# RESPONSE OF SUGAR DRIP FORAGE SORGHUM TO SUBSOIL APPLICATION OF PHOSPHORUS FERTILIZER AS AFFECTED BY SOURCE, RATE AND MOISTURE


by

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# INTRODUCTION

In western Oklahoma, which has a sub-humid to semi-arid climate, soil moisture is generally a limiting growth factor during part of the season. When the water content of the upper soil horizon approaches the critical moisture point, the water and nutrients within this layer become relatively unavailable to crops. In many years, plant survival and crop yields are dependent on the level of soil moisture and fertility in the deep layers of the soil profile. Investigations and observations have shown that many profitable crops have been produced with minimum rainfall if the plants begin the season with abundant moisture in the soil profile. During the growing season, as moisture is depleted from the upper horizons, the plant roots encounter zones of lower fertility in the subsoil from which it is receiving moisture. Failure of a crop to be produced profitably in this area is usually considered to be due to the drouth, but in many instances, the difference between profitable crop yield and failure may be solved by proper fertilization of the subsoil. Since crops in the less humid regions must use the subsoil moisture as well as the topsoil moisture in order to survive, it seems practical, therefore, to place the fertilizer deeply in the soil in order to provide a source of nutrition in the portions of the soil still moist during a prolonged drought.

The objectives of this investigation were to:

(1) To study the effect of deep placement of phosphorus fertilizer upon yield when placed in either a dry subsoil or

a wet subsoil.

(2) To study the effect of depth of placement and soil moisture content on utilization of nutrient elements from four fertilizer materials.

(3) To study the effect of depth of fertilizer placement on rate and amount of nutrient element absorption by the sorghum plant.

(4) To study the residual effect of each fertilizer material over a period of several crops.

## REVIEW OF LITERATURE

During periods of limited moisture in the soil, deficiencies in plant development are usually attributed to water stress within the plant. However, Brown (4) pointed out that there is a possibility that low soil moisture content, or a high water stress, may also limit growth by restricting ion absorption.

Richards and Wadleigh (28) found that most experimental evidence showed that decreasing soil moisture supply is associated with an increased nitrogen content, decreased potassium content, and a variable effect upon the calcium, magnesium and phosphorus content of plant tissue.

Investigations by Greaves and Nelson (13) showed that corn grains have a higher percentage of phosphorus, potassium and calcium when grown on irrigated soils than when grown on non-irrigated soils. Other workers (19) indicated the same to be true for corn plant tops and roots.

In recent years, several investigators have suggested that the subsoil is an important source of plant nutrients. Many of the assumptions were based upon root penetration studies (10, 26, 29) which indicated that the root system of many agronomic crops penetrates the subsoil to considerable depth.

Many investigators (6, 7, 21, 23, 30) have claimed that enhanced root penetration has been obtained by placement of fertilizer and lime in the subsoil. Albrecht (1) reported that deep rooted crops may have either deep or shallow roots, depending on tye type of subsoil in which the roots develop. He found that rooting was extended to depths as great as 18 inches by the application of lime and fertilizer to the subsoil. Other investigators (17) found that subsoiling and subsoil fertilization increased the growth of corn roots in years of low rainfall. Alfalfa was another crop that responded to subsoil liming and fertilization by showing deeper root penetration according to Engelbert and Truog (7). They also reported that subsoil fertilizing helped materially in establishing a stand during dry years and yields were increased in the following years.

Some investigators (14, 20) have used radioactive tracers, to show that many agronomic plants obtain more fertilizer phosphorus from the six to 12 inch horizon than from the plow layer. These investigators pointed out that the fertility pattern of the soil may effect production more than gross fertility of any single horizon. Deeper penetration of plant roots, however, has not always given the greatest crop yields (11, 29). Younts (31) failed to show any distinct advantage of deep placement of lime and fertilizer in terms of plant response, and little evidence was obtained that deep placement of lime and fertilizer stimulated root activity at greater depths in the soil.

The source of phosphorus for plants is the soil (the medium of uptake is the soil solution in equilibrium with the solid phase). The rate of reaction is limited by the slowest reaction in the system. This system of phosphorus reactions from the soil to the plant was proposed by Fried et al. (12).

Magistad and Breazeale (18) plus Hunter and Kelley (16) reported that not only will roots elongate into dry soil, but the plant can absorb water through the roots in moist soils, transport the water to other roots and increase the moisture content of a dry soil zone up to, or near the wilting point. Breazeale (3) pointed out that roots in contact with dry soil cannot absorb significant quantities of the nutrients. Results reported by Dean (5) indicated alteration in the physiology of roots exposed to moisture stress and low phosphorus. Changes were also observed in the power of the dry soil to supply phosphorus to the plant root.

Extensive research has been carried out for many years in an effort to solve the problem associated with the additions of phosphate to various soils used for crop production. The results have indicated that both plant and soil variables are responsible for the responses obtained. The use of both calcium and ammonium phosphates have been compared as a source of fertilizer for different soils and crops and only small differences were found between the two carriers (2, 9, 25). Ammonium bearing phosphates were reported by Olsen et al. (22) to be more readily absorbed during early growth of cereal crops than are the corresponding phosphatic materials without ammonium.

## MATERIALS AND METHODS

To study the effects of moisture, phosphorus sources and rates of phosphorus on phosphorus uptake and yield, a greenhouse experiment was designed using four phosphorus fertilizer sources, two fertilizer rates and two moisture regimes. The two moisture regimes were wet topsoil and dry subsoil (coded W/D) and dry topsoil and wet subsoil (coded D/W). Sources of phosphorus were monocalcium phosphate, diammonium phosphate, ammonium polyphosphate, and ferrous ammonium phosphate. Rates were equivalent to 0, 40, and 160 pounds of $P_2O_5$ per acre. Details of the treatments are given in Table I. Radioactive phosphorus was used in this experiment as a tracer. To be sure that no other plant nutrients would limit yield, certain plant nutrients were applied as listed in Table II.

Sugar Drip forage sorghum, Sorghum Vulgare var. Saccharatum (L.), was used as the indicator plant.

The pots used in this experiment were transite pipes 26 inches high and ten inches inside diameter set into 14 x 14 x 4 inch metal pans fitted with drain plugs. Holes were cut into the sides of the containers for observational purposes and servicing the pots. The interior of the pots and pans were painted with a water and acid resistant paint. Detailed plans of the containers are illustrated in Figure 1.

A Miles loamy fine sand was selected for this experiment. The soil for the study was obtained from a pasture area located on the Sandy Land Research Station near Mangum, Oklahoma. The area from which the soil

TABLE I

PHOSPHORUS SOURCES, RATES AND MOISTURE REGIMES USED IN GREENHOUSE EXPERIMENT

| Treatment Number | Water Regime* | Rate** | Source |
|---|---|---|---|
| 1 | W/D | Check | None |
| 2 | D/W | Check | None |
| 3 | W/D | 40 | $Ca(H_2PO_4)_2 \cdot H_2O$ (MCP) |
| 4 | D/W | 40 | " |
| 5 | W/D | 160 | " |
| 6 | D/W | 160 | " |
| 7 | W/D | 40 | $(NH_4)_2HPO_4$ (DAP) |
| 8 | D/W | 40 | " |
| 9 | W/D | 160 | " |
| 10 | D/W | 160 | " |
| 11 | W/D | 40 | $(NH_4)H_2PO_4)_2$ (APP) |
| 12 | D/W | 40 | " |
| 13 | W/D | 160 | " |
| 14 | D/W | 160 | " |
| 15 | W/D | 40 | $FeNH_4H_2PO_4$ (FEP) |
| 16 | D/W | 40 | " |
| 17 | W/D | 160 | " |
| 18 | D/W | 160 | " |

