RESPONSE OF DIFFERENT PLANT SPECIES TO PHOSPHORUS

by

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ABSTRACT

Response of cotton, tomato, tobacco, lettuce and sorghum in growth and phosphorus content to superphosphate was evaluated on five Arizona soils under greenhouse conditions.

It was found that cotton and sorghum produced the greatest oven dry plant material. The growth of tobacco, tomato and lettuce were similar on three soils. This study showed that the average dry weight of plant was significantly increased by phosphate application. Lettuce showed the greatest response. No plant weight response to superphosphate was obtained with tobacco.

Significant differences in phosphorus content per unit dry weight was also found among plants. Utilization of superphosphate was greatest with cotton and sorghum, intermediate with lettuce and tomato, and least with tobacco. No consistent effectiveness in total phosphorus uptake was shown by the plant species tested on the different soils. Sorghum represented the extremes in total phosphorus uptake.

Available phosphorus content of the soils after cropping showed considerable variability and was inversely

related to the total phosphorus uptake by the plant species.

Total soluble salts of the soils after cropping were not significantly affected by phosphorus application. Sorghum appeared to be more effective than the other plant species in lowering the total soluble salts of the soils employed.

INTRODUCTION

Of the essential nutrient elements required by plants, phosphorus is second in importance to nitrogen for plant growth. In addition to phosphorus requirement for life processes such as photosynthesis and utilization of carbohydrates, phosphorus constitutes a major portion of the nucleus of the cell and is involved in transfer of energy within the plant.

In view of the wide importance and interest in this element, phosphorus has long been subjected to intensive investigations. The main criterion by which a plant's performance has been judged has been through its yield increase and phosphorus uptake from soil or from applied fertilizer.

Many workers have reported that plant species or even varieties differ in their ability to extract the less soluble forms of phosphorus from the soils. The uptake of phosphorus from added fertilizer is also known to vary greatly among plant species. In general, it has been found that Leguminosae and Cruciferae can utilize the soluble phosphate to a greater extent than the Graminae. While the plant growth in some instances was arrested by phosphorus deficiency, in other instances phosphate application was not associated with a growth response.

The study of phosphorus availability in Arizona soils has been a major project mainly because the total amount of phosphorus present in these soils is adequate to support crop production for many years, but the low availability of this native phosphorus to plant species grown on these soils forms the main problem. The alkalinity and the calcium content of Arizona soils appear to be the principal factors contributing to this problem. However, it has been reported that some plant species were able to utilize this native phosphorus to greater extent than others. Generally response to phosphate application in Arizona soils has been obtained with grains and alfalfa. Cotton response to phosphorus has been infrequent mostly occurring on coarse textured soils.

The objective of this experiment was to make a quantitative evaluation of the relative response of five plant species to phosphorus on five Arizona soils and to study the relationship among such factors as the relative phosphorus response of each plant specie and phosphorus content of the plants in relation to the phosphorus level of these soils.

LITERATURE REVIEW

One of the earliest extensive investigations with phosphate was reported by Merrill (28). Merrill used acid phosphate (superphosphate), rock phosphate and redonite (a phosphate of aluminum and iron) in quartz sand cultures and grew eighteen species of plants. He found that acid rock (superphosphate) gave the best returns in all cases and especially with the graminae. With graminae, redonite gave better results than rock phosphate, but in other cases the reverse was true. Plants of the cruciferae family were especially strong feeders on rock phosphate.

Truog (45) observed great differences in the ability of twelve agricultural plants to absorb different kinds of phosphate. The various plants exhibited considerable differences in the utilization of tricalcium phosphate and ferric phosphate. While barley made an exceptionally vigorous growth on the ferric phosphate, rape made a comparatively poor growth. In addition, the plants showed striking differences in their ability to utilize the phosphorus of rock phosphate. Some of the plants appeared to have little ability to obtain phosphorus from this source, while rape, buckwheat, tobacco and alfalfa exhibited considerable ability. He also found

that plants containing a relatively high calcium content had a relatively high "feeding power" for the phosphorus in raw rock phosphate. Therefore, he related the high plant ability to absorb phosphorus in rock phosphate to the high calcium content of the plants.

Studies by Fuller and McGeorge (11) on calcareous Arizona soils showed that the yield response of barley to phosphate fertilizer additions was much less than that of tomatoes. Yield response of both barley and tomatoes to phosphate application was not significant on soil well supplied with CO_2 soluble phosphorus. Barley grown on soil less well supplied with soluble phosphorus responded very little to phosphate treatment, though tomato yields were raised appreciably by phosphate application. Furthermore, addition of phosphorus caused an increase in phosphorus content of the plant. The percentage of phosphorus in barley tops was very similar to that in tomato tops grown on the same soil. Those soils having the greatest amount of phosphorus soluble in both water and CO_2 solution also had the highest percentage phosphorus in the plant. They also found a significant decrease in calcium percentage of the barley and tomato tops as a result of phosphate application. The lowest calcium content was found in samples taken from soils showing the least yield response to phosphorus.

Jackson and Burton (16) compared rock phosphate and superphosphate for several forage crops. They found that the application of lime to a Rains soil in Georgia resulted in sweet clover utilizing rock phosphate more efficiently than the other legumes. The others, in order of decreasing efficiency, were crimson clover, trefoil, ladino clover and big trefoil. On unlimed soil, trefoil was the most efficient in rock phosphate utilization. Bahai grass and Dallis grass responded similarly to each of the different phosphorus treatments.

Fuller (10) found that the yield and the phosphorus content of alfalfa grown on calcareous soils low in available phosphorus was increased significantly by application of phosphate fertilizer. On the other hand, there was no significant increase in yield and phosphorus content by the application of phosphate fertilizer to a soil well supplied with available phosphorus. Differences were also found in absorption of fertilizer phosphorus by cotton grown on two soils. The greater absorption of fertilizer phosphorus was from the soil having less naturally occurring available phosphorus. Cantaloupe absorbed more fertilizer phosphorus per unit weight of dry matter than cotton or barley grown under similar field conditions. Alfalfa absorbed only slightly less fertilizer phosphorus than cantaloupe. Cotton

and barley were found to be good users of native soil phosphorus. Thus, their demand for fertilizer phosphorus was relatively low compared with alfalfa and cantaloupe.

McLean (24) showed that in both oats and alfalfa, superphosphate produced a significant increase in yield over the combination of rock and superphosphate. In contrast, buckwheat produced a near significant increase in yield with the rock-superphosphate combination over the superphosphate alone. Buckwheat contained a much higher concentration of calcium when grown on the check and on the rock phosphate treatments than on the superphosphate or on the combination of rock and superphosphate. When oats were grown repeatedly as test crops, the first and the second test crops responded better to superphosphate than to rock phosphate.

In pot experiments, McGeorge (26) found that for alkaline calcareous soils, rye and Sudan grass showed a slight increase in absorption of phosphate when fertilized with magnesium sulphate, and the absorption of phosphate by cotton was reduced. He also observed that addition of calcium carbonate to the calcareous soils had no effect in the phosphate fertilized cultures, but a slight reduction in phosphate absorption in the unfertilized soils by rye plants. During the course of these experiments, one important

observation was made. Plants with high calcium requirements were considered strong phosphate "feeders" because the accumulated calcium ions tend to reduce phosphate solubility in the soil solution and the root-soil contact films if the soluble calcium is not removed.

