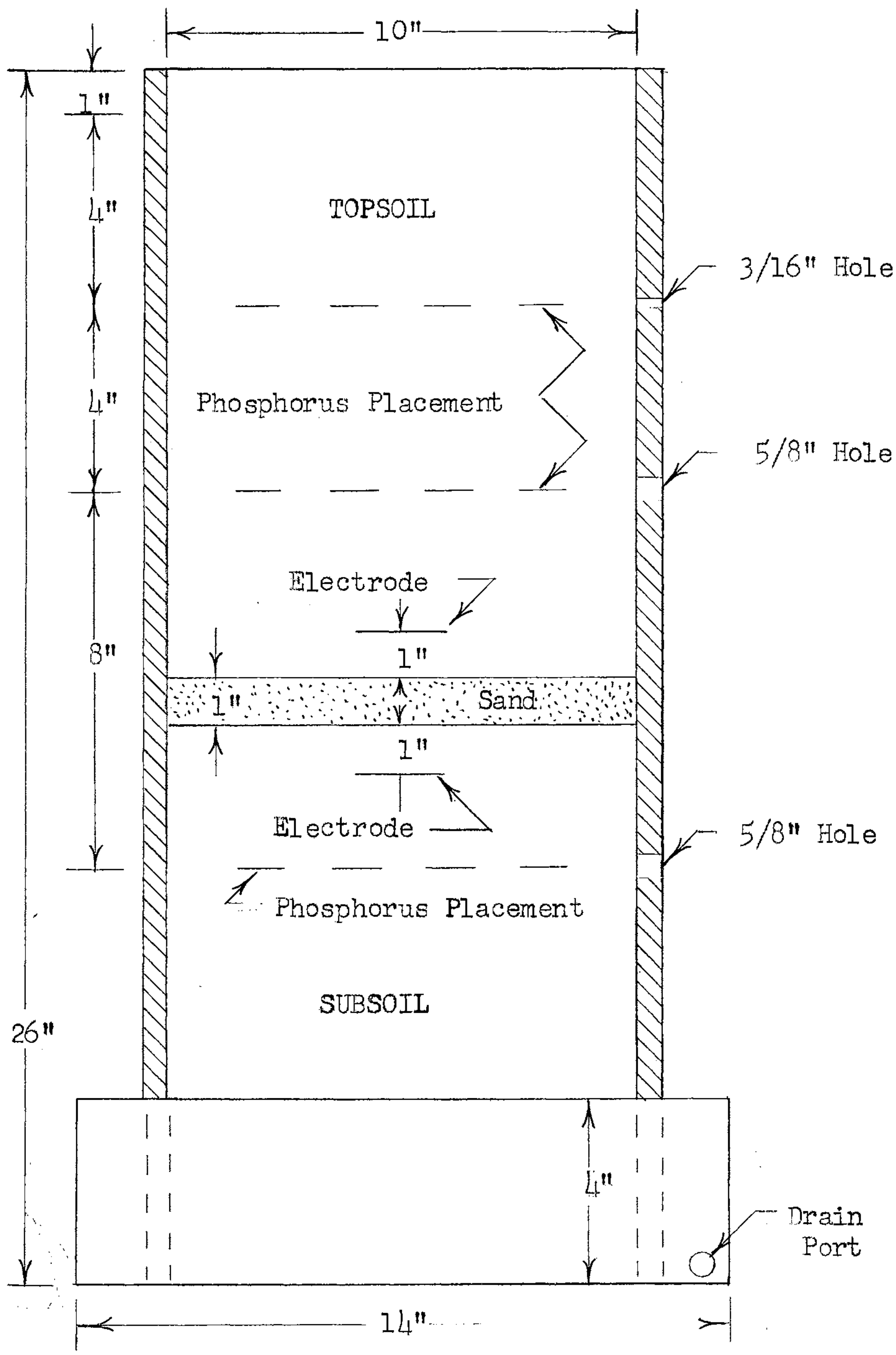

Figure 1. Details of Construction and Assembly of the Soil Container.

other end of the wire. The bare ends of the stranded wire were coated with solder to keep the strands in place and to add rigidity. The two inch bare ends of wire were straightened and inserted through holes in the sides of one-fourth inch diameter by one inch long pieces of hard inert plastic tubing. Two pieces of plastic tubing were used as spacers to hold the two primary strands of wire at an equal distance of one half inch apart throughout the stripped area.

All fertilizer materials were applied as solutions and were calculated in pounds per acre. Details of the soil fertility treatments are presented in Table II. One inch of the topsoil was removed and the fertilizer solutions, except phosphorus, were poured uniformly over the surface. Reagent grade chemicals were used to supply all elements except phosphorus.

The pots were planted to Sugar Drip forage sorghum on June 9, 1959. The pots were uniformly watered on June 14 and the seedlings started to emerge on June 17. The stands were adjusted periodically until there were 4 plants per pot. The soil was kept moist until the plants were well established and the roots were visible in the lower portion of the pots. When it was apparent that the root system was distributed throughout the pot, water was withheld until there were visible signs of moisture stress in the plants of all pots. At this time the fertilizer phosphorus was added and the moisture regimes were established. Fertilizer phosphorus was added at the rate of 80 pounds of P_2O_5 per acre and was placed at 4, 8, 16 and a split application at 4 and 16 inch depths in the pots. The split application consisted of 20 pounds of P_2O_5, 4 inches deep and 60 pounds of P_2O_5, 16 inches deep. For convenience the placements were designated P_1 (4 in.), P_2 (8 in.), P_3 (16 in.), and P_4 (4 and 16 in.).

TABLE II

FERTILIZER ELEMENTS, CARRIERS, AND AMOUNTS USED ON BROWNFIELD LOAMY FINE SAND, GREENHOUSE EXPERIMENT

Element	Element and Carrier Rate lbs./acre	Chemical Compound
Nitrogen	80	$Ca(NO_3)_2 \cdot 4H_2O$ $Mg(NO_3)_2 \cdot 6H_2O$
Phosphorus	80 P_2O_5	$Ca(H_2PO_4)_2 \cdot H_2O$[1]
Potassium	80 K_2O	K_2SO_4
Calcium	75% base sat.	$Ca(NO_3)_2 \cdot 4H_2O$
Magnesium	10% base sat.	$MgCl_2 \cdot 6H_2O$
Manganese	25	$Mn\ SO_4 \cdot H_2O$
Copper	2	$Cu\ SO_4 \cdot 5H_2O$
Iron	2	$Fe_2(SO_4)_3\ (NH_4)_2\ SO_4 \cdot 24H_2O$
Zinc	4	$Zn\ SO_4 \cdot 7H_2O$
Boron	10	$H_3\ BO_3$
Sulfur	50	Included in other compounds

[1]Phosphorus was supplied as concentrated superphosphate, courtesy Tennessee Valley Authority: laboratory no. 67,595, material no. 291.