* W/D--Wet topsoil and dry subsoil
D/W--Dry topsoil and wet subsoil

** Rate is based on pounds $P_2O_5$ per two million pounds of soil.

TABLE II

FERTILIZER ELEMENTS, CARRIERS AND AMOUNTS
APPLIED IN GREENHOUSE EXPERIMENT

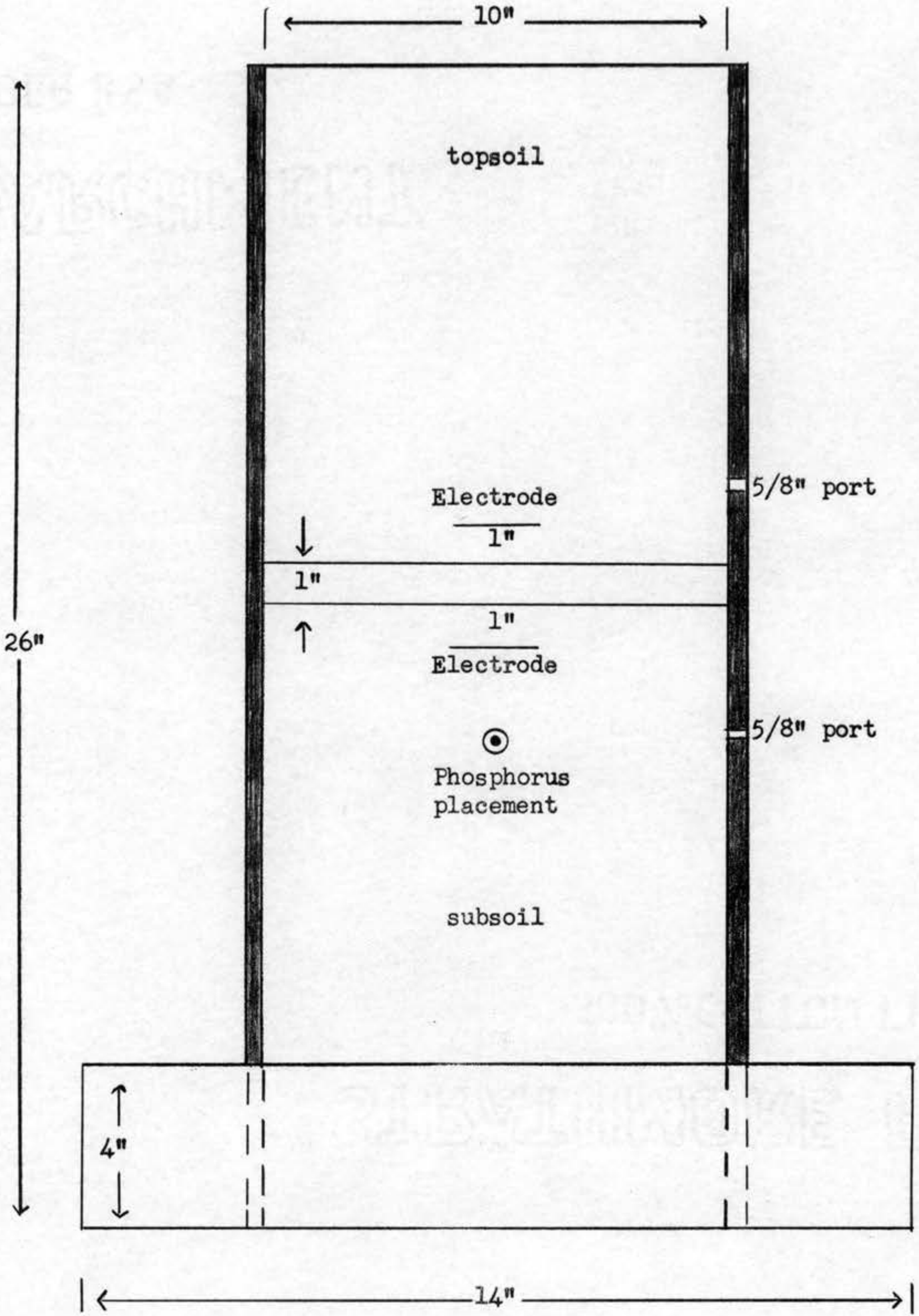
| Element | Rate* | Chemical Compounds** |
|---|---|---|
| Nitrogen*** | 240 | $NH_4NO_3$ |
| Potassium | 80 | $K_2SO_4$ |
| Calcium | 75% Base Saturation | $Ca(NO_3)_2 \cdot 4H_2O$ |
| Magnesium | 10% Base Saturation | $MgCl_2 \cdot 6H_2O$ |
| Manganese | 25 | $MnSO_4 \cdot H_2O$ |
| Copper | 2 | $CuSO_4 \cdot 5H_2O$ |
| Iron | 2 | $Fe(SO_4 \cdot)_3(NH_4)_2SO_4 \cdot 2H_2O$ |
| Zinc | 4 | $ZnSO_4 \cdot 7H_2O$ |
| Boron | 10 | $H_3BO_3$ |
| Sulfur | 50 | Included in other compounds |

* Rate listed is in pounds per two million pounds of soil for the actual element, except for potassium which is listed as $K_2O$.

** Reagent grade chemicals were used.

*** Nitrogen was applied in three 80 pound increments as ammonium nitrate prior to planting and after the first and second harvests. When phosphorus fertilizer sources contained nitrogen, the rate of ammonium nitrate was reduced to correspond to amount added with phosphorus fertilizer.

Figure 1




Detail Plan of Pots Used in Greenhouse Experiment came had never been deep plowed to change the surface texture. A complete profile description of this soil is given in the appendix.

The soil was taken from the field in increments of 12 inches. The first 12 inches were designated as topsoil and the second 12 inches as subsoil. Each 12 inch increment of soil was thoroughly mixed, dried, and sieved through a four-mesh sieve before being placed in the pots. Twenty-three kilograms of subsoil were packed into the bottom of the transite pipe. One and eight-tenths kilograms of phosphorus free quartz sand were placed on top of the subsoil to serve as a barrier to capillary movement of water from the subsoil to the topsoil. Twenty-six kilograms of topsoil were then packed on top of the sand. The topsoil was packed until it was one inch from the rim of the transite pipe.

Bare electrodes were placed in the soil one inch below the sand layer in the subsoil and one inch above the sand barrier in the topsoil as illustrated in Figure 1. The purpose of the upper electrode was to detect downward movement of water in the topsoil or over-wetting from the subsoil. The lower electrode in the subsoil was used to detect the wetting front in the subsoil or over-wetting from the topsoil.

Electrodes were constructed from 18 inch number 18 copper wire. Two inches of the cord's insulation was stripped for electrical contacts. Each end of the wire was treated with solder to add rigidity. The two wires were placed in two $\frac{1}{4}$ x 1 inch polyethylene plastic tubes. These tubes were used as spacers to hold the bare wires $\frac{1}{2}$ inch apart throughout the stripped area.

Monitoring of the electrodes was accomplished with the use of an RCA Junior Volt OHmyst set at R x 100 k. Presence of water was easily detected by a change in resistance between the electrodes with this instrument.

## Experimental Procedure

The pots were planted to Sugar Drip forage sorghum on February 7, 1961 and watered the same day. The seedlings began emerging on February 8 and all plants were up on February 9, then the stand was thinned to four plants per pot. The soil was kept moist until the plants were well established and roots were visible in the lower portion of the pots. After the plants were well established, water was withheld until visible signs of moisture stress were apparent. Water was then added on March 10 to establish the moisture regime. One half of the pots were watered from the top until moisture reached the top electrode and the remaining pots were watered from the bottom free water surface in the pans until water had reached the lower electrodes. Water was not added to the dry portions of the pots after the moisture regimes had been established. Periodic monitoring was all that was necessary for determining the amount of water each pot required.

On February 13 and 14, all fertilizer materials were added as solutions to the pots at a depth of 16 inches (or the subsoil) into the middle of the pots. A 30 ml. syringe was used to add the fertilizer solutions. Filling the syringe was accomplished through a three inch, 19 guage, hyperchrome stainless steel needle inserted through a number seven rubber stopper and into a 500 ml. Erlenmeyer flask. Injection of fertilizer and radioactive isotopes was accomplished with a 14 guage Ruhens Catheter, number I.J.S. 7899, with the round bulb cut off the end. The end of the catheter was plugged with solder, and three holes were cut into the sides at ½ inch intervals back from the tip. The holes extended 1½ inches back from the tip of the needle. The syringe was coupled to the needle of the catheter for injection of the solution into the pots.

A solution containing 18.9 microcuries of $P^{32}$ per ml. was prepared. Seven ml. of this solution was injected into each pot on March 3 with the same instrument used in injecting the fertilizer materials. Each injection was placed in the same area in which the fertilizer had been previously placed. Monitoring of plants was done each day after the radioisotope was added and on the second day activity was observed in the plant material.

The plants were first harvested on March 28-30. The leaves and stems were separated, chopped and placed in a forced draft oven at 90°C. for 24 hours. Oven dry weights of stems and leaves were recorded. The successive second, third, fourth and fifth harvest dates were May 1, June 9, July 7, and August 8, respectively. Samples were handled as mentioned above. Plants were harvested when booting had become apparent.

## Analytical Procedures

Samples were run through a sample splitter until a sample of approximately three grams was obtained. This sample was weighed, digested, filtered and brought to 100 ml. in volume. One ml. of this stock solution was placed in glass planchets and brought to dryness under an infrared lamp on a 16 rpm sample spinner. The samples were then placed in a detector and counts per minute per ml. were recorded, as suggested in Radiological Health Handbook (27). The equipment used was a Borg-Warner Scaler using a Geiger-Muller detector and Nuclear Chicago Scaler model 186 with a DS 5-IP scintillation detector probe equipped with a XTB anthracene crystal. All scalers were standardized and compared with a $Cs^{137}$ standard.

Phosphorus in the plant tissue was determined by the procedure outlined by Harper (15). The same sample that was used to determine radioactive phosphorus was used for total phosphorus in the plant material.

## Statistical Methods

The Experimental design was a randomized block design with a factorial arrangement. Three replicates were used in this experiment. An analysis of variance (24) and Duncan's multiple range (6) test were used to analyze the data. Statistical analyses were determined by two methods in this experiment. The first method was done as a randomized block design. Upon removing the checks from the design, a complete factorial analysis was possible.

## RESULTS AND DISCUSSION

Total yield, percent of phosphorus fertilizer utilized and total phosphorus in the plant were used to study the effect of different moisture regimes, phosphorus sources, and rates of phosphorus.

### Forage Yields

Yields in grams of oven-dried Sugar Drip forage sorghum were obtained from five consecutive harvests in the greenhouse from March to August. The yields are presented numerically in Table III and graphically in Figure 2. The analysis of variance is given in Table IV and Duncan's multiple range test is presented in Table V.