These results support the suggestion that plants differ in the utilization of soil phosphorus because of differences in their ability to absorb calcium from the soil.

Hartwell and Damon (15) found that beets, cabbage and rape yielded on the standard acid-phosphate areas, where annual average of 42 pounds of P_2O_5 per acre was applied, more than twice as much as on the non-phosphorus plots. Carrots, potatoes, tomatoes and wheat yielded about one and a half as much on the standard acid-phosphate areas as on the non-phosphorus plots. The carrots and millet were the only crops which yielded about the same where there was applied an average of 42 and 125 pounds of P_2O_5 per acre. Therefore, the relative yields of carrots and millet with different phosphates were of little significance from the standpoint of phosphorus availability. The alfalfa and timothy showed relatively high phosphorus response as compared with the other plant species. The amount removed by each crop depended mainly on the size of the crop. With cereals, there

was a threefold increase in removal resulting from the applied phosphorus. After three months the oats removed more phosphorus than the carrots and three times as much as the wheat.

In a seedling growth study, McGeorge (27) showed that for alkaline-calcareous soils, barley had a stronger extracting power for soil phosphorus than rye, which is consistent with the greater volume of roots produced by barley. The difference in extracting power of these two plants was more evident in the soil of lower available phosphorus content. Variation in phosphate extraction by rye, barley and wheat was also found. Wheat extracted the most phosphate, and rye the least from the soil. Phosphate absorption, at least by rye seedlings, increased with a decrease in solubility of calcium and also with the decrease in percentage of calcium carbonate in the soils.

Lilleland et al. (20) found an increase in the yield of 18 crops on a green weight basis from the application of 500 pounds per acre of superphosphate to an extremely low phosphorus soil. The legume yields were increased at least twofold. Cereals made from three to eight times the yield on the phosphated plot. Cucumbers, crookneck squash and lettuce showed a marked response and increased 18-fold, 43-fold and 30-fold, respectively. The ratios of dry matter

yields between the fertilized and check plot were from 1.6 in the case of the wax bean to 29.4 in the case of the crookneck squash. The mature fruit trees failed to respond in growth to phosphate on this soil, but the growth of nursery fruit trees was stimulated by heavy applications placed in the hole at planting time.

Nelson et al. (33) reported that potatoes, corn, cotton and tobacco varied greatly in absorption of fertilizer phosphorus on soils of comparable native phosphorus content. Potatoes and corn represented the extremes, with potatoes absorbing a relatively high proportion from the fertilizer throughout the growing period, and corn absorbing high proportions early and only small amounts in the later portion of its growing period. The percentage of fertilizer phosphorus absorbed by potatoes, corn and cotton decreased as the amount of native soil phosphorus increased. On the soils highest in native soil phosphorus cotton and potatoes absorbed approximately 2.5 percent and 10 percent of the applied phosphorus, respectively.

Blaser and McAuliffe (2) found that the yield and phosphorus content of orchard grass and ladino clover which were seeded on plots treated with radioactive phosphate fertilizer were not associated with the rate of application. The amount of phosphorus uptake by ladino clover from the

fertilizer was higher for superphosphate at all sampling periods than for the other phosphate fertilizers. During early season more fertilizer was absorbed from calcium metaphosphate than from either dicalcium or tricalcium phosphates. The percentage of phosphorus in ladino clover did not differ for the seasonal harvests. Conversely, with orchard grass the phosphorus content of the herbage harvested late in the season was much higher than for the two earlier dates. With ladino clover more phosphorus was absorbed from the drilled fertilizers than from the broadcast applications, whereas with orchard grass the reverse occurred.

Nelson et al. (34) reported that on low phosphorus soil, cotton absorbed approximately twice as much fertilizer phosphorus as on high phosphorus soil. In one treatment on low phosphorus soil 5.4 percent of the applied phosphorus was absorbed, whereas only 2.7 percent was absorbed on the high phosphorus soil. There was an early vegetative growth response to phosphorus application on both corn and cotton. Cotton yields were increased by phosphate application on the low phosphorus soil, but there was no significant difference in the yield or phosphorus content of corn grain due to phosphorus application.

Krantz et al. (19), comparing phosphorus utilization by crops, found that corn, potatoes and soybeans varied greatly in the percentage of phosphorus derived from the fertilizer. The percentages for both corn and soybeans decreased sharply during the season. Potatoes absorbed the most fertilizer phosphorus and soybeans the least. Corn, however, absorbed the greatest total amount of phosphorus and potatoes the least. The corn and soybean plants absorbed the bulk of their phosphorus late in the season after the root system was nearly fully extended. Corn and cotton were similar in proportion of phosphorus absorbed from the fertilizer at high and low soil phosphorus levels. Potatoes gave a yield response on both low and high phosphorus soil, whereas soybeans and cotton gave a yield response only on low phosphorus soil.

Comparison of various phosphate fertilizer materials on sugar beets, wheat, barley, potatoes and alfalfa, by Olsen et al. (36) showed that the amount of phosphorus in the plants derived from the fertilizers varied with crop and stage of growth. The utilization of the applied phosphorus ranged from about two percent on first-year alfalfa to 12 percent on sugar beets. Yield responses due to the applied fertilizer were obtained with alfalfa and sugar beets, usually in the earlier stages of growth, but the final yields were not affected significantly.

Mitchell (29) pointed out that barley and oats responded better to phosphate than wheat. The order of yield increase in two trials was wheat (least), barley, oats. It was noted that barley utilized a greater proportion of the fertilizer phosphorus and showed a greater uptake of total phosphorus on the fertilizer plots. The proportion of phosphorus obtained by barley from the soil increased rapidly after the fourth week. While certain varieties of barley responded better to phosphatic fertilizer than did others, this differentiation did not appear in the wheat and oat varieties.

Lutz et al. (21) found in two tests in Virginia with oats and wheat that broadcasting the fertilizers was equally as effective for increasing yields of grain as application with the seed. There was greater forage yield response early in the season to placement of phosphorus near the seed. Later, observable growth differences disappeared and the crop obtained most of its phosphorus throughout the root zone and was much less dependent on application near the seed. Thus, differences in root system of various plant species appears to reflect the differential phosphorus uptake from the soil.

Tests made by Smith (42) in sand and water cultures under greenhouse conditions with 24 inbred and 23 single

crosses of maize showed that many inbred lines behaved very much alike, but a few showed distinct differences when grown with a limited phosphorus supply. Two inbred lines which grew well on low phosphorus and two which grew poorly were found to have a significantly differential response when grown on a low phosphorus medium. No definite relationship was found between phosphate efficiency and percentage composition of phosphorus in the inbred lines.