Moisture regimes were established by wetting the topsoil of 16 pots, the subsoil of 16 pots, and both topsoil and subsoil of 16 pots. The moisture treatments were coded W/D, D/W and W/W in the same order as mentioned above. Details of the phosphorus fertilizer treatments and the moisture treatments are presented in Table III.

On July 23 and 24 concentrated superphosphate fertilizer, $Ca(H_2PO_4)_2 \cdot H_2O$, was injected into the pots in solution at depths indicated in

Table III. A 30 ml. medical syringe with Luer-lock fittings was used. The syringe was filled through a 3 inch, 19 gauge, hyperchrome stainless steel needle that had been cut to 1 inch and inserted through a number 7 rubber stopper and into a 500 ml. Erlenmeyer flask. Injection into the pot was accomplished with a 14 gauge Lukens catheter, number I.J.S. 7899, with the round bulb cut off the end. The end of the catheter was plugged with solder and holes were cut into the side at $\frac{1}{4}$ inch intervals from the tip on opposite sides. The holes extended $1\frac{1}{2}$ inches back from the tip of the needle. The syringe was filled from the 500 ml. Erlenmeyer flask, uncoupled from the needle through which it was filled, and then coupled to the catheter for injection of the solution into the pots.

Preparation of Radioactive Phosphorus Solution

On July 20, 1959, 2.2 grams of radioactive calcium dihydrogen orthophosphate monohydrate, $Ca(H_2PO_4)_2 \cdot H_2O$ (30), with an activity of 10.4 millicuries, dated 8:00 a.m. July 20 were received.[1] The radioactive salt was dissolved in 200 ml. of distilled water. An aliquot of 120 ml. of the solution was diluted with 450 ml. of concentrated superphosphate solution and made to a volume of 600 ml. with water. The activity of the resulting solution at 5:00 p.m. July 23, was approximately 5.2984 millicuries. An aliquot of 12 ml. should have had an activity of 105.9677 microcuries or the desired amount to be applied to each pot in the greenhouse. The activity of a 1 ml. aliquot of the resulting solution was determined to be 18,975 c.p.m. This sample was kept for

[1] P32 was purchased from the Volk Radio Chemical Company, 5412 North Clark Street, Chicago 40, Illinois.

TABLE III

PHOSPHORUS FERTILIZER AND MOISTURE TREATMENTS USED ON BROWNFIELD LOAMY FINE SAND IN THE GREENHOUSE EXPERIMENT

	Treatment Symbol			Water Treatment*		P_2O_5
No.	Moisture	Placement	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" and 16"	Wet	Dry	20 and 60
11.	D/W	P_4	4" and 16"	Dry	Wet	20 and 60
12.	W/W	P_4	4" and 16"	Wet	Wet	20 and 60

* Wet Soil -0-3 atmospheres (approximate)
Dry Soil - 10-15 atmospheres (approximate)

reference.

Injection of P32

On July 25, 1959 the radioactive phosphorus solution was injected with the same apparatus and using the same procedure as for the ordinary concentrated superphosphate. Extreme care was exercised to avoid spillage and to protect the operator. Twelve ml. of the solution were injected into each pot. Where there was only one placement, 2 ml. of the solution were placed at 1 inch intervals beginning 2.5 inches inside the pot on one side and ending 2.5 inches from the near side of the pot. This gave six 2 ml. injections. The split application received 9 ml. of P32 solution in the 16 inch placement distributed as above, but with 1 - 1 - 2 - 1 - 2 - 1 - 1 ml. at each injection. The 4 inch placement received 3 ml. with one ml. at 2.5, 5, and 7.5 inches from the wall of the container. This procedure resulted in a band-like placement of the phosphorus at each depth.

Watering

Moisture was added to the portions of the pots as indicated in Table III. By monitoring the electrodes in the topsoil with a Bouyoucos bridge, the wetting front could be detected. An approximation of the amount of water each pot needed could be made after recording the readings before and after watering a few times. Monitoring the electrodes each time water was added made the operation slow and laborious. Water was not added purposely to any of the dry portions of the pot after the moisture regime was established.

Harvest

The plants were harvested on August 19, 20, 21 and 22, 1959. The leaves and stems were separated, chopped by hand while green, and dried in a forced draft oven at 85°C. Oven-dry weights of stems and leaves were recorded.

Analysis of Plants for Phosphorus

Digestion of approximately 5 grams of the plant material was conducted according to the procedure outlined by Jackson (26) with the exception that the stock solution was washed into volumetric flasks and allowed to stand 24 hours so that the solid material would settle to the bottom. This avoided contaminating more waste and glassware with P32.

A 1 ml. aliquot of the stock solution of active samples and 2 ml. of less active samples were pipetted into nickel plated sample pans and dried under an infrared lamp on a 16 rpm sample spinner. The infrared lamp did not bring the samples to complete dryness and it was necessary to transfer the pans to a hotplate. Counts per minute per aliquot of stock solution were determined and recorded. The counting equipment consisted of a Nuclear-Chicago model 186 scaler and a model DS 5-1P (scintillation) detector probe equipped with a XTB anthracene crystal. The detector was housed in a model 3053 lead shield. Total phosphorus was determined colorimetrically by the procedure outlined by Jackson (26). Micrograms of phosphorus per gram of plant material and total micrograms per pot were calculated and recorded (40). The percent phosphorus absorbed from the fertilizer was determined as suggested by Fuller (16).

Statistical Analyses

The total yield of forage, milligrams of phosphorus per gram of plant material and milligrams of phosphorus in the total plant material were subjected to analysis of variance according to procedures of Snedecor (36). Multiple range test were calculated according to Duncan (14).

RESULTS AND DISCUSSION

Results from the greenhouse study were concerned with the forage yields and the phosphorus content of Sugar Drip forage sorghum as affected by various treatments. Four phosphorus fertilizer placements with a uniform rate of phosphorus under three moisture regimes were compared. Treatment symbols given in Table III will be used in discussion of the results.

Forage Yields

Forage yields are presented in Table IV and are illustrated in Figure 2. Analysis of variance and a multiple range test are presented in Table V. Yields under moisture treatments W/W were highest, W/D were intermediate, and D/W were lowest. Moisture treatments were significantly different at the 1 percent level.