Significant differences in yields due to the moisture regime, rate of phosphorus and time of harvest are shown in Table IV. There was a significant difference at the 5% level for source of fertilizer phosphorus. There were highly significant moisture regime x rate and moisture regime x harvest interactions. Interactions were also obtained between moisture regime x source, rate x source, source x replication and replication x harvest.

Comparisons between treatment according to the multiple range test showed that the D/W moisture regime yielded better than the W/D moisture in this experiment. Duncan's multiple range test also showed a difference in yield due to source of phosphorus, time of harvest and rate.

TABLE III

EFFECT OF SOURCES, RATES OF PHOSPHORUS FERTILIZER AND MOISTURE REGIMES ON YIELDS OF SUGAR DRIP FORAGE SORGHUM GROWN IN GREENHOUSE

| Treatment | Total Grams Oven-Dry Forage Per Pot | | | | | |
|---|---|---|---|---|---|---|
| | Harvests* | | | | | |
| | 1 | 2 | 3 | 4 | 5 | Mean |
| Check W/D | 33.69 | 15.96 | 21.41 | 24.84 | 26.11 | 24.40 |
| Check D/W | 35.53 | 18.68 | 26.70 | 27.34 | 27.31 | 27.11 |
| 40 lb. MCP W/D | 38.01 | 13.16 | 17.57 | 25.26 | 26.34 | 24.07 |
| 40 lb. MCP D/W | 37.95 | 30.58 | 21.49 | 21.38 | 23.77 | 27.03 |
| 160 lb. MCP W/D | 39.52 | 19.23 | 23.39 | 27.16 | 27.21 | 27.30 |
| 160 lb. MCP D/W | 38.78 | 37.68 | 51.44 | 30.59 | 26.04 | 36.90 |
| 40 lb. DAP W/D | 33.24 | 20.05 | 23.87 | 25.48 | 24.87 | 25.50 |
| 40 lb. DAP D/W | 41.78 | 25.05 | 33.10 | 22.08 | 18.19 | 28.04 |
| 160 lb. DAP W/D | 36.61 | 17.03 | 25.89 | 28.23 | 27.81 | 27.11 |
| 160 lb. DAP D/W | 37.88 | 51.72 | 32.42 | 30.66 | 26.96 | 35.93 |
| 40 lb. APP W/D | 37.92 | 17.07 | 19.01 | 29.72 | 28.06 | 26.35 |
| 40 lb. APP D/W | 37.27 | 32.89 | 31.93 | 31.14 | 25.54 | 31.75 |
| 160 lb. APP W/D | 38.98 | 12.18 | 24.32 | 26.34 | 28.94 | 26.15 |
| 160 lb. APP D/W | 40.35 | 36.58 | 41.66 | 35.82 | 30.74 | 37.03 |
| 40 lb. FAP W/D | 37.53 | 17.22 | 16.41 | 31.53 | 30.16 | 26.57 |
| 40 lb. FAP D/W | 39.84 | 23.23 | 31.68 | 24.74 | 16.71 | 27.24 |
| 160 lb. FAP W/D | 36.71 | 15.87 | 20.37 | 27.45 | 25.91 | 25.26 |
| 160 lb. FAP D/W | 39.18 | 20.91 | 34.75 | 24.68 | 23.22 | 28.55 |

* Values are an average of three replications.

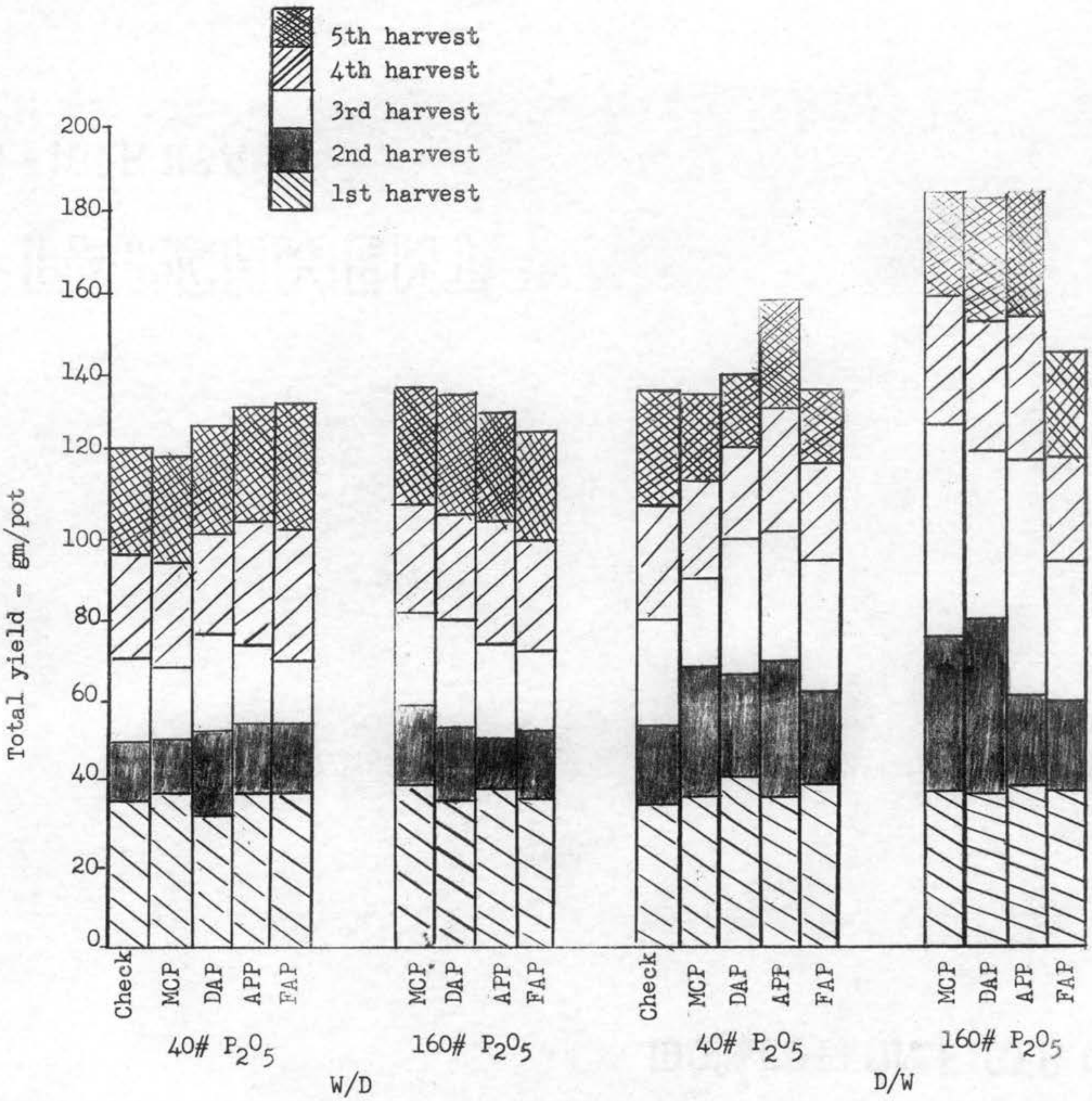



Figure 2: The Effect of Sources, rates and moisture regimes on yield forage sorghum produced in greenhouse.

TABLE IV

A SUMMARY OF THE ANALYSIS OF VARIANCE SHOWING THE SIGNIFICANT LEVEL OF TREATMENTS

| Treatment | Yields | Total P Uptake | Mgm. P/gm forage | % Ferti-lizer |
|---|---|---|---|---|
| Moisture regime | ** | ** | ** | ** |
| Rate | ** | ** | ** | ** |
| Source | * | ** | ** | ** |
| Replication | ns | ns | ns | ns |
| Harvests | ** | ** | ** | ** |
| Moisture regime x rate | ** | ** | ** | * |
| Moisture regime x source | * | ** | ** | ns |
| Moisture regime x harvest | * | ns | ** | ns |
| Rate x source | * | ** | ** | ns |
| Rate x harvest | ns | * | ** | * |
| Source x replication | * | ns | * | ns |
| Source x harvest | ns | ** | ** | * |
| Rate x source x harvest | ns | ns | ns | ns |
| Moisture regime x source x harvest | ns | ns | * | ns |

* Significant at 5% level of probability

** Significant at 1% level of probability

ns = Not significant

TABLE V

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST ON YIELD, MILLIGRAMS OF PHOSPHORUS AND PERCENTAGE OF PHOSPHORUS FERTILIZER IN PLANT

---

Total yield of Sugar Drip forage sorghum

| | |
|---|---|
| Individual | 14 6 10 12 18 8 5 16 9 2 4 15 11 13 7 17 1 3 |
| Harvest | 1 3 4 5 2 |
| Sources | 3 2 1 4 |
| Rate | 2 1 |
| Moisture | 2 1 |

---

Milligrams of phosphorus absorbed by plant

| | |
|---|---|
| Individual | 10 14 6 4 8 11 7 13 17 15 3 12 18 1 16 9 2 5 |

---

Percentage of radioactive phosphorus fertilizer utilized by plant

| | |
|---|---|
| Individual | 14 10 6 13 9 5 12 18 8 4 11 17 16 1 7 3 15 2 |

---

Treatments underscored by a common line are not significantly different.

The overall average yield for D/W treatment in this experiment was 31.56, as compared to 26.04 for all treatments of W/D moisture regimes. This indicates that fertilizer in moist soil can be more readily assimilated.