Mitchell et al. (30) also studied the uptake of soil and fertilizer phosphorus by varieties of wheat, oats, and barley on a slightly and highly responsive soils. They found that on the less responsive soil, increased yields were obtained on the phosphate plots with a fairly high utilization of the fertilizer phosphate but with a rather marked decrease in utilization of soil phosphorus as compared to the uptake on the untreated plots. On the responsive soil a higher uptake of fertilizer phosphate occurred for all crops, and uptake of soil phosphorus in the case of oats and barley remained about the same on both fertilized and unfertilized plots, although there was a lower uptake of soil phosphorus on the fertilized wheat plots. Varietal differences in yield appeared in oats and barley, but it was only in the barleys that varietal differences in response to phosphate fertilizer were obtained.

These differences were not accompanied by significant difference in uptake of soil or fertilizer phosphorus. Barley showed greater ability to utilize the applied phosphate than wheat, but there were no significant differences between wheat and oats, or barley and oats.

Mitchell et al. (31) in determining the availability of phosphorus from monoammonium phosphate and superphosphate for Exeter oats, Titan barley, Montcalm barley and Thatcher wheat, found that the only significant increase in grain yield was from ammonium phosphate (11-48-0) on Thatcher wheat. A significant increase in plant weight was obtained for Titan barley and Thatcher wheat from both (0-20-0) and (11-48-0) applications. Total phosphorus uptake was also significantly higher for both fertilizers on Titan barley and Thatcher wheat, while soil phosphorus uptake was significantly lower for Montcalm barley and Exeter oats.

Corn, during four seasons of growth under greenhouse conditions was found by Terman et al. (44) to be more responsive to applied phosphorus than millet, oats or wheat grown at appropriate seasons. The maximum yields of corn were not usually attained by the highest rate of application, while the other crops exhibited definite yield maximums. Responses by all crops increased in a similar manner with increase in water soluble phosphorus content of the applied phosphates.

McLean and Hoeloscher (23) found the buckwheat yielded much higher and took up much more phosphorus than did oats and alfalfa on all soils pretreated with phosphorus fertilizer. Soil from the field check plot when treated with superphosphate brought about greater crop yields and phosphorus uptake in every case than did the untreated soil. Buckwheat recovered about 40 percent of the fertilizer phosphorus applied to the soil, oats recovered on the average about 12 percent and alfalfa only about four percent of that applied. The total uptake of phosphorus from the fertilizer source was remarkedly constant for a given crop, but it varied tenfold between crop extremes.

Rossiter and Ozanne (39) found that application of superphosphate to a lateritic soil deficient in available phosphorus led to an increase in total pasture production. Differential species effects were also found. Subteranean clover and cape-weed responded about equally to superphosphate, but the clover responded to rock phosphate to a greater extent than did cape-weed. Such differences in feeding power for rock phosphate would be expected if the growth effects of rock phosphate were materially influenced by positional availability.

Haddock et al. (14) reported that rate of application of phosphorus had no effect on either yield or

phosphorus content of cotton, caster beans, corn, tomatoes and cantaloupe. Although phosphorus uptake from the fertilizer applied was relatively small, the difference in uptake among the crops was highly significant. The vegetable crops (tomatoes and cantaloupe) absorbed a higher percentage of phosphorus from the fertilizer than the field crops (corn, cotton and caster beans). Thus, differences in the amount of phosphorus absorbed were reflected among plant species.

Nye and Foster (35), using labelled phosphate fertilizer, found that in neutral and acid soils the proportions of soil phosphorus to added phosphorus taken up by a range of plants was much the same for a given soil in spite of very great differences in the growth of the plants and their total uptake of phosphorus. Marked differences also occurred in total phosphate absorbed by the crops on very phosphorus-deficient soil. Since root growth was not restricted in the large volume of permeable sandy soil employed, it is apparent that some species were more efficient than others in the absorption of soil phosphate due to their ability to take up phosphate rapidly at very low concentration in the soil solution.

In greenhouse experiments with acid soil, the development of clover, fescue and redtop seedlings was studied by Shoop et al. (41). Application of phosphorus caused

significant differences in the rate of seedling development and the relative response of different species to phosphorus. Maximum growth of fescue on unlimed soil was obtained with 640 pounds of P_2O_5 per acre, but on limed soil maximum growth was obtained with only 80 pounds of P_2O_5. Height of redtop on either limed or unlimed soils was greater with high phosphorus application. Ladino clover showed continuous response to phosphorus even with a high rate of application on both limed and unlimed soils.

A test conducted by Read et al. (38) with oats and alfalfa on three soils indicated that these crops behaved differently as phosphorus extractants. Under short-term absorption conditions, oats were much more sensitive to differences in soils and fertilizers than alfalfa.

Dean et al. (7) found an inverse relationship between the phosphorus fertility status of the soil and the percentage of phosphorus in the crop that was derived from the fertilizer applied at the time of planting. Factors that influenced the growth did not necessarily affect the percentage of phosphorus in the crop that was derived from the fertilizer.

Thus, the relative utilization of fertilizer phosphorus is influenced by the plant species grown and the level of native soil phosphorus in addition to inherent characteristics of the plants.

Gerretson (12) indicated that the amount of phosphorus assimilated by the plants as well as the weight of these plants increased markedly by the presence of organisms in the soil. This fact proved that the microorganisms had definitely made available certain amount of phosphorus, otherwise inaccessible. In sterile cultures, however, the amount of phosphorus assimilated by the plants from $Ca_3(PO_4)_2$ and bonemeal, though much smaller than in the infected cultures was quite considerable. This proved that in absence of microorganisms, the roots might take an active part in solubilizing difficultly soluble phosphates. Therefore, if different plant species favor differentially the growth of microorganisms near the root surface, these plants would vary in their ability to utilize soil phosphorus.

The increase in phosphorus level of an acid soil, as shown by Woltz et al. (46), resulted in an increase in total growth and total phosphorus uptake and a decrease in the percentage phosphorus in tobacco. There was no difference in the amount of fertilizer phosphorus taken up by the plant from different rates of application. At a high level of soil phosphorus, an increase in calcium level of the soil lowered the percentage of phosphorus in the plant from the fertilizer and increased the total growth. There was no effect of

calcium level on growth with low soil phosphorus. Thus, the utilization of soil phosphorus by tobacco appeared to be enhanced by calcium at high levels of soil phosphorus.

A comparison of absorption of soil phosphate by different species, made by Russell et al. (40), suggested that barley was markedly less effective at absorbing phosphate than rye when the external supply was low. They concluded that the absorption of phosphate by plants depended on root surfaces reducing the free energy of the entering ions to a greater extent than complexes with which they would be otherwise associated. Thus, the lower specific activities of absorbed phosphate found with rye and cabbage than with barley indicated that barley was unable to lower the free energy of phosphate to the same extent as cabbage or rye. Interspecific differences arising in this way would be expected to be marked only in soils containing significant quantities of labile phosphate, the free energy of which is too low for one specie to absorb it.

Fried (9) determined the relative absorption of phosphate fertilizer by buckwheat, barley, beets, oats, ryegrass, alfalfa and sweet clover. Large differences in total uptake of phosphorus from monocalcium phosphate occurred among these plant species, but these differences in total uptake were not reflected in the percent phosphorus in the

plant derived from the fertilizer. He suggested that differences such as size of the root systems and metabolic level in the plant rather than differences in interaction between plants and the phosphate sources in the soil system might be responsible for the differential uptake. Plant species also differed in their feeding power for rock phosphate even when the effect of the size of the root absorbing surface was eliminated.