Depth of placement under different moisture regimes affected yields very little. Yields under W/W (moisture throughout the pot) were essentially the same regardless of phosphorus placement depth. There was an increase in yield as depth of placement increased under D/W (dry soil over moist soil) where the deeper placements were in moist soil. Placements of 4 (P_1) and 8 (P_2) inches in the moist zone of W/D (moist topsoil with dry subsoil) produced more forage than the placement at 16 inches (P_3). The split phosphorus application with 20 pounds of P_2O_5 at 4 inches and 60 pounds of P_2O_5 at 16 inches (P_4) produced yields similar to the other placement methods when averaged over all moisture treatments. There were no differences among placements P_1, P_2, and P_3 when averaged over all moisture treatments. Placements P_1, P_2, and P_3 responded differently under W/D than under D/W. Under W/D as depth of placement increased the yields tended to decrease, whereas under D/W the yields increased. This difference was significant at the 5 percent level.

TABLE IV

EFFECTS OF PHOSPHORUS FERTILIZER PLACEMENTS AND SOIL MOISTURE REGIMES ON YIELDS OF SUGAR DRIP FORAGE SORGHUM, GROWN IN THE GREENHOUSE

Treatment	Replications				
Symbol	A	B	C	D	Mean
	Grams Oven-Dry Forage Per Pot				
W/W P_1	70.514	84.560	75.370	64.189	73.658
W/W P_2	75.545	80.917	61.168	68.052	71.398
W/W P_3	79.200	76.113	79.790	62.801	74.476
W/W P_4	78.076	76.332	67.949	65.552	71.977
W/D P_1	55.466	54.542	59.275	43.356	53.167
W/D P_2	53.223	61.405	66.135	45.113	56.482
W/D P_3	40.432	57.029	51.891	39.660	47.253
W/D P_4	50.400	39.726	48.979	37.562	44.166
D/W P_1	33.348	36.594	40.309	39.613	37.466
D/W P_2	36.102	30.573	45.335	46.907	39.729
D/W P_3	45.684	41.666	63.120	43.605	48.518
D/W P_4	53.490	30.349	43.745	34.008	40.398

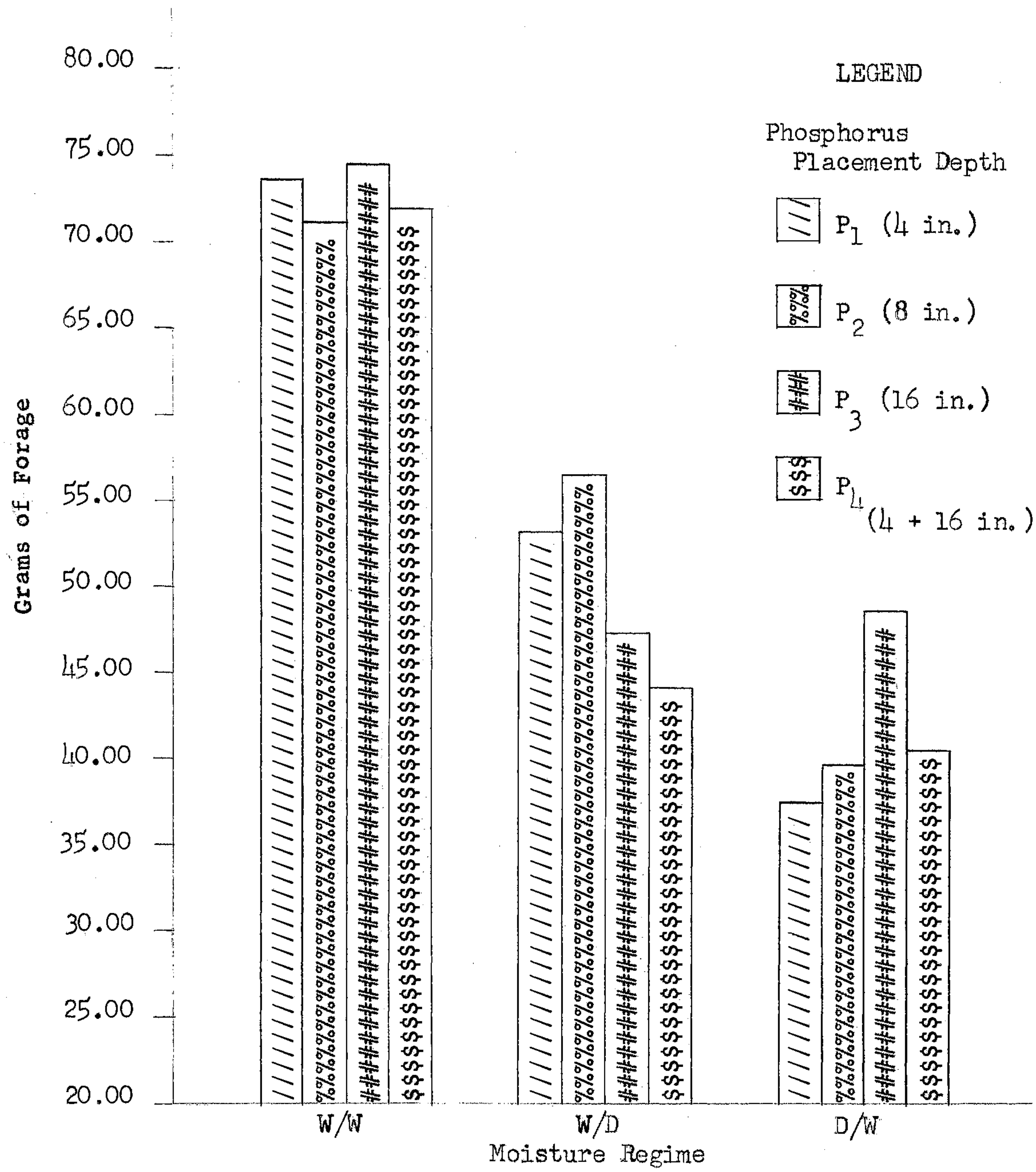

Figure 2. The Grams of Oven-Dry Forage Produced per Pot when Phosphorus was Placed at Four Depths Under Three Moisture Conditions.

TABLE V

STATISTICAL ANALYSES OF FORAGE YIELDS

Analysis of Variance

Source	df	M.S.	F
Total	47		
Replications	3	191.161	
Treatments	11	823.257	15.58**
W/D + D/W vs W/W⊕		(7,767.614)⊕	(146.99)⊕**
W/D vs D/W⊕		(610.978)⊕	(11.56)⊕**
W/D + D/W vs W/W (A)	(1)	(5,442.287)	(102.98)**
W/D vs D/W (B)	(1)	(6,484.505)	(122.71)**
P_4 vs $P_1 + P_2 + P_3$	(1)	(117.679)	(2.23)
Among P_1, P_2, and P_3			
P Linear	(1)	(23.651)	(0.45)
P Quadratic	(1)	(0.116)	(0.002)
P Linear x A	(1)	(4.090)	(0.08)
P Quadratic x A	(1)	(30.629)	(0.58)
P Linear x B	(1)	(287.879)	(5.45)*
P Quadratic x B	(1)	(121.209)	(2.29)
Error	33	52.844	

⊕ Comparisons made with all placements. Other comparisons exclude P_4.
* Denotes statistical significance at the 5 percent probability level.
** Denotes statistical significance at the 1 percent probability level.