The dry weight yield for all five harvests was higher for the ammonium polyphosphate source than for any other source in the D/W treatment as shown in Table V. Monocalcium phosphate had a slightly higher average yield in the 160 pound W/D treatment and ferrous ammonium phosphate was higher in the 40 pound W/D treatment. This was not the case in all the treatments as indicated in Figure 2. Differences in the W/D check and D/W can be attributed to the addition of other fertilizer nutrients to the subsoil.

The effect sources, rates and moisture regimes on yield for each harvest is shown in Table III. The table shows that only small increases were obtained with fertilizer when compared to none. This indicated a fairly high level of fertility in the soil at the beginning of this experiment. However, the differences in yield on the second harvest were due to treatment. A general trend of yields can be seen from Table II, where the yield from 40 lb W/D 160 lbs. W/D 40 lb. D/W 160 lbs. D/W.

The greatest difference in sources was obtained on the second and third harvests as shown on Figures 3 and 4. There were large decreases in yield for all the sources in the second harvest compared to the first harvest. This was followed by a slight increase in yield for the third harvest. This could have been due to the fact that the remaining harvests were obtained from sucker growth.

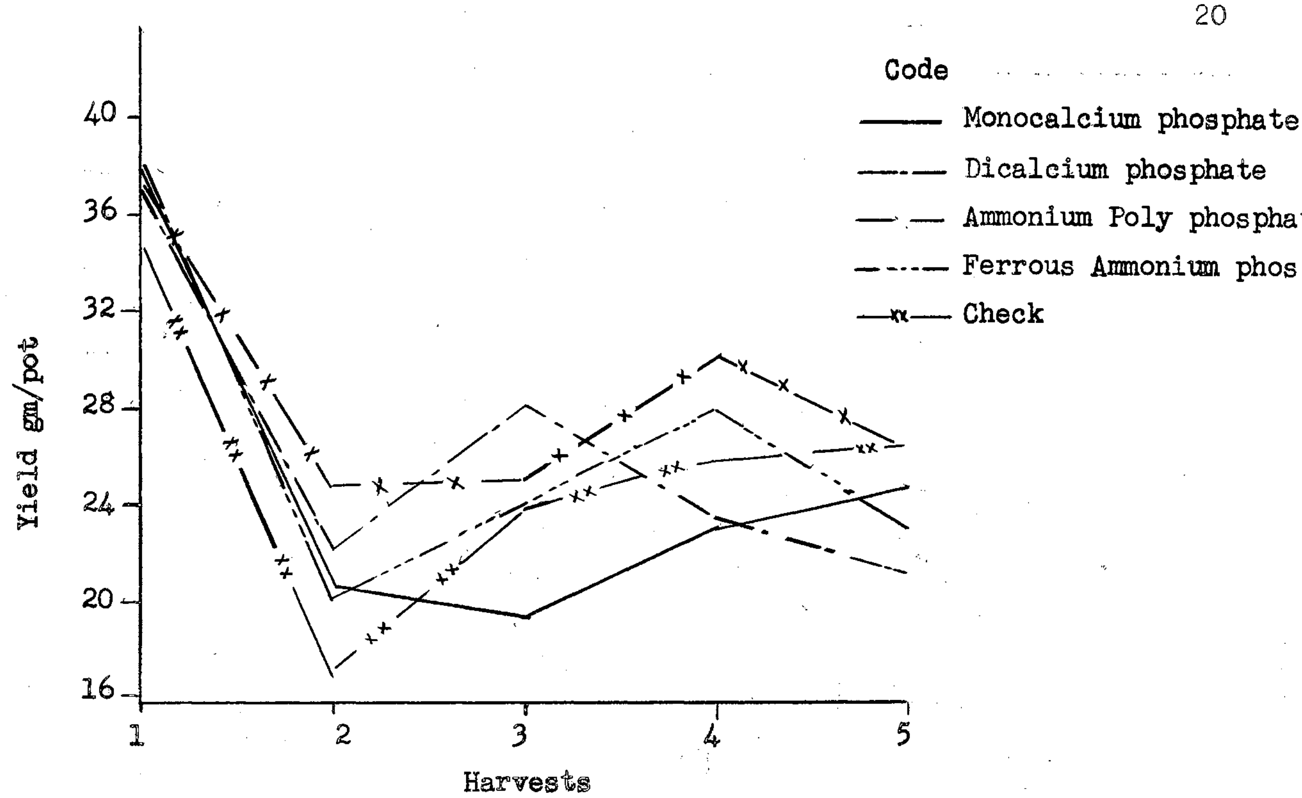



Figure 3: The effect of 40# $P_2O_5$ from four phosphorus values (values are an average of two moisture regimes) over a period of five harvests.

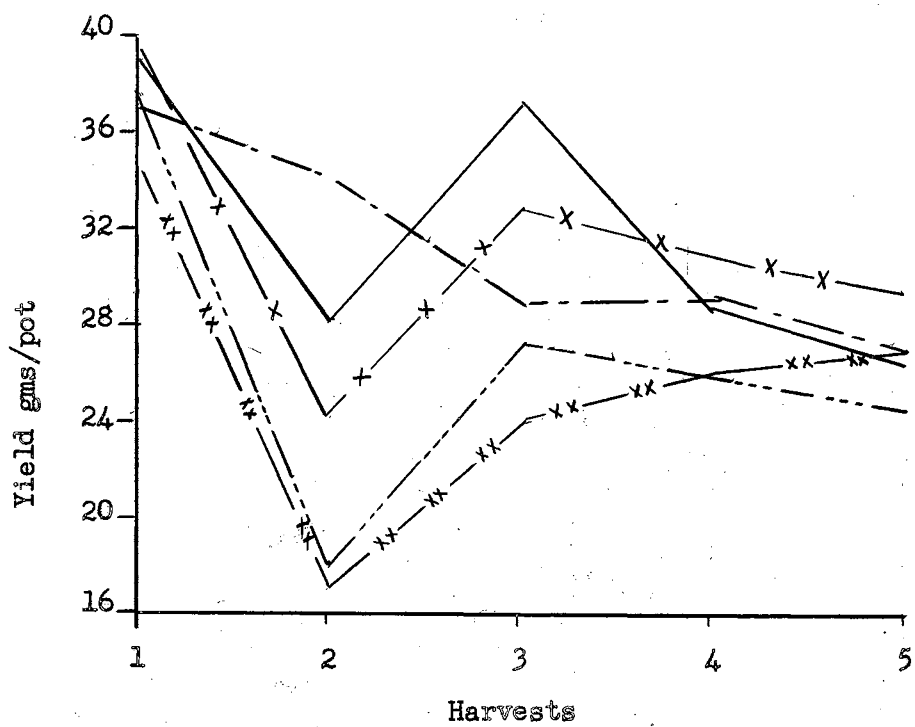



Figure 4. The effect of 160# $P_2O_5$ from four phosphorus sources (value an average of 2 moisture regimes) over a period of five harvest.

Response to phosphorus depended on the moisture regime. In the W/D moisture regime, differences in total yield were not large for the 40 lb. $P_2O_5$ application and the 160 lb. application. There was a larger difference in the D/W moisture regime between the 40 lb. rate and the 160 lb. rate. The D/W check produced as much in five harvests as did any source in the W/D moisture regime with the exception of monocalcium phosphate. This indicated a limited uptake of fertilizer phosphorus from the dry subsoil.

Residual fertilizer effects were readily observed in the D/W moisture regime when comparing response of fertilized treatments with the check on the second, third, fourth, and fifth harvests. Ammonium polyphosphate yielded more than any other source at the 160 lb rate, followed closely by monocalcium phosphate and diammonium phosphate. The ferrous ammonium phosphate yielded 20.5 grams, or 38 grams less than the ammonium polyphosphate as shown on Figure 2. Ammonium polyphosphate was far better at the 40 lb. D/W treatment than all other sources as shown in Table II. There was little effect from other phosphorus sources at the 40# D/W treatment. Response to 160 lb. monocalcium phosphate was greater in the W/D moisture regime than to the other three sources. Ferrous ammonium phosphate responded better at the 40 lb. rate than the other sources.