Graham (13) found that the amount of phosphorus weathered from rock phosphate as well as the amounts of phosphorus taken up by plants were related to the initial pH value and to the bonding energy of the colloidal system for calcium. H-Amberlite, which had the highest calcium bonding energy of the colloid studied, was the most effective in making phosphorus available. He concluded that the relative driving energies of all plants containing high percentages of calcium would probably be high for calcium resulting in conditions which would lead to availability of phosphorus from natural sources.

McLean and Baker (25) reported that cation bonding energies of plant roots for calcium differed greatly with plant species. The calcium bonding values increased as the measured root cation exchange value increased. Calcium bonding values were low for oat roots and high for buckwheat.

High cation exchange roots such as buckwheat with a high bonding energy in a rock phosphate system would be expected to lower calcium activity by absorption to a greater degree than the lower cation exchange oat roots. Thereby, one would expect greater solubilization of the phosphorus from rock phosphate by buckwheat roots than by oat roots.

The results of Drake and Steckel (8) agreed with the results of McLean and Baker. They showed that phosphorus uptake from the subsoil rock phosphate system increased in the order wheat/ Lamb's quarters/ ragweed /smartweed. This phosphorus uptake corresponded approximately to the measured cation exchange values of the roots. The results demonstrated the greater solubilization of phosphorus from rock phosphate by roots with high calcium bonding energy. The phosphorus uptake increased as the root cation exchange capacities increased.

Asher and Ozanne (1) found that the concentrations of calcium and phosphorus in the tops of plants utilizing rock phosphate were each positively correlated with root cation exchange capacity. These results supported the hypothesis that the ability of plants to obtain phosphorus from relatively insoluble phosphates of divalent metals increased with increasing root cation exchange capacity. The relationship between the percentage phosphorus in the tops

and the ratio of root weight to top weight indicated that relatively large root systems were of little help in accumulating phosphorus in the plant tops.

It can be seen from the foregoing discussion that the growth and phosphorus content of various plant species were influenced by many factors. Although variations in size of root system brought about significant differences in yield and amount of phosphorus absorbed from the soil, large root systems were of little help in accumulation of phosphorus in the plants. Plant species differed in their abilities to absorb phosphorus more than can be attributed to the size of the root absorbing surface. While utilization of soil phosphorus was influenced by the calcium solubility and percentage of calcium carbonate in calcareous soils, different root cation exchange capacities associated with various abilities of plant species to absorb calcium were related to the observed differential in growth and phosphorus uptake. On the other hand, the level of native soil phosphorus and the inheretent characteristics of the plant, in addition to the effect of microorganisms on the solubilization of phosphate in the soil around the roots, influenced the growth and utilization of soil phosphorus by different plant species.

Under greenhouse conditions, the differential response of plant species to phosphorus should not be complicated by environment effects. Under these conditions, evaluation of real differences in phosphorus response on different calcareous soils should reflect the effect of nature of root systems, utilization of calcium in the soil, and other inheretent characteristics of the plant species.

MATERIALS AND METHODS

Selection and preparation of soils:

Since this study was designed to evaluate the relative response of five plant species to phosphate application on five Arizona soils, the soil materials used were selected from the surface five inches of fields in different areas expected to be deficient in phosphorus content.

Soil (1) Clay loam texture from an area mapped as Atlanto (reclassified as Mohave) at the Cotton Research Center in Tempe.

Soil (2) Clay loam texture from an area mapped as Leveen at the Agricultural Experimental Station in Mesa.

Soil (3) Clay texture from an area mapped as Gadsden at the Tucson City Farm west of Tucson.

Soil (4) Clay loam texture from an area mapped as Leveen Sand, south of Prince road and east of Campbell Avenue in Tucson.

Soil (5) Clay texture from an area mapped as Bagly Clay Loam near Snowflake.

The soils were dried and screened to remove stones and gravels, then mixed thoroughly. Two and a half kilograms

of each soil were placed in metal pots coated with Asphaltum. Two replications were used for each treatment which consisted of a control and phosphorus treatment on each soil and for each plant specie. Each phosphated pot received 2.25 grams of 45 percent superphosphate. This corresponded to an application of 442 milligrams of phosphorus per pot or about 354 pounds of phosphorus per acre six inches. The superphosphate was mixed with the soil by quartering on brown paper. The drainage hole in each pot was plugged with cotton fiber to prevent any loss of soil.

Planting and preparation of plants for analysis:

Tobacco was planted in sand and vermiculite cultures on September 19, 1964. The seedlings were transplanted in the soils on October 10, 1964. Sorghum, tomato and lettuce plants were planted directly in the soil on October 4, 1964. Cotton was planted on July 15, 1964. The tomato and lettuce were placed in a portion of the greenhouse with lower light intensity.

After planting, all the pots were covered with brown paper until the seeds germinated and emerged. When the first leaf started to develop, the plants were thinned to one per pot except tomato which was thinned to four plants per pot. The positions of the pots were placed at random. All pots

were first regularly watered with 100 ml. distilled water. The pots then were watered at regular intervals but with different amounts of distilled water according to the apparent dryness of the soils. A nutrient solution lacking phosphorus was used at different growth periods to insure an adequate supply of other nutrients.

The above ground portions of the plants were harvested on September 30 for cotton, December 9 for tobacco and December 24 for tomato. Sorghum and lettuce were harvested on January 21, 1965. These dates corresponded to initial flowering for tobacco, cotton and tomato, to seed formation for sorghum, and to initial head formation for lettuce. The plants were dried at 75°C., weighed, then ground to pass a 40-mesh screen in a Wiley mill. Two aliquots of plant materials from each pot were taken for phosphorus determination.

Determination of phosphorus in the plants:

Total phosphorus in the plants was determined colorimetrically by the vanadomolybdophosphoric acid method, described by Dr. C. O. Stanberry, which is a modification of Kitson and Mellon method (18). The modifications included substitution of sulfuric acid for nitric acid, narrowing acid concentration limits, use of filter with shorter wave length,

and permitting longer color development period before reading. An outline of the method is given as follows:

Reagents:

Ammonium vanadate NH_4VO_3 -0.25 percent solution: Five grams of ammonium vanadate was dissolved in a small volume of water and mixed with 55.5 ml. of concentrated sulfuric acid in 800 ml. distilled water and diluted to 2000 ml.

Five percent solution of ammonium molybdate $[(NH_4)_6\ Mo_7O_{24}\ 4H_2O]$: One hundred grams of ammonium molybdate were dissolved in approximately 1000 ml. of warm distilled water and the solution was made up to 2000 ml.

Sulfuric acid - Selenium digestion solution: In 1000 ml. of hot concentrated sulfuric acid, 1.15 grams selenium metal was dissolved.

Procedure:

A five hundred milligram sample of ground plant material was digested with 10 ml. of the digestion solution in a 100 ml. volumetric flask on hot plate until the black carbon disappeared. Then, the sample was further digested with 10 drops of concentrated perchloric acid on the hot plate for 30 minutes. The sample was then cooled, diluted to the volume with distilled water, cooled again, brought to

volume, and well mixed.