Multiple Range Test[1]

$S_m = 3.635$ 1% P - level

D/WP_1	D/WP_2	D/WP_4	W/DP_4	W/DP_3	D/WP_3	W/DP_1	W/DP_2	W/WP_2	W/WP_4	W/WP_1	W/WP_3
37.47	37.73	40.40	44.17	47.25	48.51	53.17	56.48	71.48	71.98	73.66	74.48
								____	____	____	____
						____	____	____	____		
			____	____	____	____	____				
	____	____	____	____	____	____					
____	____	____	____	____	____						

[1]Note: Any two means not underscored by the same line are statistically significantly different. Any two means underscored by the same line are not significantly different.

Milligrams of Phosphorus Per Gram of Plant Material

The milligrams of phosphorus per gram of plant material are presented in Table VI and illustrated in Figure 3. The analysis of variance and multiple range test are shown in Table VII.

TABLE VI

EFFECTS OF PHOSPHORUS FERTILIZER PLACEMENTS AND SOIL MOISTURE REGIMES ON THE MILLIGRAMS OF PHOSPHORUS ABSORBED PER GRAM OF SUGAR DRIP FORAGE SORGHUM GROWN IN THE GREENHOUSE

Treatments	Replications				
Symbol	A	B	C	D	Mean
		Milligrams of Phosphorus			
W/W P_1	1.31	1.35	1.50	1.10	1.31
W/W P_2	1.43	1.34	1.61	1.21	1.40
W/W P_3	0.93	1.15	0.92	0.70	0.92
W/W P_4	1.03	1.14	1.24	0.95	1.09
W/D P_1	1.85	1.97	1.57	1.23	1.73
W/D P_2	1.72	1.73	1.41	1.33	1.55
W/D P_3	0.95	0.98	0.93	0.78	0.91
W/D P_4	1.18	1.68	1.57	1.19	1.41
D/W P_1	0.66	1.06	0.89	0.43	0.76
D/W P_2	0.73	0.82	0.96	0.53	0.76
D/W P_3	0.83	0.84	0.83	0.51	0.75
D/W P_4	0.81	0.81	0.69	0.56	0.72

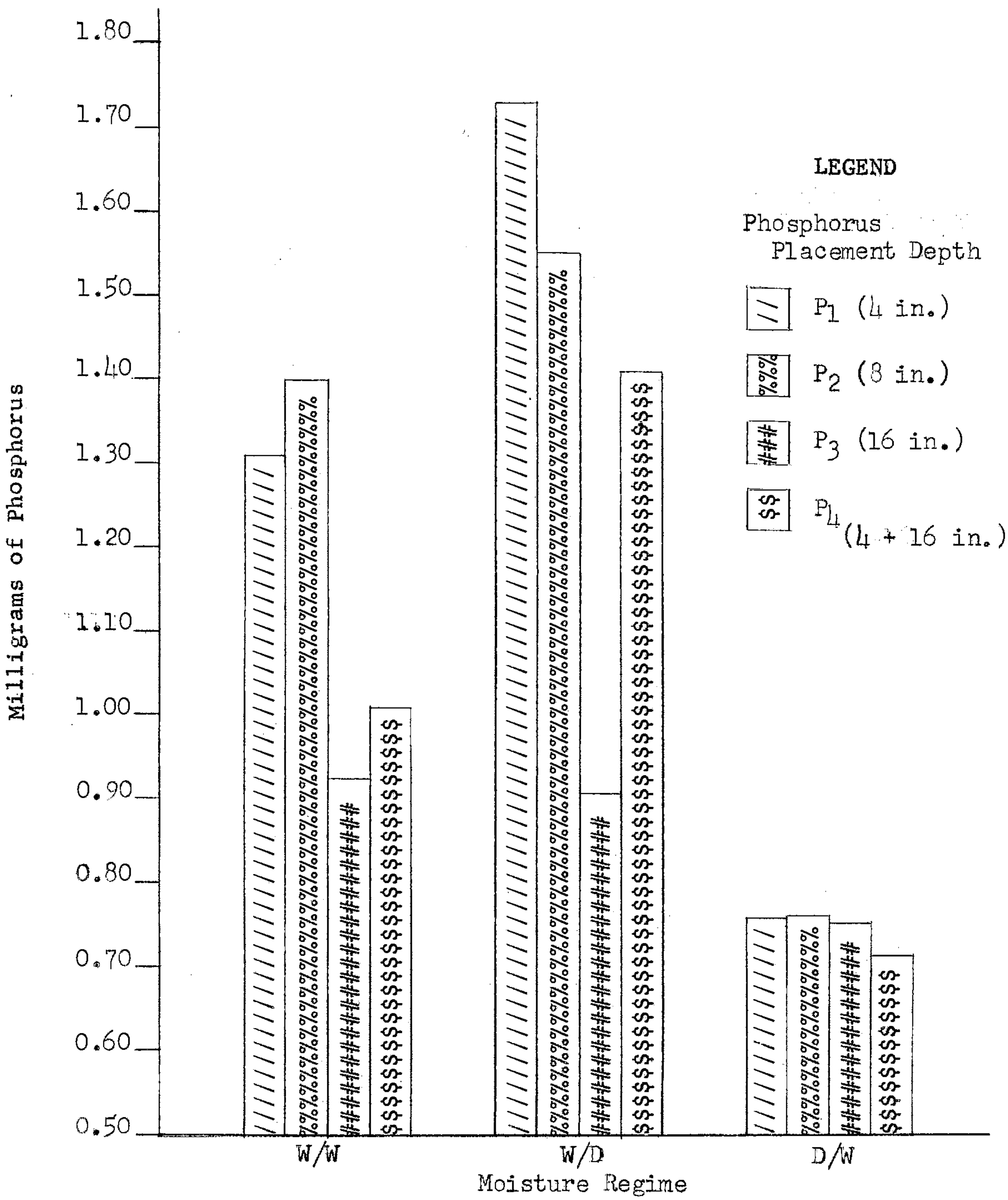

Figure 3. Milligrams of Phosphorus per Gram of Plant Material as Affected by Placement Under Different Moisture Conditions.