## Total Phosphorus Uptake by Plants

Total phosphorus in milligrams per pot was determined from the first two harvests of the greenhouse experiment and is reported in Table VI and is shown graphically in Figure 5. The statistical data shows a significant difference in total phosphorus uptake due to moisture regime,

TABLE VI

TOTAL UPTAKE OF PHOSPHORUS BY SUGAR DRIP SORGHUM IN GREENHOUSE EXPERIMENT

| Milligrams of Phosphorus per Pot | | | |
|---|---|---|---|
| Treatment | Harvests | | Mean |
| | 1* | 2* | |
| Check W/D | 67.38 | 33.48 | 50.43 |
| Check D/W | 52.72 | 30.28 | 41.50 |
| 40 lb. MCP W/D | 81.57 | 25.53 | 53.52 |
| 40 lb. MCP D/W | 101.31 | 53.76 | 77.53 |
| 160 lb. MCP W/D | 144.64 | 27.14 | 85.89 |
| 160 lb. MCP D/W | 195.77 | 136.42 | 166.19 |
| 40 lb. DAP W/D | 80.11 | 39.16 | 59.63 |
| 40 lb. DAP D/W | 92.28 | 44.29 | 68.28 |
| 160 lb. DAP W/D | 101.60 | 38.55 | 70.07 |
| 160 lb. DAP D/W | 158.73 | 137.40 | 98.06 |
| 40 lb. APP W/D | 88.62 | 38.84 | 63.73 |
| 40 lb. APP D/W | 136.86 | 57.33 | 97.09 |
| 160 lb. APP W/D | 124.90 | 33.88 | 78.39 |
| 160 lb. APP D/W | 250.76 | 132.75 | 191.25 |
| 40 lb. DAP W/D | 71.60 | 36.57 | 54.09 |
| 40 lb. DAP D/W | 60.17 | 36.35 | 48.26 |
| 160 lb. DAP W/D | 80.61 | 32.20 | 56.40 |
| 160 lb. DAP D/W | 73.26 | 33.26 | 53.26 |

* Number of harvests

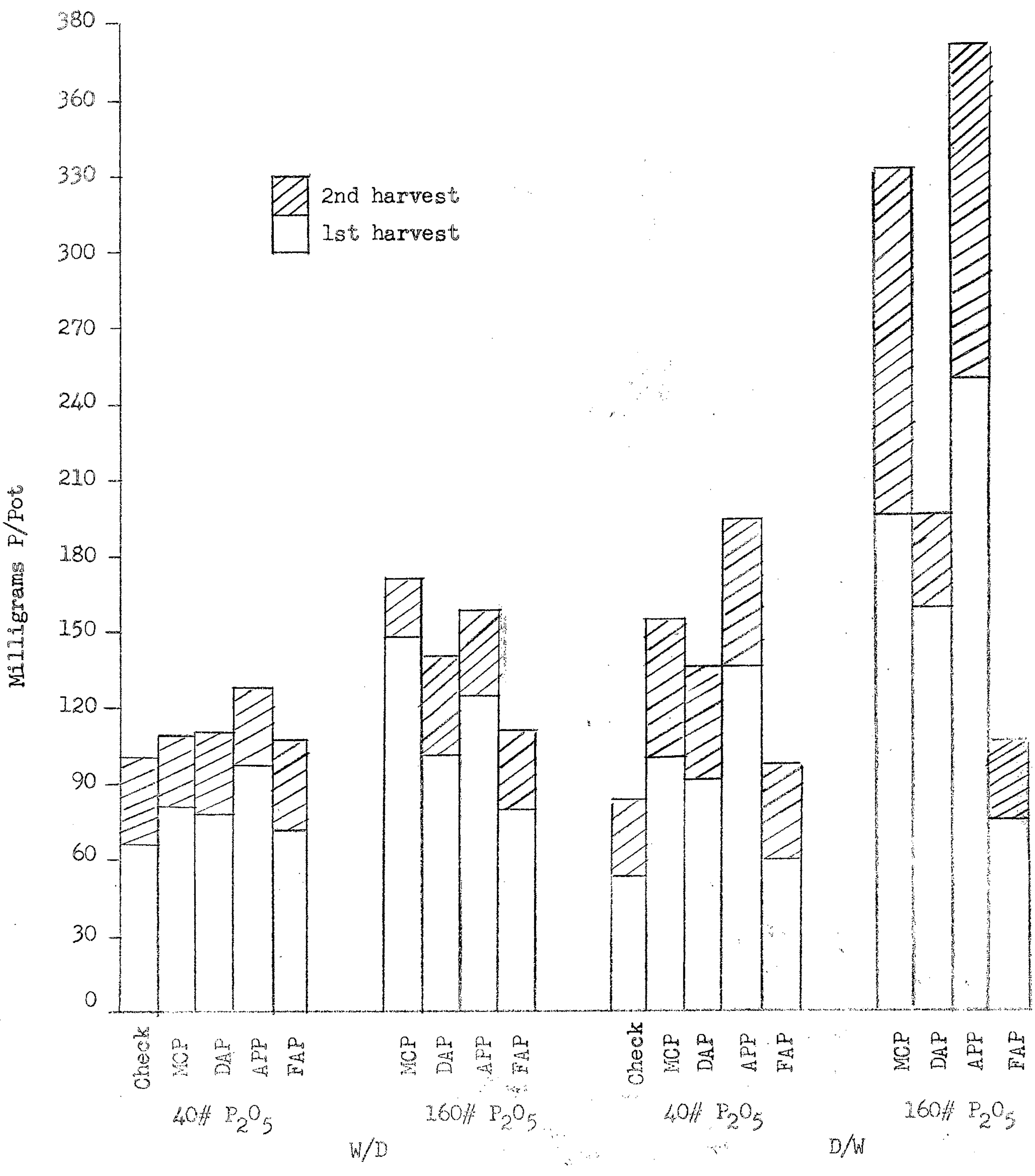



Figure 5: The Influence of Different Phosphorus Sources, Rates and Moisture location upon total content phosphorus in plant.

as did all other criteria used for measurement.

Results from analysis of variance of total phosphorus uptake corresponded closely to analysis of yields as indicated in Table IV. As was pointed out in the total yield discussion, there were significant differences in total phosphorus uptake at the 1% statistic level in time of harvests. The statistical analysis also shows moisture regime x source, rate x source, rate x harvest and source x harvest interactions in the factorial analysis that were not present in yield analysis as indicated in Table IV.

The average phosphorus yield for the 40 lb. rate in the W/D moisture regime was 57.75 milligrams and 72.79 milligrams for the D/W regime. The 160 lb. treatment averaged 72.94 milligrams for the W.D treatment and 139.79 milligrams for the D/W medium. This substantiated the previous statement that the best response is obtained when fertilizer phosphorus is in moist soil instead of the dry portion of the soil. In the D/W medium, all fertilized plots yielded twice as much, or more, than the check plot. This shows the need for placing fertilizers in areas of moist soil. The difference is not nearly as great in the W/D moisture condition where the plants were unable to utilize the fertilizer to its greatest extent.

Ammonium polyphosphate phosphorus was more readily absorbed by the plant than phosphorus from any other source. Monocalcium phosphate and diammonium phosphate were next with the latter contributing the most. Ferrous ammonium phosphate contributed far less than any other source, with a large reduction noted in the wet soil. Figure 5 graphically shows that ammonium polyphosphate appeared to be the best source in all cases, with the exception of 160 lb. W/D treatments.

As was pointed out in the discussion of total phosphorus and illustrated in Figure 5, smaller differences in phosphorus uptake were observed between sources with the 40 lb. W/D treatments than with any other treatments. There was a very large spread in amount of phosphorus uptake from different sources at the 160 lb. D/W treatment. The 160 lb. D/W ammonium polyphosphate more than doubled the amount of phosphorus absorbed from the ferrous ammonium phosphate 160 lb. D/W treatment.

Uptake of Phosphorus by Sorghum Plants

The effect of the various treatments on phosphorus uptake is shown in Table VII. The results corresponded closely with total yield and total phosphorus uptake. There was a highly significant difference due to moisture regime, rate, source and harvests as shown in Table IV. The W/D treatment averaged 2.37 milligrams per gram of plant material as compared with 2.92 milligrams for the D/W treatment, which indicated an increased uptake of phosphorus by the plant due to the moisture location.

Ammonium polyphosphate treatments had the most phosphorus in the plant when compared to all other sources as shown by Figure 6. Ammonium polyphosphate was significantly better than other sources at the five per cent level according to the multiple range test. This is substantiated by results which were discussed earlier.

The amount of phosphorus per gram of plant material varied directly with the rate within like treatments. This was generally true from a W/D moisture situation to a D/W moisture regime for the first harvest. However, in the second harvest, for the lower rate, the W/D generally did

TABLE VII

MILLIGRAMS OF PHOSPHORUS PER GRAM OF PLANT MATERIAL IN SUGAR DRIP FORAGE SORGHUM AS AFFECTED BY RATE, SOURCE AND MOISTURE IN GREENHOUSE EXPERIMENT

| Treatments | Harvests | | Mean |
|---|---|---|---|
| | 1 | 2 | |
| Check W/D | 2.046 | 2.129 | 2.087 |
| Check D/W | 1.498 | 1.777 | 1.637 |
| 40 lb. MCP W/D | 2.158 | 2.258 | 2.208 |
| 40 lb. MCP D/W | 2.705 | 1.776 | 2.240 |
| 160 lb. MCP W/D | 3.688 | 1.512 | 2.600 |
| 160 lb. MCP D/W | 5.188 | 3.785 | 4.486 |
| 40 lb. DAP W/D | 2.437 | 2.094 | 2.265 |
| 40 lb. DAP D/W | 2.243 | 1.680 | 1.961 |
| 160 lb. DAP W/D | 2.444 | 2.278 | 2.361 |
| 160 lb. DAP D/W | 4.203 | 2.607 | 3.405 |
| 40 lb. APP W/D | 2.345 | 2.261 | 2.303 |
| 40 lb. APP D/W | 3.798 | 1.794 | 2.796 |
| 160 lb. APP W/D | 3.229 | 2.810 | 3.019 |
| 160 lb. APP D/W | 6.255 | 3.847 | 5.051 |
| 40 lb. FAP W/D | 1.897 | 2.003 | 1.950 |
| 40 lb. FAP D/W | 1.522 | 1.558 | 1.540 |
| 160 lb. FAP W/D | 2.217 | 2.045 | 2.131 |
| 160 lb. FAP D/W | 2.075 | 1.670 | 1.872 |