A 10 ml. aliquot of the sample was placed into a 50 ml. volumetric flask. Five ml. of 0.25 percent ammonium vanadate solution and five ml. 5 percent ammonium molybdate were added and diluted to volume with distilled water. The solution was well mixed and read on Bausch and Lomb Spectromic 20 after 30 minutes at 420 mu. the phosphorus concentration in the sample was determined using a standard curve made from known standards in the same manner as the unknown samples.

This method gave a good sensitivity and accuracy for samples containing more than 0.2 ppm. phosphorus. The accuracy was also checked by the standard addition method and the recovery ranged from 99.1 to 100 percent in the samples.

Analysis of soils:

Representative soil samples were taken before planting for analysis. The soils were dried and screened to pass a 2 mm. screen. The texture, pH value, cation exchange capacity, exchangeable cations, electrical conductivity, and CO_2 soluble phosphorus content were then determined. Particle size distribution was determined by the Bouyoucos method (3). Cation exchange capacity was determined by the method of Piper (37). Phosphorus content was determined by the method

of Murphy and Riley (32) using CO_2 soil extract. Exchangeable sodium and potassium were determined flame photometrically using Beckman Model DU equipment according to Chapman and Pratt (5). Determination of exchangeable calcium and magnesium, after extraction the soil with alcoholic potassium chloride (5) was made by titration with cyclohexanediaminetetraacetic acid using calcein indicator for calcium and Eriochrome Black T. indicator for magnesium plus calcium (4). Total soluble salts in the saturated extract of the soils were determined using "solu-bridge cell" according to Jackson (17).

Another set of representative soil samples were taken after cropping for determination of CO_2 soluble phosphorus and total soluble salts. All the soils used in this experiment were low in CO_2 soluble phosphorus which is a measure of available phosphorus. Results of the soil analysis on the initial samples are shown in Table 1.

Statistical Analysis:

All the data obtained in this experiment were analyzed statistically by the analysis of variance (43). The differences between the means and the correlation analysis between yield and total soluble salts were also tested after the methods reported by Steel and Torrie (43).

Table 1. Some characteristics of soils used in greenhouse study.

Soils	Type	Texture	Paste pH	E.C. of Soil Saturation Extract	P	C.E.C.	Exchangeable Ca	Mg	K	Na
				m mhos/cm	ppm.		meq./100gm.			
1	Mohave	Clay loam	8.00	4.30	0.37	10.61	5.80	1.75	0.89	1.42
2	Leveen	Clay loam	7.90	2.80	0.23	12.42	8.07	1.12	0.85	1.06
3	Gadsden	Clay	7.65	9.50	4.05	23.36	15.10	2.15	2.84	3.03
4	Leveen Sand	Clay loam	8.10	0.79	0.51	10.18	6.98	0.61	1.47	0.21
5	Bagley Clay loam	Clay	7.75	0.98	4.32	22.12	11.13	5.03	1.51	0.35

RESULTS AND DISCUSSION

Yield of the plant species

Yield of the plant species on different soils:

The yields of the above-ground tobacco, tomato, sorghum, lettuce and cotton plants on the five soils are given in Table 2. The vegetative growth on dry weight basis is regarded as yield throughout the discussion. The analysis of variance of these data (Table 3) illustrates that, on the average, significant differences occurred among the yields of the plant species. This is as would be expected considering the vast differences among these plants. Significant variation in yields on the different soils was also shown.

The mean yields of the plants on the five soils may be seen in Table 4. It may be inferred from this table that the yield among these plants differed markedly on the different soils. Cotton and sorghum produced more dry weight than either tobacco, tomato or lettuce on all the soils. However, cotton yields were highest on Soil 3 and lowest on Soil 4. Sorghum did not follow the same pattern. On the other soils, these two plants yielded similarly and no significant difference was detected. Since the nutrient

Table 2. Above ground yield of five plant species grown on five Arizona soils with and without phosphorus treatment.

Soil	1		2		3		4		5	
Treatment	0	P	0	P	0	P	0	P	0	P
Plant	Oven-dry weight gms./plant									
Tobacco	2.20	3.09	2.90	3.62	4.82	3.31	4.60	4.01	5.82	4.04
Tomato	0.08	2.49	0.74	1.60	1.72	2.11	0.76	1.66	1.09	1.82
Sorghum	7.28	5.82	7.44	11.01	6.08	8.16	7.84	10.60	13.90	11.74
Lettuce	0.36	1.23	0.55	1.03	1.54	2.72	0.06	0.41	4.22	6.50
Cotton	3.42	6.88	8.30	11.34	11.70	10.96	1.46	5.89	14.47	11.46

All data reported are a mean of two replicates.

Table 3. Analysis of variance of above ground yield of the five plants.

Source of Variation	d.f.	SS	MS
Plants	4	1043.07	260.77**
Treatments	1	14.62	14.62*
Soils	4	229.21	57.30**
Plant x Treatment	4	10.28	2.57
Plant x Soil	16	209.02	13.06**
Treatment x Soil	4	25.57	6.39
Plant x Treatment x Soil	16	53.90	3.37
Error	50	138.29	2.77

* Significant at 5% level of probability.
** Significant at 1% level of probability.

Table 4. Above ground yield of five plant species grown on five soils. Means of treatments and replications.

	Soil				
Plant	1	2	3	4	5
	Dry weight gm/plant				
Tobacco	2.64a*	3.26a	4.06a	4.31b	4.93b
Tomato	1.28a	1.17a	1.92a	1.22a	1.95a
Sorghum	6.55b	9.22b	7.12b	9.22c	12.82c
Lettuce	0.80a	0.79a	2.13a	0.24a	5.36b
Cotton	5.15b	9.82b	11.33c	3.68b	12.97c

* Values followed by the same letter are not significantly different for a given soil.

solution lacking phosphorus, applied to the soils to correct the unbalanced condition of nutrients, was applied in the same amount to the soils on which a particular plant specie was grown but in different amount to different plant species, this could have resulted in upset of nutrient balance on Soil 3 which was associated with the lower yield of sorghum on this soil. On the other hand, application of nutrient solution to sorghum grown on Soil 4, could have resulted in satisfactory nutrient balance within the plant thus permitting more growth on this soil.

It also can be noticed that lettuce, tomato and tobacco produced the same amount of dry matter on each of Soils 1, 2 and 3. However, on Soil 4 more growth was obtained from tobacco whereas on Soil 5 the least growth was shown by tomato. These data illustrate the difference in the behavior of plant species that can occur on soils having different characteristics. In general, Soil 5 was the most productive and judging from the data in Table 2 it was also well supplied with phosphorus.

Statistical comparisons of the data in Table 4 are between plant species on a given soil. When a comparison was made between soils for a given plant, tobacco and tomato plants produced the same amount of dry material on all soils

while lettuce yielded appreciably more on Soil 5. The greatest variability was shown for sorghum and cotton and the results indicated Soil 5 was the most productive.