TABLE VII

STATISTICAL ANALYSES OF MILLIGRAMS OF PHOSPHORUS PER GRAM OF PLANT MATERIAL

Analysis of Variance

Source	df	M.S.	F
Total	47		
Replications	3	4.143	
Treatments	11	8.098	35.21**
W/D + D/W vs W/W⊕		(2.010)⊕	(8.74)⊕**
W/D vs D/W⊕		(54.262)⊕	(235.92)⊕**
W/D + D/W vs W/W (A)	(1)	(2.346)	(10.20)**
W/D vs D/W (B)	(1)	(39.066)	(169.85)**
P_4 vs $P_1 + P_2 + P_3$	(1)	(0.369)	(1.60)
Among P_1, P_2, and P_3			
P Linear	(1)	(15.760)	(68.85)**
P Quadratic	(1)	(13.785)	(16.46)**
P Linear x A	(1)	(0.013)	(0.06)
P Quadratic x A	(1)	(0.001)	(0.01)
P Linear x B	(1)	(0.567)	(2.46)
P Quadratic x B	(1)	(1.105)	(4.80)*
Error	33	0.230	

⊕ Comparisons made with P_1, P_2, P_3, and P_4. Other comparisons exclude P_4.
* Denotes significance at the 5 percent probability level.
** Denotes significance at the 1 percent probability level.

Multiple Range Test[1]

S_m = 0.24 (1% P-level)

D/WP_4	D/WP_3	D/WP_1	D/WP_2	W/DP_3	W/WP_3	W/WP_4	W/WP_1	W/WP_2	W/DP_4	W/DP_2	W/DP_1
0.716	0.753	0.760	0.761	0.908	0.924	1.090	1.313	1.399	1.407	1.550	1.728

[1]Note: Any two means not underscored by the same line are significantly different. Any two means underscored by the same line are not significantly different.

The uptake of phosphorus per gram of plant material for all phosphorus placements was highest under W/D, intermediate under W/W and lowest under D/W. The mean of the four placements under each moisture, listed in descending order, was 1.40 mgm. W/D, 1.18 mgm. W/W, and 0.75 mgm. D/W. Placement of phosphorus at P_1, P_2, and P_3 under moisture condition W/D produced different absorption responses than P_1, P_2, and P_3 under moisture condition D/W. This difference was significant at the 5 percent level. The differences noted here frequently occur when great differences occur in the main effects (moisture treatments). Highly significant differences were found between W/D + D/W vs W/W and W/D vs D/W as shown in Table VII.

The average phosphorus uptake response of P_1 under all moisture treatments was greatest (1.27 mgm.), P_2 was second (1.24 mgm.), P_4 third (1.07 mgm.), and P_3(0.86 mgm.) last. The reason P_3 was lowest may have been due to the greater amount of energy required to move the phosphorus from the place of absorption to the place of utilization within the plant.

There were no significant differences in phosphorus uptake betweeen P_1, P_2, and P_3, versus P_4. The linear and quadratic effects of P_1, P_2, and P_3 were highly significant. These results indicate that the three plotted points (P_1, P_2, and P_3) did not fall on a straight line but underwent a nearly linear response. Interpretation of this particular measurement is limited by the fact that the three points may lie on a parabola, but which part is straight and which part is curved cannot be determined.

Phosphorus Uptake Per Pot

Total milligrams of phosphorus in the plant material produced in each pot are presented in Table VIII. The amount of phosphorus absorbed by the plants under each moisture condition at each placement is illustrated in Figure 4. Results of the analysis of variance and the multiple range test are given in Table IX.

TABLE VIII

EFFECTS OF PHOSPHORUS FERTILIZER PLACEMENTS AND SOIL MOISTURE REGIMES ON THE MILLIGRAMS OF PHOSPHORUS ABSORBED PER POT BY THE FORAGE SORGHUM GROWN IN THE GREENHOUSE

Treatments	Replications				
Symbol	A	B	C	D	Mean
		Milligrams of Phosphorus			
W/W P_1	92.20	114.30	112.79	70.38	97.42
W/W P_2	107.75	108.87	98.55	82.55	99.43
W/W P_3	73.83	87.26	73.54	43.79	69.61
W/W P_4	80.26	87.19	83.95	62.57	78.49
W/D P_1	102.36	107.52	93.08	66.25	92.30
W/D P_2	91.78	106.14	93.56	60.17	87.91
W/D P_3	38.34	55.83	48.32	30.76	43.31
W/D P_4	59.23	66.59	77.71	44.76	62.07
D/W P_1	21.91	38.68	36.04	17.08	28.61
D/W P_2	26.49	24.99	49.60	24.81	29.97
D/W P_3	37.96	39.94	52.54	22.24	38.17
D/W P_4	43.11	24.52	30.26	19.06	29.24