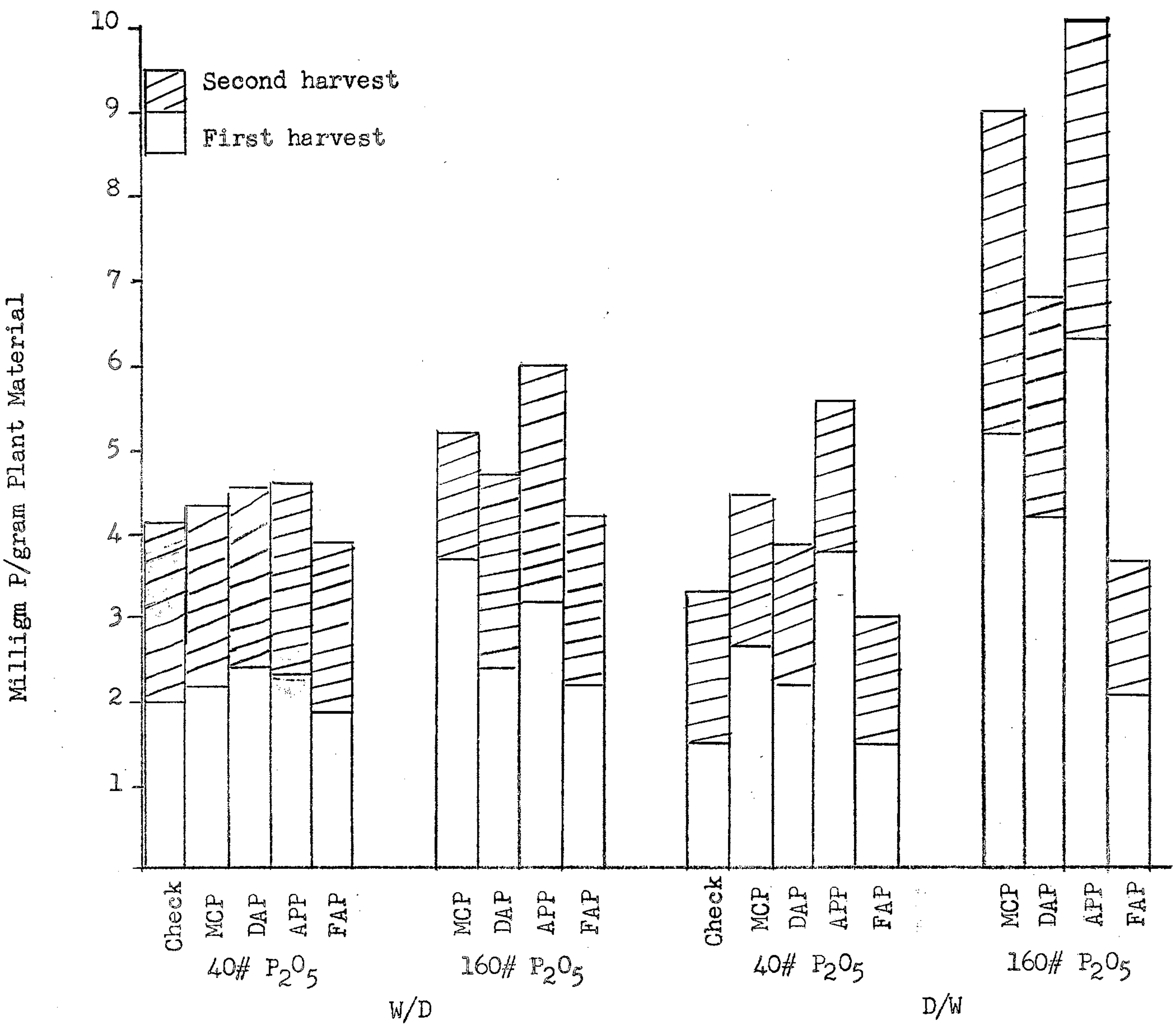



Figure 6. Milligrams Phosphorus used per gram of Plant material as effected by different treatments.

better than the D/W moisture situation. With the exception of the check, milligrams of phosphorus per gram of plant material in the first harvest were about equal to or greater than the second harvest.

In many instances, the 40 pounds W/D treatment had more phosphorus per gram of material than the 40 pounds D/W treatments. There was a very small difference in yield when comparing results obtained on the 40 pound W/D treatments for both the first and second harvests. The spread was much greater in the other treatments with the greatest spread and largest response occurring in the 160 pound D/W moisture treatment.

Phosphorus uptake was found to be highest more often in ammonium polyphosphate than any other source, followed closely by monocalcium phosphate and diammonium phosphate. Ferrous ammonium phosphate was lowest in all treatments.

## Fertilizer Phosphorus Uptake

The percent of fertilizer phosphorus uptake was determined by "tagging" the fertilizer material with radioactive $P^{32}$. The per cent of fertilizer phosphorus used is reported in Table VIII and is shown graphically in Figure 7.

Significant differences were essentially the same as were obtained from the dry forage yield. There was a significant difference at the 1% level for source, placement, rate and harvest as shown in Table 4. As in all other results, no difference was observed between replications. The percentage of uptake of all fertilizer material in the D/W moisture regime was twice as much as under W/D conditions. The overall average of percent phosphorus uptake from fertilizer under the W/D regime is 5.10% as compared to 10.64% for the D/W treatment.

TABLE VIII

PERCENTAGE OF FERTILIZER PHOSPHORUS ABSORBED BY SUGAR DRIP FORAGE SORGHUM IN GREENHOUSE

| Per Cent of $P^{32}$ Taken up by Plant Material | | | |
|---|---|---|---|
| Treatment | Harvests | | Mean |
| | 1 | 2 | |
| Check W/D | 2.29 | 2.48 | 2.38 |
| Check D/W | 1.19 | 0.10 | 0.64 |
| 40 lb. MCP W/D | 3.14 | 0.52 | 1.83 |
| 40 lb. MCP D/W | 7.42 | 1.59 | 4.45 |
| 160 lb. MCP W/D | 16.02 | 1.08 | 8.55 |
| 160 lb. MCP D/W | 16.02 | 14.18 | 15.10 |
| 40 lb. DAP W/D | 2.94 | 1.23 | 2.08 |
| 40 lb. DAP D/W | 11.65 | 0.82 | 6.23 |
| 160 lb. DAP W/D | 16.37 | 1.52 | 8.94 |
| 160 lb. DAP D/W | 25.06 | 9.46 | 17.26 |
| 40 lb. APP W/D | 7.38 | 0.52 | 3.95 |
| 40 lb. APP D/W | 10.95 | 2.98 | 6.96 |
| 160 lb. APP W/D | 22.58 | 1.07 | 11.82 |
| 160 lb. APP D/W | 35.29 | 16.87 | 26.08 |
| 40 lb. FAP W/D | 1.27 | 0.02 | 0.64 |
| 40 lb. FAP D/W | 3.09 | 1.99 | 2.54 |
| 160 lb. FAP W/D | 5.40 | 0.59 | 2.99 |
| 160 lb. FAP D/W | 6.66 | 6.31 | 6.48 |