Yield response to phosphate application:

The results also indicated that the average yield of these plants was significantly increased by the phosphate fertilization. However, no significant interaction was encountered between plants and treatments and between soils and treatments. These unexpected findings may have been a result of the salt content of the soils which might have been an important factor affecting plant growth. Since some of the soils used were salty in the original state, it was thought that application of nutrient solution lacking phosphorus may have increased the degree of salinity to an extent greatly affecting the yield response to phosphorus. To test whether the salt accumulation was responsible for these results, regression analysis was made between yield and corresponding total soluble salts determined in soils after cropping. No significant correlation was found between the yield and the total soluble salts. Thus, the hypothesis of salt accumulation having a detrimental effect on the yields was rejected.

The only explanation concerning the nonsignificance of the interaction mentioned was possibly that the large

range of differences in yield between the replicates contributed to the relatively high value of the error term in the analysis of variance. Consequently, with such variance it was not possible to detect the small differences which resulted between the plant species from phosphate application on the different soils. Evidence to support this explanation was obtained from the analyses of variance of the data from each soil separately. These analyses indicated a significant plant by treatment interaction on Soil 4 only where the smallest error term resulted.

Examination of the means on Soil 4 revealed significant differences in yield among the different plant species, the yield being the highest for sorghum and the least for lettuce on both phosphate-treated and untreated pots. Also a higher yield for tobacco than cotton was observed on the control but cotton yielded more than tobacco when phosphorus was applied. Thus the response of cotton was much greater than tobacco on this soil. Likewise the response to phosphorus was greater for sorghum and cotton than the other plants since little or no response was shown for the yield of lettuce, tomato and tobacco. Therefore it is apparent that the different plant species had different abilities for dry matter production and response to added phosphorus.

Percentage yield of the plant species:

From the point of view of the relative growth of these plant species on the untreated soils relative to the phosphate-fertilized soils, percentage yields were calculated and are shown in Table 5. Tobacco had the highest relative average yield and lettuce the lowest. The average yield produced by tobacco on the five untreated soils was even more than that produced under heavy phosphate fertilization. These results demonstrate the high yield response of lettuce and tomato as well as the absence of any yield response in the case of tobacco to phosphate fertilizer on these soils. Sorghum, cotton, and tomato yields were in overlapping population and discrete separation could not be made.

The percentage yield of the different plants also differed on the different soils. While a yield response was obtained only with lettuce on Soil 5, a relatively high yield response was suggested for at least three plants on each of the other soils. This shows that Soil 5 was the least responsive to phosphorus of all the soils for these plant species, and Soils 1, 2, and 4 were the most responsive. On Soil 3 superphosphate addition appeared to increase the growth of tomato, sorghum and lettuce. Not only was a differential response indicated among the plant species but also differences were shown in the relative response of the plants on different soils.

Table 5. The relative yield of five plant species on five soils expressed as percentage of the yield on the same phosphate-fertilized soils.

Soil	1	2	3	4	5	Mean
Tobacco	71	80	146	115	144	111c
Tomato	3	46	82	46	115	58ab
Sorghum	125	68	74	74	118	92bc
Lettuce	29	53	57	15	65	44a
Cotton	50	73	107	25	126	76ab
Mean	56a	64ab	93bc	55a	114c	

Phosphorus content of the plants

Response in phosphorus uptake by plants to phosphate fertilizer:

The phosphorus content of the plant species grown on each soil is presented in Table 6. The analysis of variance of these data is shown in Table 7. The effect of all factors involved as well as their interactions influenced the phosphorus content of the dry plant material.

The data show a differential response of plant species to phosphate application in term of phosphorus concentration. Phosphorus treatment increased the concentration of tobacco and cotton plants on Soil 5 only while the phosphorus content of tomato plants was increased on Soils 2 and 5. With sorghum, phosphorus treatment increased plant phosphorus on Soils 1, 2, and 3 whereas lettuce phosphorus was increased on Soils 4 and 5.

A definite pattern could not be established between plant phosphorus and phosphorus response on the different soils. Here the factors that influenced the growth did not affect the phosphorus content of the plant that was derived from the fertilizer as was reported by Dean et al. (7).

These results indicate that the same plant specie responded differently to superphosphate on different soils. On some soils the phosphorus content of a certain plant

Table 6. Phosphorus content of five plant species grown on five soils with and without phosphorus treatment. Means of replicates.

Soil	1		2		3		4		5	
Treatment mgm.P/pot	0	442	0	442	0	442	0	442	0	442
Plant	mgm.P/gm. dry weight									
Tobacco	0.77a*	1.21a	0.83a	1.13a	1.52a	1.56a	0.86a	1.28a	1.60a	3.13b
Tomato	1.30a	1.88b	1.08a	1.94b	1.50a	1.58a	1.32ab	1.80a	1.84a	3.84c
Sorghum	1.31a	2.74c	0.90a	2.70c	1.88a	2.85b	1.73b	1.72a	2.49b	1.96a
Lettuce	2.04b	2.36bc	1.92b	2.49bc	2.80b	2.94b	1.01a	1.88a	2.20ab	4.64d
Cotton	2.98c	2.69c	1.75b	2.28bc	2.48b	2.58b	1.71b	1.66a	2.56b	3.24b

* Values followed by the same letter are not significantly different at 5% level within a given column.

Table 7. Analysis of variance of phosphorus content of the plants

Source of Variation	d.f.	SS	MS
Plants	4	14.96	3.74**
Treatments	1	9.87	9.87**
Soils	4	18.77	4.69**
Plant x Treatment	4	1.45	0.36**
Plant x Soil	16	6.83	0.427**
Treatment x Soil	4	3.12	0.78**
Plant x Treatment x Soil	16	8.18	0.511**
Error	50	4.30	0.086

** Significant at 1% level of probability.

specie was increased by added fertilizer while on other soils fertilization had no effect. The greatest increase in plant phosphorus content was shown for lettuce on Soil 5.

With phosphorus as factor limiting yield on the soils used, on the average, addition of this nutrient to the soil resulted in increase of phosphorus content in the plant associated with an increase in yield indicated by the significant treatment in Table 3. The critical nutrient concept of Macy (22) seems to apply on the average below the zone of critical percentage. However, in many specific cases the effect of phosphorus addition on yield and plant phosphorus content does not appear to follow Macy's theory. It is possible that some factor or factors other than phosphorus influenced yield in these cases which resulted in the apparent failure of this concept.

Differential phosphorus content among the plants on different soils:

Table 6 shows a marked variability in phosphorus content among the plant species grown on the same soil, either on the phosphate-treated or untreated pots. The relative magnitude of phosphorus absorption among these plants grown on the phosphorus treated pots varied greatly from that on the untreated pots of the same soil. Not only did

this indicate a difference among the plant species for soil phosphorus absorption but also a variable effect of phosphorus application on plant phosphorus content.

Cotton, lettuce, and sorghum took up greater amounts of phosphorus from the treated pots of Soils 1, 2 and 3 than the other plant species. The phosphorus content of lettuce on the treated pots of Soil 5 reached a maximum for all plants and soils. However, no significant differences were found in phosphorus content of the different plant species grown on treated pots of Soil 4. Thus, utilization of superphosphate was greatest with cotton, lettuce, and sorghum, intermediate with tomato and least with tobacco. Differences in the nature of the root systems and metabolic level of phosphorus in the plant as suggested by Fried (9), rather than differences in interaction between plants and the phosphate compounds in the soil system may have been responsible for the differential phosphorus content.