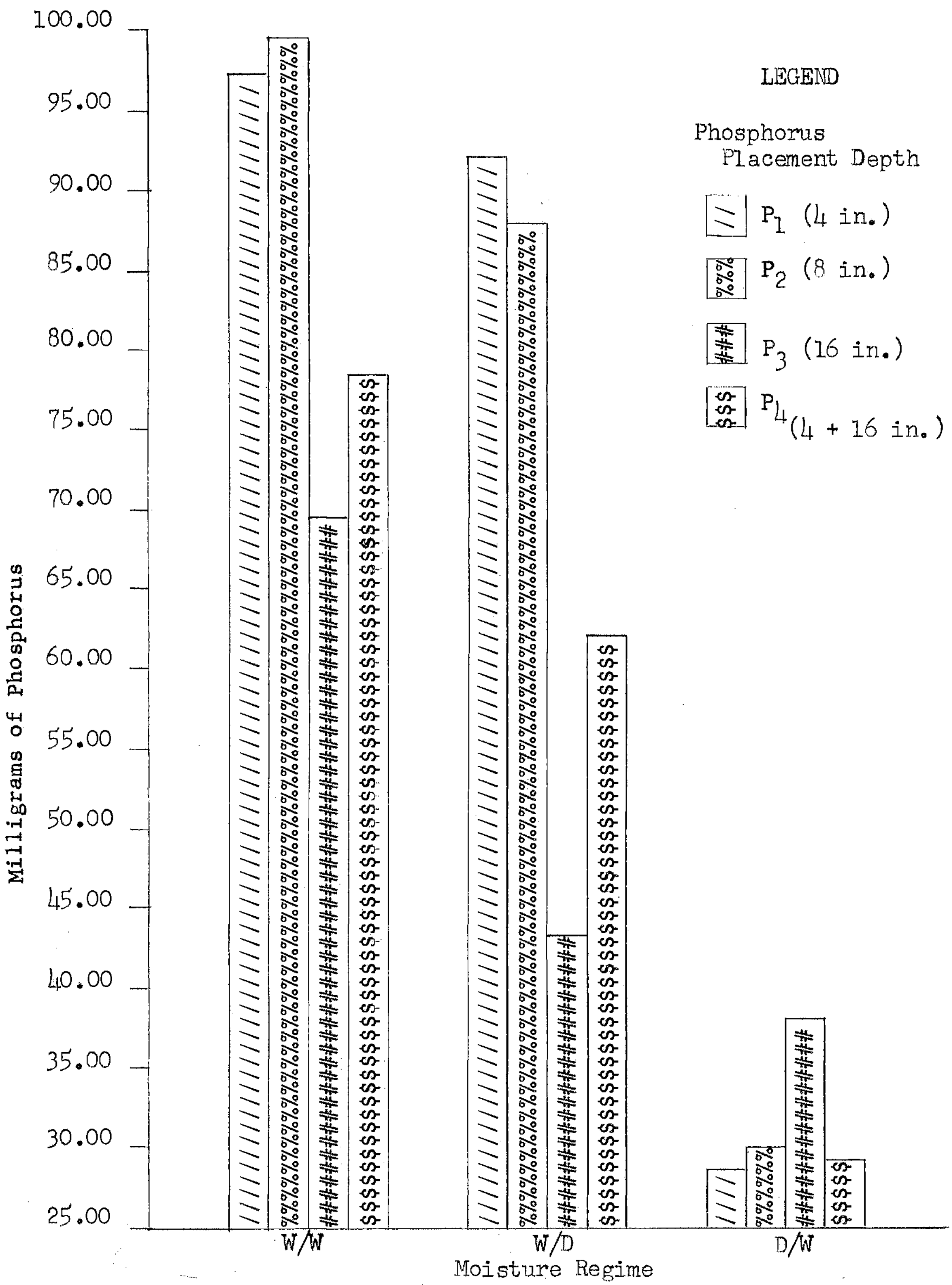

Figure 4. Milligrams of Phosphorus in the Total Forage as Affected by Placement Under Different Moisture Conditions.

TABLE IX

STATISTICAL ANALYSES OF MILLIGRAMS OF PHOSPHORUS IN TOTAL PLANT MATERIAL

Analysis of Variance[1]

Source	df	M.S.	F
Total	47		
Replications	3	28,475.461	
Treatments	11	50,645.753	47.00**
W/D + D/W vs W/W⊕		206,799.712⊕	191.93⊕**
W/D vs D/W⊕		204,271.861⊕	189.58⊕**
W/D + D/W vs W/W (A)	(1)	(161,022.166)	(149.45)**
W/D vs D/W (B)	(1)	(171,919.922)	(159.56)**
P_4 vs $P_1 + P_2 + P_3$	(1)	(10,573.238)	(9.81)
Among P_1, P_2, and P_3			
P Linear	(1)	(221.166)	(0.21)
P Quadratic	(1)	(15,201.288)	14.11**
P Linear x A	(1)	(1,430.018)	1.33
P Quadratic x A	(1)	(1,611.099)	1.49
P Linear x B	(1)	(55,190.695)	51.22**
P Quadratic x B	(1)	(11,714.000)	10.87**
Error	33	1,077.463	

⊕ Comparisons made with P_1, P_2, P_3, and P_4. Other comparisons exclude P_4.
** Denotes significance at the 1 percent probability level.
[1]Analysis done on micrograms of phosphorus reduced by a factor of 250.

Multiple Range Test[2]

S_m = 32.825 (1% P-level)

D/WP_1	D/WP_4	D/WP_2	D/WP_3	W/DP_3	W/DP_4	W/WP_3	W/WP_4	W/DP_2	W/DP_1	W/WP_1	W/WP_2
28.61	29.25	29.97	38.17	43.31	62.07	69.61	78.49	87.91	92.30	97.42	99.43

[2]Note: Any two means not underscored by the same line are significantly different. Any two means underscored by the same line are not significantly different.

The total phosphorus uptake under all moisture conditions and phosphorus placement depths followed closely the same pattern as the total yield. The average milligrams of phosphorus absorbed under moisture treatment W/W over all placement depths were 86.2. Moisture regime W/D averaged 71.4, and D/W averaged 31.5 milligrams of phosphorus. Differences in phosphorus uptake under the different moisture conditions were significant at the 1 percent level. Phosphorus uptake under moisture condition W/D decreased rapidly as the placement increased in depth and went from the wet soil into dry soil. Under treatment D/W the phosphorus uptake increased as the depth of placement increased and went from a dry soil into a moist soil. The overall uptake response under W/W was similar to that of W/D. There were 97.4 mgm. of phosphorus absorbed by the plants at P_1, a slight increase to 99.4 mgm. at P_2, a very rapid decrease to 69.6 mgm. at P_3, and an intermediate amount of 78.5 mgm. at P_4. The response of phosphorus uptake at different placements under W/D and W/W were opposite those under D/W. There was an increase in phosphorus absorption at deeper placements in D/W, whereas the converse was evident under W/D and W/W.

Placement quadratic effects among P_1, P_2, and P_3 were significant at the 1 percent level. The uptake of phosphorus from placement P_1, P_2, and P_3 under W/D was significantly different at the 1 percent level compared to the same placements under D/W. The large differences in main effects (moisture treatments) probably accounted for this significant interaction. The average milligrams of phosphorus absorbed under each placement, listed in ascending order, were P_3, 50.4; P_4, 56.6; P_2, 72.4; and P_1, 73.1.

Relative Radioactivity of Plant Material

Relative activity in counts per minute per gram of plant material are presented in Table X and are graphically illustrated in Figure 5. The uptake of P32 followed the same pattern obtained in the conventional laboratory determinations of milligrams of phosphorus per gram of plant material. Thus, the results of the determination of the radioactive phosphorus absorbed confirmed the data obtained by ordinary laboratory analytical procedures for phosphorus.