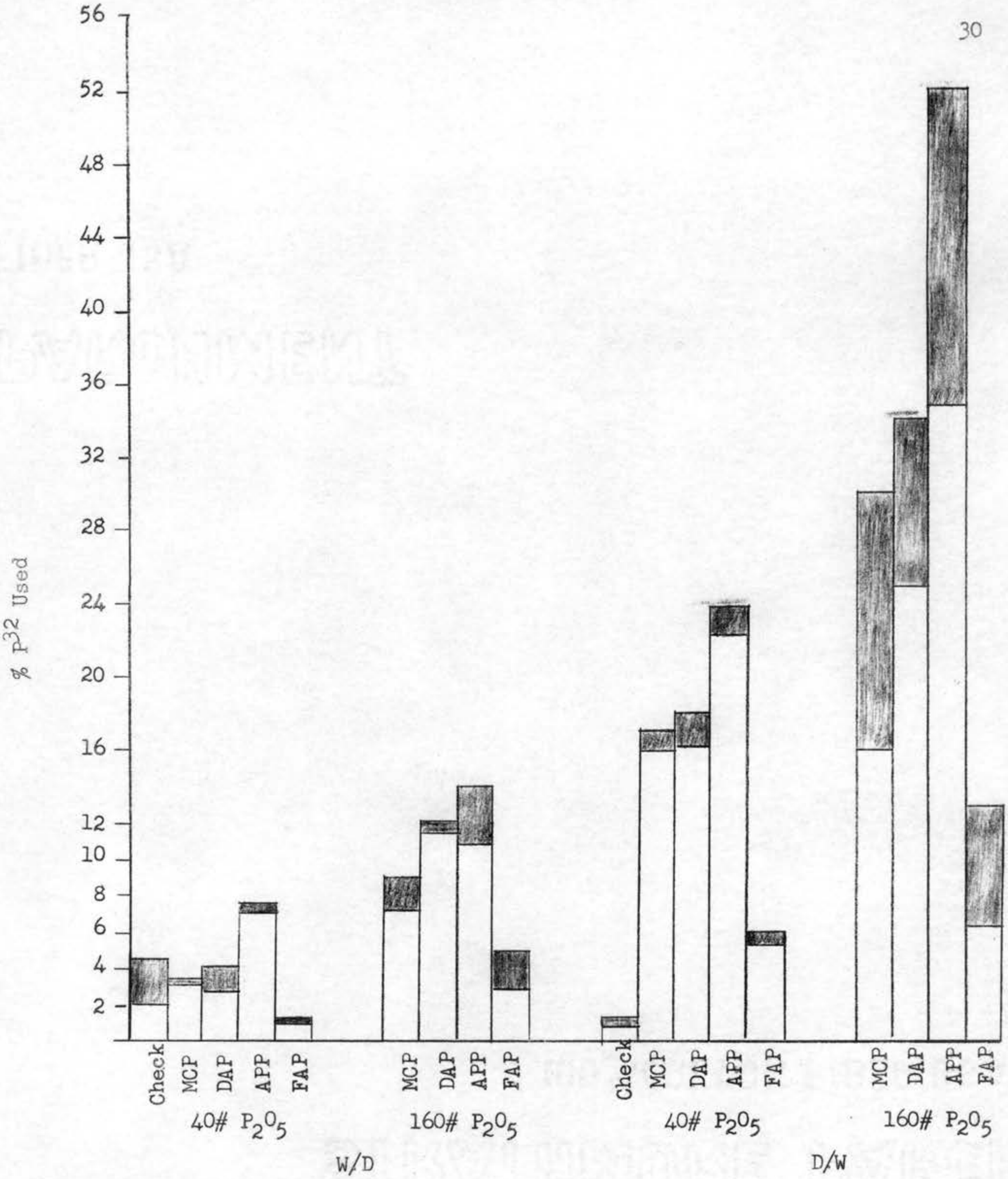



Figure 7. Percentage of Radioactive Phosphorus Used By Sugar Drip Forage Sorghum as affected by Rate, Source and Moisture.

The radioisotope $P^{32}$ study indicated that ammonium polyphosphate fertilizer contributed more fertilizer to the plant than any other source. In the first harvest, the 160 pound D/W treatment averaged 35.29% fertilizer uptake. The lowest percentage in the series of treatments was ferrous ammonium phosphate, which was 6.3%.

The overall average of fertilizer uptake for all treatments and both harvests was 12.20% for ammonium polyphosphate, 8.63% for diammonium phosphate, 7.49% for monocalcium phosphate, and 3.16% for ferrous ammonium phosphate. Duncan's multiple range test indicated that ammonium polyphosphate was significantly better than the other sources.

The overall uptake of fertilizer phosphorus at the 40 lb. level was 3.59%, as compared to 12.15% for the 160 lb. treatment.

## SUMMARY

Responses to different phosphorus sources, phosphorus rates and moisture regimes were investigated, using Sugar Drip forage sorghum as an indicator plant.

The main objectives of this research was to (1) determine feasibility of deep placement of phosphorus fertilizer for maximum plant growth during grouth periods; (2) determine if any of the phosphorus sources were better suited for objective (2) and (3) determine a yield curve when applied to work done previously.

D/W water placement gave the best results, which indicated that deep placement of phosphorus for good crop response would be important during years of drouth. Significant differences were obtained between all variables, Duncan's multiple range indicates that the D/W moisture regime was the better of the two moisture treatments.

Among the four sources used in this experiment, ammonium polyphosphate was consistently the best source. Only small differences were found between monocalcium phosphate and diammonium phosphate. Ferrous ammonium phosphate was the least available phosphorus source and did not show as great a response as other sources. For all results except total phosphorus uptake, Duncan's multiple range at the 5% level, ranks the phosphorus sources in the following order: ammonium polyphosphate, diammonium phosphate, monocalcium phosphate, and ferrous ammonium phosphate.

Although increases in yield were obtained with increased rates, field results will be needed to determine the economic feasibility of

the rate and depth of placement of phosphorus fertilizer recommendation.

It was concluded that phosphorus should be placed deep enough in the soil to contact soil moisture for maximum uptake. It was further concluded that ammonium polyphosphate was the most efficient phosphorus source investigated in this experiment.

The following assumptions can be made from the results reported:

1. Deep placement of phosphorus fertilizer on deep sandy soils is feasible in Western Oklahoma if there is adequate subsoil moisture.
2. Response data from the experiment indicated ammonium polyphosphate was the best source under the situation imposed upon the different sources in this experiment.
3. Ferrous ammonium phosphate did not give as much response as other sources even after five harvests.
4. Small differences were detected between monocalcium phosphate diammonium phosphate and ammonia polyphosphate.
5. When fertilizer is present in the soil profile, the plant will utilize it in preference to soil phosphorus.
6. Phosphorus fertilizer can be taken up in small amounts in dry soils, as long as roots have a source of water in the soil profile. This uptake will not be as great as when phosphorus fertilizer is placed in a moist soil.

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# A P P E N D I X

## LIST OF APPENDIX TABLES

APPENDIX TABLE I

PROFILE DESCRIPTION OF MILES LOAMY FINE SAND OBTAINED FROM SANDY LAND EXPERIMENT STATION, MANGUM, OKLAHOMA 1/

| | | |
|---|---|---|
| I | Soil Profile | |
| | $A_1$ 0-14" | Light brown gray (10 YR 6/2 dry) loamy fine sand; structureless; loose; clear wavy boundry. |
| | $A_2$ 14-30" | Brown (7.5 YR 5/4 dry) loamy fine sand; structureless; loose; clear wavy boundry. |
| | $B_2$ 30-36" | Dark brown (7.5 YR 3/2 moist) sandy clay loam; structureless to weak medium granular; loose to medium friable; smooth abrupt lower boundry. |
| | C 36-54" | Very dark gray (10 YR 3/1 moist) crushes to dark reddish brown (5 YR 3/4, moist) clay with shines of ped faces; many black concretions; some evidence of slickensides; a lot of the shines appear to be moisture. |
| II. | General: | The Brownfield series includes loose sandy soils with reddish friable subsoils and no horizon of carbonate accumulation. These 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. |
| III. | Topography: | Undulating to billowy upland. |
| IV. | Drainage: | Free. |
| V. | Vegetation: | Shin Oak and coarse grasses. |
| VI. | Remarks: | Pit was dug 48" deep, augered to 85" on a ½ to 1% slope. Sample was obtained in pasture area just east of house on Sandy Land Experiment Station and was collected on November 2, 1960. |

1/ Profile described at site by Ruel Bain, former instructor, Soil Survey, Oklahoma State University.

APPENDIX TABLE II.

YIELD OF SUGAR DRIP FORAGE SORGHUM FOR EXPERIMENT IN GREENHOUSE

| | | Total Grams of Oven-Dry Forage per Pot | | | | |
|---|---|---|---|---|---|---|
| Treat-ment Number | Repli-cation | Harvests 1 | 2 | 3 | 4 | Total |
| 1 | 1 | 26.56 | 22.77 | 30.84 | 26.19 | 28.21 |
| | 2 | 37.97 | 22.46 | 16.52 | 33.17 | 27.81 |
| | 3 | 36.55 | 13.66 | 16.88 | 15.16 | 22.31 |
| 2 | 1 | 34.59 | 24.05 | 31.85 | 37.65 | 21.91 |
| | 2 | 29.13 | 15.00 | 10.37 | 27.30 | 36.11 |
| | 3 | 42.89 | 27.99 | 37.90 | 22.08 | 23.91 |
| 3 | 1 | 37.28 | 12.00 | 16.76 | 25.70 | 25.31 |
| | 2 | 41.04 | 16.95 | 22.67 | 26.48 | 23.71 |
| | 3 | 35.73 | 10.54 | 13.30 | 23.60 | 30.01 |
| 4 | 1 | 34.56 | 37.39 | 18.95 | 20.25 | 20.81 |
| | 2 | 41.22 | 38.59 | 24.77 | 25.89 | 26.41 |
| | 3 | 38.08 | 20.76 | 20.75 | 18.02 | 24.11 |
| 5 | 1 | 35.66 | 15.45 | 19.10 | 35.95 | 29.31 |
| | 2 | 38.83 | 20.07 | 26.89 | 25.09 | 21.81 |
| | 3 | 44.09 | 22.14 | 24.19 | 20.44 | 30.51 |
| 6 | 1 | 35.72 | 24.93 | 59.36 | 28.15 | 24.21 |
| | 2 | 36.07 | 39.40 | 48.43 | 33.11 | 27.01 |
| | 3 | 44.55 | 48.72 | 46.53 | 30.51 | 26.91 |
| 7 | 1 | 30.29 | 19.78 | 28.66 | 23.65 | 22.71 |
| | 2 | 35.18 | 10.95 | 12.45 | 34.78 | 25.31 |
| | 3 | 34.25 | 29.42 | 30.50 | 18.01 | 26.61 |
| 8 | 1 | 39.38 | 15.67 | 45.76 | 30.12 | 29.61 |
| | 2 | 38.65 | 33.50 | 22.42 | 8.87 | 4.96 |
| | 3 | 47.42 | 26.00 | 31.12 | 27.26 | 20.01 |
| 9 | 1 | 38.49 | 22.12 | 31.96 | 25.70 | 29.01 |
| | 2 | 35.39 | 14.46 | 21.08 | 25.59 | 25.11 |
| | 3 | 35.95 | 14.52 | 24.65 | 32.42 | 29.21 |