From the data for the control pots, it also appears that differential absorption of the native soil phosphorus occurred among the plant species. Tobacco and tomato absorbed the same amount of phosphorus per unit dry weight when they grew on untreated pots of Soil 5, but less than any other plant specie. Tobacco, tomato and sorghum

contained less phosphorus when grown on the untreated pots of the other soils. Cotton was superior in phosphorus content to tobacco and tomato on all the soils, to lettuce on Soils 1 and 4 and to sorghum on Soils 1, 2 and 3, but it was just equal to sorghum and lettuce in other comparisons.

The ability of cotton to extract phosphorus from low phosphorus soils is apparent. The failure of cotton to respond significantly in phosphorus content to phosphate application may be related to the ability of this plant to extract considerable amount of phosphorus from the phosphorus-deficient soils relative to that derived by the other plant species.

Cooper and Mitchell (6) noticed that cotton plants contained considerable amount of calcium and therefore, it was considered as a calcium accumulator plant. Truog (45), Drake and Steckel (8), and Asher and Ozanne (1) also found that phosphorus content of the plants increased as the amount of calcium in the plant tissues increased. It is also known that most forms of the phosphorus in calcareous soils exist in different combinations of phosphorus and calcium. Thus, it is probable that cotton in this study accumulated a considerable amount of calcium enhancing the greater solubilization of phosphorus from the phosphorus forms in these soils.

Total phosphorus uptake by plants on different soils:

The total phosphorus uptake by the different plant species is given in Table 8. These data show that cotton and sorghum consistently removed larger amounts of phosphorus from all the unfertilized pots than the total CO_2 soluble phosphorus determined on the initial soils. For example, cotton and sorghum removed 11 and 10 times, respectively, the amount of phosphorus extractable with CO_2. Tobacco, tomato and lettuce showed a similar trend but of lesser magnitude on some soils. These results probably can be attributed to one or several factors. One reason could be that these different plant species extracted some of CO_2 insoluble forms of phosphorus from the soils which were not present in CO_2 extract of the soils. Another possibility could be that the CO_2 extractable method removed only a proportional part of the available form or forms of phosphorus from the soils.

It also was found that the total uptake of phosphorus by different plants corresponded, to a large degree, to the yield obtained. Usually there was an increase or decrease in yield of a given plant on a given soil when there was also an increase or decrease in total amount of phosphorus in the plant. For a given plant this relationship between yield and total phosphorus uptake appears to hold across all soils

Table 8. Total uptake of phosphorus by the different plant species from the phosphate-fertilized and unfertilized pots.

Soil	1		2		3		4		5	
	O	P	O	P	O	P	O	P	O	P
	mgm P per pot									
Tobacco	1.69	3.74	2.41	4.09	7.33	5.16	3.96	5.13	9.31	12.64
Tomato	0.21	11.70	0.80	12.42	10.32	11.67	3.51	7.47	15.38	27.96
Sorghum	9.54	15.95	6.70	29.73	11.43	23.26	13.56	18.23	34.61	23.01
Lettuce	0.73	2.90	1.06	2.56	4.31	8.00	0.06	0.77	9.28	30.16
Cotton	10.19	18.51	14.52	25.86	29.02	28.28	2.50	9.78	37.04	37.13
Initial CO_2 soluble P mgm/pot	0.92		0.58		10.12		1.28		10.80	

All data reported are a mean of two replicates.

studied. This relationship was best with tobacco and lettuce and the most variable with cotton and sorghum.

It can also be seen from Table 8 that the different plant species differed in the total amount of phosphorus absorbed from the phosphate fertilized and unfertilized soils. Cotton removed the greatest amount of phosphorus of the plant species from all untreated pots but Soil 4. Sorghum was superior to all the plants in total phosphorus uptake on Soil 4 but about equal to cotton on Soil 1 and on the fertilized pots of Soil 2. Both sorghum and cotton accumulated larger amount of phosphorus than the other plants except on Soil 5.

In all instances, the total phosphorus uptake by the plants from the different soils showed considerable variations. Soil 5 supplied the greatest amount of phosphorus to all the plants and was the best soil tested in this respect. On the other soils, the results did not indicate consistent variation in phosphorus uptake for all the different plant species, but in general, Soil 3 was superior in phosphorus supplying ability to Soils 2 and 1, for most of the plants studied.

Response to superphosphate in total phosphorus uptake by plants:

The increments of total phosphorus uptake by different plant species are shown in Table 9. Only for lettuce

Table 9. Increment of phosphorus uptake by different plant species as result of phosphate application.

Soil	1	2	3	4	5
			mgm P/pot		
Tobacco	2.05	1.68	-2.17	1.17	3.33
Tomato	11.49	11.62	1.35	3.96	12.58
Sorghum	6.41	23.03	11.83	4.67	-11.60
Lettuce	2.17	1.50	3.69	0.71	20.88
Cotton	8.32	11.34	-0.74	7.28	0.09

did the increased increments of phosphorus uptake appear to be related positively to increased increments of dry matter production. The increment of phosphorus uptake of tobacco and cotton on Soil 3, and sorghum on Soil 5, was inversely proportional to the external concentration of phosphorus. These values were expected from the depression of yield that occurred on these soils as a result of phosphate application. However, the reduced absorption of phosphorus on Soil 5 was greater than would have been predicted on the basis of the yield depression. Sorghum showed striking differences in response to superphosphate in term of phosphorus uptake which probably indicates this plant varied markedly in ability to utilize native soil phosphorus.

On the other hand, it appears lettuce could utilize fertilizer phosphorus effectively on Soil 5 and to a greater extent than the other plant species. It failed to maintain this effectiveness on Soils 1, 2 and 4 where inferiority was indicated to all the plants tested on these soils. The increase in phosphorus uptake by cotton due to fertilizer was greater than that of tobacco and lettuce on Soils 1, 2 and 4 but lower on Soil 5. Tomato plants on Soils 1, 2 and 5 showed a marked increase in total phosphorus uptake when fertilizer was applied.

Phosphorus content of the soil after cropping

Effect of the plant growth upon the phosphorus level in the soils:

The phosphorus content of the soils studied after cropping is shown in Table 10. The phosphorus was extracted by the CO_2 soluble method and determined by the method of Murphy and Riley (32). The analysis of variance of these data presented in Table 11 shows that there were significant differences at the one percent level in phosphorus content among the soils. The different plant species contributed differently to the variation of the phosphorus content in the different soils. Differences in phosphorus of the soils after cropping as result of fertilizer addition also occurred.

The data in Table 10 indicate that on the unfertilized soils only Soils 3 and 5 showed significant differences in CO_2 soluble phosphorus remaining after cropping of the four plant species. Phosphorus was lower on these two soils when sorghum was grown. The most phosphorus remained in Soil 5 after tomato. These amounts reflect, to a large degree, the total relative amount of phosphorus derived from the soil during the growth period for these plants.

Although the amount of phosphorus remaining in the soils after cropping was related inversely to the total

Table 10. Phosphorus content of five Arizona soils before and after cropping. Means of two replicates.