TABLE X

RELATIVE ACTIVITY OF P32 IN COUNTS PER MINUTE PER GRAM OF SUGAR DRIP FORAGE SORGHUM GROWN IN THE GREENHOUSE UNDER 3 MOISTURE REGIMES WITH 4 DIFFERENT PHOSPHORUS FERTILIZER PLACEMENT DEPTHS

Treatment	Replications				
Symbol	A	B	C	D	Mean
			Counts Per Minute		
W/W P_1	1,191.1	1,069.4	1,226.4	1,134.0	1,155.2
W/W P_2	1,339.5	943.0	1,322.1	1,051.9	1,164.1
W/W P_3	547.1	411.9	415.3	479.5	463.4
W/W P_4	627.6	682.3	622.1	614.0	636.5
W/D P_1	1,608.8	1,859.8	1,340.2	1,655.0	1,616.0
W/D P_2	1,489.0	1,603.8	1,403.5	1,234.1	1,432.6
W/D P_3	154.4	86.6	43.5	232.0	129.1
W/D P_4	594.1	926.3	708.0	657.6	724.0
D/W P_1	122.5	150.8	220.3	120.9	153.6
D/W P_2	124.3	155.2	170.1	233.4	170.8
D/W P_3	602.6	502.0	515.4	753.0	593.2
D/W P_4	541.0	715.9	553.2	444.4	563.6

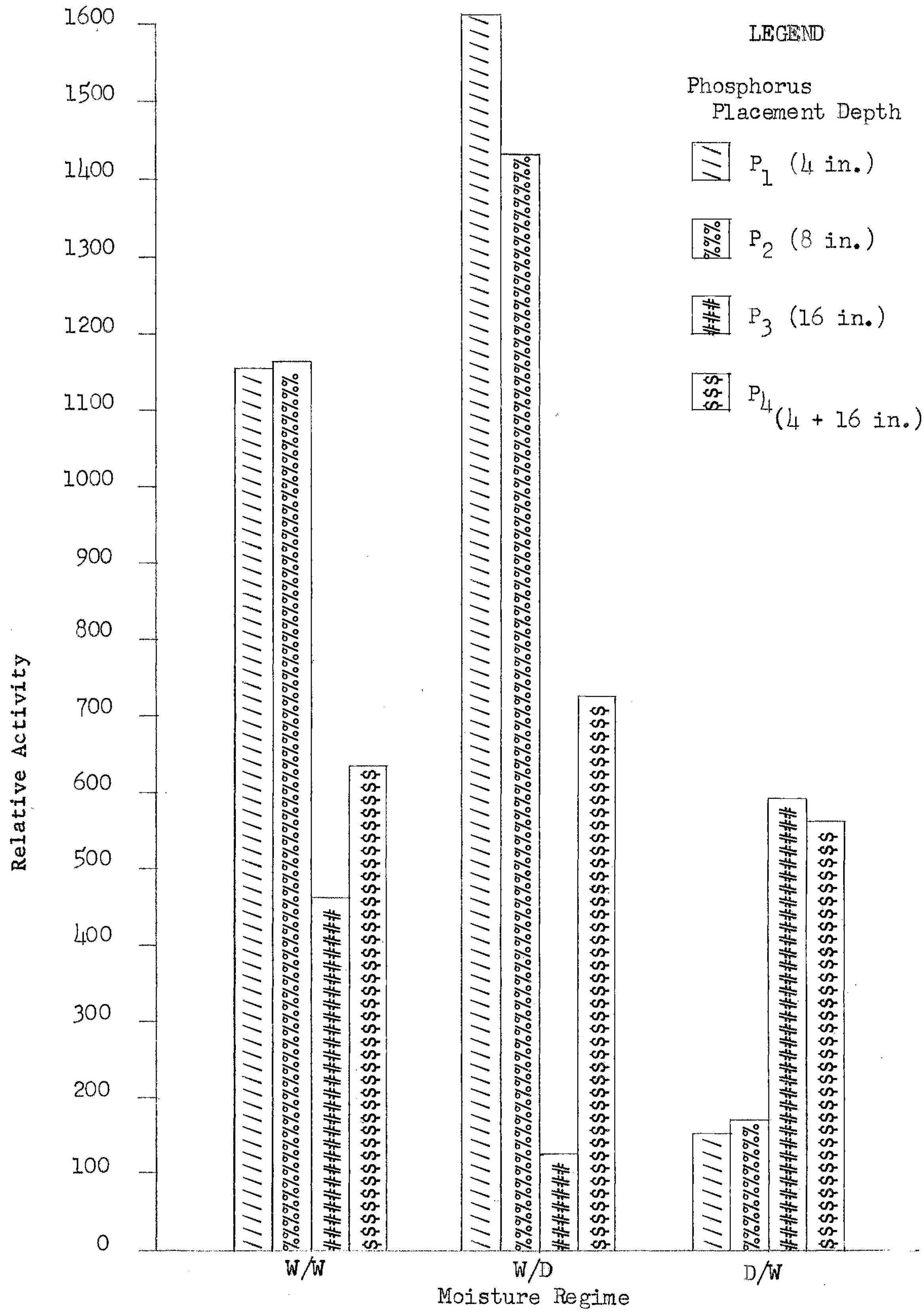

Figure 5. The Relative Activity of P32 per Gram of Plant Material as Affected by Treatments.

The response under D/W was very similar to that obtained for milligrams of total phosphorus per pot as illustrated in Figure 4. Under D/W, the increase in counts per minute per gram of plant material as depth of placement increased indicates that more of the fertilizer phosphorus was being utilized from the deeper depths where moisture was present.

Percentage of Phosphorus Absorbed From the Fertilizer

The percentage of phosphorus absorbed by the forage sorghum from the fertilizer is presented in Table XI and illustrated in Figure 6.

The data indicate that the uptake of phosphorus at P_1 and P_2 under W/D and W/W were approximately the same. As depth of placement was increased to P_3 and P_4 the percentage uptake from the fertilizer phosphorus decreased. The decrease was much more drastic under W/D than W/W. Under D/W, as the depth of phosphorus placement increased from the dry topsoil into the moist subsoil, the percentage of phosphorus absorbed from the fertilizer increased. The fertilizer phosphorus uptake from the split application (P_4) almost equaled the P_3 placement under D/W.

The percentage of fertilizer phosphorus absorbed by the forage sorghum plants was much greater when the phosphorus was placed in moist soil rather than when the phosphorus was placed in dry soil. The absorption ranged from 1.65 percent under W/D P_3 to 25.84 percent under W/D P_2. The mean percent of fertilizer phosphorus taken up from all placements in dry zones of soil was 1.79 percent and for all placements in moist zones 19.70 percent. There was an average of 7.88 percent fertilizer phosphorus absorbed under the split application (P_4) when one of the placements was in dry soil.