(Continued from previous page)

| | | | | | | |
|---|---|---|---|---|---|---|
| 10 | 1 | 30.82 | 40.83 | 37.79 | 27.31 | 26.36 |
| | 2 | 32.18 | 59.57 | 20.92 | 33.72 | 19.61 |
| | 3 | 50.65 | 54.77 | 38.56 | 30.90 | 34.91 |
| 11 | 1 | 37.50 | 18.26 | 13.96 | 28.61 | 28.56 |
| | 2 | 40.29 | 17.60 | 24.82 | 32.75 | 29.31 |
| | 3 | 36.44 | 15.36 | 18.26 | 27.50 | 26.31 |
| 12 | 1 | 37.61 | 18.17 | 40.01 | 34.42 | 18.66 |
| | 2 | 28.52 | 43.64 | 32.31 | 30.30 | 23.86 |
| | 3 | 45.68 | 36.88 | 23.48 | 28.70 | 34.11 |
| 13 | 1 | 34.74 | 14.47 | 24.07 | 28.91 | 24.01 |
| | 2 | 40.88 | 11.54 | 24.10 | 28.06 | 32.61 |
| | 3 | 41.32 | 10.54 | 24.80 | 22.06 | 30.21 |
| 14 | 1 | 39.83 | 34.79 | 48.90 | 40.30 | 34.11 |
| | 2 | 40.96 | 48.55 | 43.66 | 32.38 | 28.41 |
| | 3 | 40.27 | 26.42 | 32.44 | 34.80 | 29.71 |
| 15 | 1 | 35.32 | 24.64 | 23.01 | 31.70 | 24.91 |
| | 2 | 39.08 | 14.48 | 14.91 | 35.35 | 31.96 |
| | 3 | 38.21 | 12.56 | 11.31 | 27.55 | 33.61 |
| 16 | 1 | 37.88 | 21.84 | 28.83 | 19.37 | 17.11 |
| | 2 | 43.48 | 26.62 | 35.52 | 28.05 | 10.11 |
| | 3 | 38.16 | 21.25 | 30.70 | 26.80 | 22.91 |
| 17 | 1 | 41.61 | 17.19 | 23.30 | 31.25 | 26.31 |
| | 2 | 34.24 | 14.15 | 18.53 | 21.00 | 24.71 |
| | 3 | 34.29 | 16.28 | 19.28 | 30.10 | 26.71 |
| 18 | 1 | 34.38 | 19.51 | 24.20 | 21.15 | 19.86 |
| | 2 | 38.05 | 25.51 | 40.60 | 27.81 | 27.41 |
| | 3 | 45.11 | 17.72 | 39.46 | 25.02 | 22.41 |

* See Table 1 for treatment numbers.

APPENDIX TABLE III

TOTAL MILLIGRAMS OF PHOSPHORUS ABSORBED BY SUGAR DRIP FORAGE SORGHUM IN GREENHOUSE STUDY

| | Harvest 1 | | | Harvest 2 | | |
|---|---|---|---|---|---|---|
| Code No. | Replications 1 | 2 | 3 | Replications 1 | 2 | 3 |
| 1 | 61.36 | 71.05 | 69.72 | 45.20 | 25.64 | 29.59 |
| 2 | 50.38 | 44.58 | 63.20 | 37.22 | 24.8 | 28.84 |
| 3 | 93.74 | 85.87 | 65.11 | 22.22 | 34.42 | 19.95 |
| 4 | 120.15 | 121.66 | 62.12 | 53.37 | 68.04 | 39.87 |
| 5 | 135.73 | 136.15 | 162.04 | 38.97 | 20.91 | 21.54 |
| 6 | 204.06 | 187.89 | 195.36 | 121.17 | 119.90 | 168.21 |
| 7 | 78.06 | 80.12 | 82.15 | 39.82 | 28.41 | 49.25 |
| 8 | 90.60 | 95.84 | 90.40 | 22.11 | 72.90 | 37.87 |
| 9 | 133.91 | 88.91 | 82.00 | 48.21 | 37.04 | 30.41 |
| 10 | 121.84 | 134.81 | 219.54 | 99.44 | 189.62 | 123.16 |
| 11 | 86.94 | 92.01 | 86.92 | 41.52 | 44.93 | 30.09 |
| 12 | 144.21 | 123.86 | 142.47 | 37.85 | 79.85 | 54.30 |
| 13 | 112.83 | 134.37 | 127.52 | 36.00 | 34.51 | 31.15 |
| 14 | 244.33 | 256.55 | 251.41 | 113.49 | 149.12 | 137.64 |
| 15 | 73.89 | 77.39 | 63.52 | 48.12 | 28.90 | 32.69 |
| 16 | 63.71 | 64.08 | 52.73 | 34.88 | 43.41 | 30.78 |
| 17 | 88.36 | 73.14 | 80.32 | 30.12 | 32.35 | 34.14 |
| 18 | 72.22 | 75.32 | 72.22 | 26.04 | 47.65 | 26.09 |

* See Table I for code numbers

APPENDIX TABLE IV

MILLIGRAMS OF PHOSPHORUS PER GRAM OF PLANT MATERIAL ABSORBED BY SUGAR DRIP FORAGE SORGHUM IN GREENHOUSE STUDY

| | Harvest 1 | | | Harvest 2 | | |
|---|---|---|---|---|---|---|
| Code No. | Replications 1 | 2 | 3 | Replications 1 | 2 | 3 |
| 1 | 2.334 | 1.884 | 1.921 | 1.985 | 2.237 | 2.166 |
| 2 | 1.468 | 1.545 | 1.483 | 1.547 | 2.182 | 1.603 |
| 3 | 2.532 | 2.106 | 1.836 | 2.851 | 2.030 | 1.893 |
| 4 | 3.504 | 2.970 | 1.643 | 1.647 | 1.763 | 1.920 |
| 5 | 3.835 | 3.531 | 3.698 | 2.522 | 1.042 | 0.973 |
| 6 | 5.906 | 5.248 | 4.412 | 4.860 | 3.043 | 3.452 |
| 7 | 2.600 | 2.295 | 2.417 | 2.013 | 2.595 | 1.674 |
| 8 | 2.316 | 2.497 | 1.917 | 1.411 | 2.176 | 1.454 |
| 9 | 2.503 | 2.531 | 2.298 | 2.171 | 2.094 | |
| 10 | 4.027 | 4.225 | 4.358 | 2.435 | 3.138 | 2.248 |
| 11 | 2.335 | 2.299 | 2.403 | 2.273 | 2.552 | 1.959 |
| 12 | 3.873 | 4.384 | 3.137 | 2.083 | 1.829 | 1.472 |
| 13 | 3.273 | 3.308 | 3.106 | 2.487 | 2.990 | 2.955 |
| 14 | 6.176 | 6.305 | 6.284 | 3.262 | 3.071 | 5.209 |
| 15 | 2.108 | 1.994 | 1.590 | 1.952 | 1.996 | 2.063 |
| 16 | 1.694 | 1.483 | 1.391 | 1.597 | 1.630 | 1.448 |
| 17 | 2.137 | 2.153 | 2.361 | 1.752 | 2.286 | 2.097 |
| 18 | 2.117 | 1.993 | 2.117 | 1.673 | 1.867 | 1.472 |

## APPENDIX TABLE V

## PERCENTAGE OF PHOSPHORUS FERTILIZER USED BY PLANTS IN GREENHOUSE STUDY

| | Harvest 1 | | | Harvest 2 | | |
|---|---|---|---|---|---|---|
| Code No. | Replications 1 | 2 | 3 | Replications 1 | 2 | 3 |
| 1 | - | 5.84 | 1.03 | 4.30 | 3.04 | 0.12 |
| 2 | - | 0.93 | 2.65 | - | - | 0.30 |
| 3 | 3.37 | 3.28 | 2.74 | 1.28 | 4.23 | 0.27 |
| 4 | 7.12 | 11.12 | 4.02 | 0.36 | 0.53 | 0.17 |
| 5 | 13.63 | 21.99 | 12.42 | 0.77 | 2.13 | 0.34 |
| 6 | 17.47 | 15.55 | 18.88 | 18.16 | 18.78 | 5.62 |
| 7 | 4.36 | 1.99 | 2.46 | 3.35 | - | 0.35 |
| 8 | 14.29 | 9.82 | 10.85 | 0.65 | 0.89 | 0.92 |
| 9 | 26.15 | 8.44 | 14.54 | 3.23 | - | 1.34 |
| 10 | 13.33 | 37.02 | 24.85 | 3.18 | 14.10 | 11.10 |
| 11 | 5.89 | 9.44 | 6.80 | - | 0.86 | 0.70 |
| 12 | 11.33 | 4.60 | 16.90 | 0.56 | 7.28 | 1.08 |
| 13 | 8.56 | 22.36 | 37.82 | 0.42 | 0.67 | 2.13 |
| 14 | 28.38 | 29.37 | 48.23 | 7.81 | 26.51 | 16.29 |
| 15 | 1.49 | 1.19 | 1.13 | - | - | - |
| 16 | 3.79 | 2.08 | 3.39 | - | 3.69 | 2.28 |
| 17 | 5.67 | 8.54 | 1.99 | - | 1.45 | 0.33 |
| 18 | 8.96 | 6.84 | 4.18 | 5.33 | 13.30 | 0.32 |

VITA

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