Soil	1		2		3		4		5	
Treatment mgm P/pot	0	442	0	442	0	442	0	442	0	442
					P. ppm.					
After Tobacco	0.41a*	2.11b	0.19a	1.58ab	2.30b	2.67b	0.42a	1.92b	2.34b	8.74a
After Tomato	0.18a	2.78c	0.14a	2.07b	2.14b	2.44b	0.22a	2.11b	3.36c	13.50d
After Sorghum	0.22a	0.89a	0.20a	1.22a	1.05a	1.79a	0.10a	0.68a	0.74a	8.02a
After Lettuce	0.21a	3.13c	0.18a	2.98c	2.46b	3.41c	0.44a	2.22b	2.18b	10.64c
Before Cropping	0.37		0.23		4.05		0.51		4.32	

* Values followed by the same letter are not significantly different at 5% level within a column.

Table 11. Analysis of variance of phosphorus content of the soils after cropping.

Source of variation	d.f.	SS	MS
Plants	3	24.601	8.20**
Treatments	1	153.486	153.49**
Soils	4	310.315	77.57**
Plants x Treatments	3	7.439	2.48**
Plants x Soils	12	21.995	1.83**
Treatments x Soils	4	144.933	36.23**
Plants x Treatments x Soils	12	6.587	0.55**
Error	40	3.255	0.081

** Significant at 1% level of probability.

phosphorus uptake per plant, a quantitative relationship cannot be established between plant removal and the difference in soil phosphorus content indicated by chemical analysis.

Data in Table 10 also show great differences in the phosphorus content of the phosphate-fertilized soils after cropping. The phosphorus level of the treated soils after cropping was higher than the initial soil phosphorus as well as the untreated soils after cropping. The level of CO_2 soluble phosphorus ranged from 0.68 ppm. in Soil 4 after sorghum to 13.50 ppm. in Soil 5 after tomato. These differences in the phosphorus level probably are related to the fact that the total amount of phosphorus absorbed throughout the growth period was the greatest for sorghum and the least for tomato among the plant species. The relatively high amount of phosphorus absorbed by sorghum from Soil 4 resulted in a low level of phosphorus in this soil. The level of CO_2 soluble phosphorus was consistently lower in the treated pots where sorghum was grown as compared with other plants. In general, the soil phosphorus level was highest after lettuce or tomato.

Total soluble salts in soils after cropping:

The total soluble salts of the soils after cropping of four different plant species are given in Table 12. The

Table 12. Total soluble salts of five soils after cropping with and without phosphorus treatment. Mean of two replicates.

Soil	1		2		3		4		5	
Treatment	O	P	O	P	O	P	O	P	O	P
	E.C. x 10^3 m.mhos/cm^3									
After Tobacco	11.50	8.75	9.25	7.65	8.00	10.75	11.50	7.50	5.75	8.00
After Tomato	5.65	5.00	5.50	4.40	3.75	4.85	4.95	5.05	2.65	3.65
After Sorghum	5.90	4.25	4.75	4.10	5.00	4.75	5.15	4.75	4.30	3.55
After Lettuce	7.85	6.00	11.25	11.00	8.75	6.65	12.75	12.85	6.05	7.25

analysis of variance of these data may be seen in Table 13. The only significant interaction was between the plants and soils. The application of superphosphate did not change the soluble salt content remaining in the soils. However, differences did exist in salt content among the different soils and the plant species grown had an effect on final salt content.

It can be seen from the means on the different soils presented in Table 14 that the effect of sorghum and tomato in lowering the total soluble salts in all the soils was similar. The salt content generally was higher where tobacco or lettuce was grown. These differences in salt content probably reflect the relative differences in these plant species to absorb and accumulate salts. In a general way the salt content of these soils appears to be related inversely to total phosphorus removed by the plants.

Table 13. Analysis of variance of total soluble salts in soils after cropping.

Source of variation	d.f.	SS	MS
Plants	3	379.74	126.58**
Treatments	1	4.51	4.51
Soils	4	73.04	18.26**
Plants x Treatments	3	2.19	0.73
Plants x Soils	12	89.89	7.49**
Treatments x Soils	4	19.03	4.76
Plants x Treatments x Soils	12	30.14	2.51
Error	40	110.55	2.76

** Significant at 1% level of probability.

Table 14. Total soluble salts of five soils after cropping. Means of treatments and replicates.

Soil / Plant	1	2	3	4	5
	E.C. x 10^3 m.mhos/cm^3				
Tobacco	10.12b*	8.45b	9.38b	9.50b	6.88b
Tomato	5.32a	4.95a	4.30a	5.00a	3.15a
Sorghum	5.08a	4.42a	4.88a	4.95a	3.92a
Lettuce	6.92a	11.12c	7.70b	12.80c	6.65b

* Values followed by the same letter are not significantly different at the 5% level for a given soil.

SUMMARY

The relative response of cotton, tomato, tobacco, lettuce and sorghum to superphosphate application was evaluated on five Arizona calcareous soils under greenhouse conditions.

Significant differences were found among the weight of oven dry material produced on the different soils. Cotton and sorghum gave the highest yield on all the soils. Tobacco yield was similar to that of tomato and lettuce on three soils.

The average yield was significantly increased by the phosphate application. However, a relatively large variation between replications probably prevented the detection of a significant treatment by plant specie interaction.

From the viewpoint of the percentage yields on these soils, lettuce showed the highest yield response. Cotton, tomato, and sorghum also responded to phosphate application but to lesser extent. A yield response to superphosphate was not obtained with tobacco.

Differential phosphorus uptake per unit dry weight was shown between the plant species tested, whereas

in some instances increased phosphorus composition resulting from superphosphate addition was not associated with significant increases in yield. In the cases of cotton, sorghum and tomato the opposite occurred. Utilization of added superphosphate was greatest with cotton and sorghum, intermediate with lettuce and tomato, and least with tobacco.

The different soils did not behave in the same manner in supplying phosphorus to the plants since the phosphorus uptake by each plant specie from the different soils was significantly different. Cotton had great ability to extract phosphorus from most soils. This could be related to the calcium accumulation in this plant specie and consequent solubilization of the form of phosphorus associated with calcium in these soils.

Total phosphorus uptake was directly proportional to the yield obtained on the same soil. However, considerable variation existed in total phosphorus uptake from different soils. Sorghum showed striking differences in response to superphosphate and represented the extremes in total phosphorus uptake. The other plants did not show consistent effectiveness in phosphorus removed from the different soils.

Determination of the phosphorus in the soils after cropping indicated differential phosphorus removal by these plants. Although an inverse relationship was found between the amount of phosphorus remaining in the soils after cropping and the total phosphorus uptake by the plants, a quantitative relationship could not be established between plant phosphorus and soil analysis. It appeared that the CO_2 extractable method removed only a proportional part of the available phosphorus in the soils.

The amount of total soluble salts in the soils after cropping was not influenced by fertilization. Sorghum and tomato were more effective than the other plant species in lowering the total soluble salts in the soils. This effect reflected the differences among the plants to accummulate salts and perhaps a difference in the relative efficiency of the plants to support leaching.

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