TABLE XI

EFFECTS OF 4 PHOSPHORUS FERTILIZER PLACEMENTS AND 3 SOIL MOISTURE REGIMES ON THE PERCENT PHOSPHORUS ABSORBED FROM FERTILIZER PHOSPHORUS BY SUGAR DRIP FORAGE SORGHUM GROWN IN THE GREENHOUSE

Treatments	Replications				
Symbol	A	B	C	D	Mean
	Percent Phosphorus from Fertilizer				
W/W P_1	24.15	26.38	26.79	21.24	24.78
W/W P_2	29.52	22.26	23.59	20.88	24.06
W/W P_3	12.64	9.14	9.66	8.78	10.16
W/W P_4	14.30	15.19	12.33	11.74	13.39
W/D P_1	26.56	29.59	23.18	20.95	25.07
W/D P_2	23.26	28.74	27.10	16.24	25.84
W/D P_3	1.82	1.44	0.66	2.68	1.65
W/D P_4	8.74	10.74	10.12	7.20	9.20
D/W P_1	1.19	1.16	2.59	1.40	1.70
D/W P_2	1.31	1.36	2.25	3.19	2.03
D/W P_3	8.03	6.10	9.49	9.58	8.30
D/W P_4	8.44	6.34	7.06	4.41	6.56

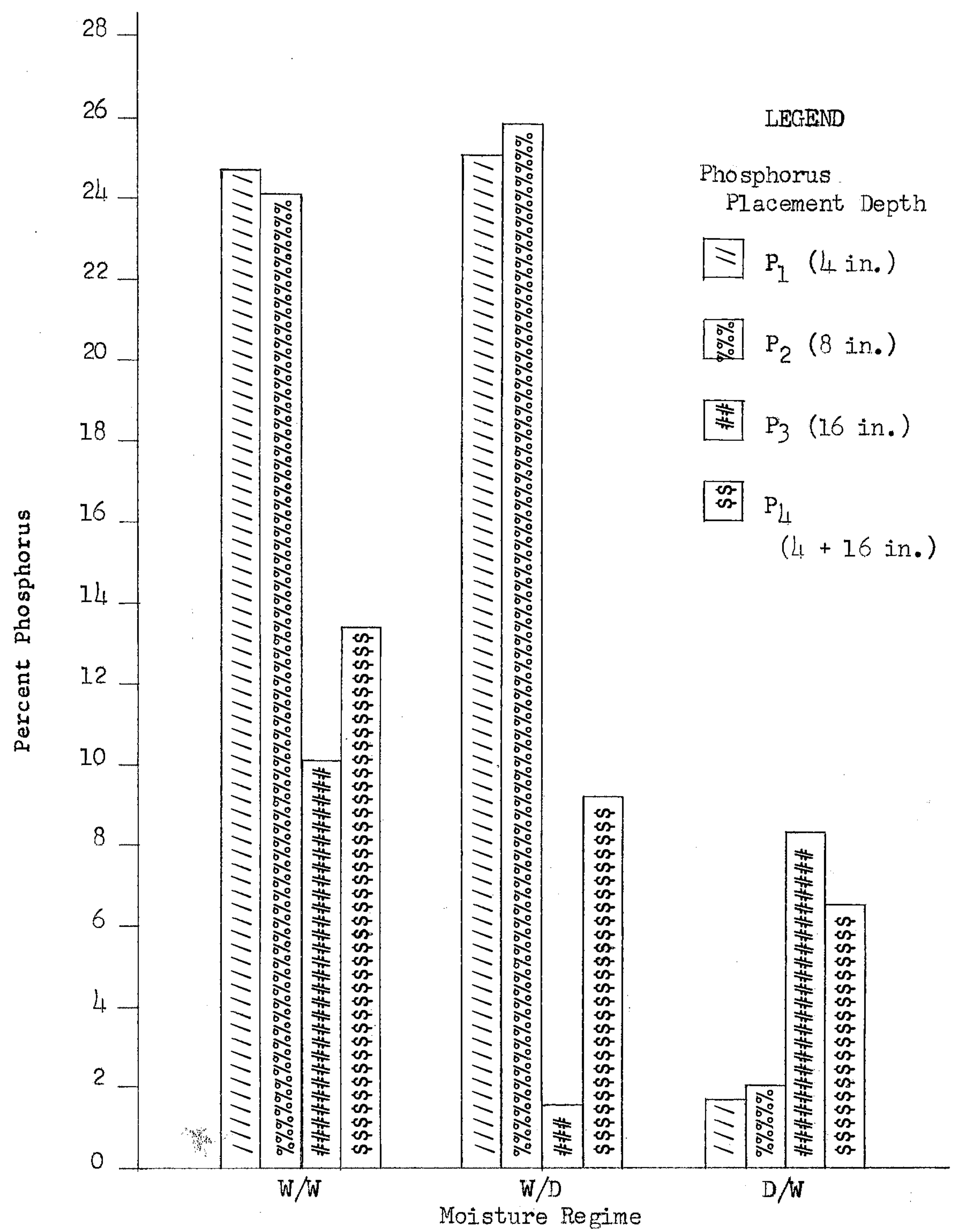

Figure 6. The Percent Phosphorus Absorbed from the Fertilizer as Affected by Placement Under Three Moisture Conditions.

SUMMARY AND CONCLUSIONS

A greenhouse experiment was conducted to determine the effect of soil moisture, phosphorus fertilizer placement and the moisture-placement interaction on the phosphorus uptake and yield of a forage sorghum. Fertilizers were applied at a uniform rate. Phosphorus labeled with P32 was placed at depths of 4, 8, and 16 inches, plus a split application at 4 and 16 inches in soils maintained with three different moisture treatments. The soil used in this experiment was a Brownfield loamy fine sand. The experimental design was a randomized block with four replications. The indicator plant was Sugar Drip forage sorghum.

The following conclusions were based on results and statistical analyses of the data obtained in this experiment.

1. Soil moisture greatly affected the uptake of phosphorus by forage sorghum. Yields and uptake of phosphorus were much greater when the phosphorus was applied to moist zones as compared to the placing of phosphorus in dry soil.
2. Placement of phosphorus at a depth greater than eight inches in continuously moist pots resulted in reduced uptake of phosphorus but did not greatly affect yields.
3. When the subsoil was dry and the topsoil moist, greatest yields of forage were obtained from phosphorus placed eight inches deep. Sixteen inch placement of the phosphorus resulted in a sharp reduction of yields and phosphorus uptake.

4. Under conditions of dry topsoil and moist subsoil, yields and phosphorus uptake increased with increasing depth of placement.
5. The percentage of phosphorus absorbed from the fertilizer did not vary when it was placed 4 or 8 inches deep in continously moist soil.
6. Placement of phosphorus fertilizer 16 inches deep in moist soil resulted in reduced uptake of phosphorus from the fertilizer phosphorus as compared to the 4 and 8 inch placement depths.

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A P P E N D I X

TABLE XII

THE PROFILE DESCRIPTION OF BROWNFIELD FINE SANDY LOAM[1]

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_{1p} 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 5/3; 4/3, 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 of 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

VITA

Carlos Paul Bickford

Candidate for the Degree of

Master of Science

Thesis: THE RESPONSE OF FORAGE SORGHUM TO APPLIED PHOSPHORUS AS AFFECTED BY SOIL MOISTURE AND DEPTH OF PLACEMENT

Major Field: Agronomy

Biographical:

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