# Influence of Water-Soluble Phosphorus on Agronomic Quality of Fertilizer Mixtures Containing Two Phosphorus Compounds

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Corn stover and hairy vetch were grown in greenhouse cultures on slightly acid Chester soil to determine the effect of variable proportions of water-soluble phosphorus in fertilizers upon yield and phosphorus uptake. Fertilizer mixtures containing varied percentages of water-soluble phosphorus, were applied to corn, and similar materials, as well as triple superphosphate and monoammonium phosphate, were applied to vetch. Increasing proportions of water-soluble phosphorus resulted in significantly greater yield and phosphorus uptake. In all but two of the test fertilizers applied, corn stover and hairy vetch gave comparable results.

PHOSPHATE FERTILIZERS are marketed in this country on the basis of their content of available phosphorus, which includes both water-soluble and water-insoluble, but citrate-soluble, phosphorus. According to the official analytical procedure (*3*), available phosphorus is determined as the difference between the total and citrate-insoluble phosphorus, and the water solubility of the phosphorus is generally an unknown property of fertilizers moving in trade. This suggests the erroneous view that all available phosphates should be equally effective in crop production, tending to divert attention away from the influence of water-soluble phosphates on the agronomic quality of fertilizers. With the advent of ammoniation of fertilizers in the late twenties and early thirties, the chief concern lay in the quality of the water-insoluble phosphates generated by neutralization of the acid phosphates (*14, 15*). The extent of neutralization with ammonia had to be restricted, in order to avoid excessive loss of available phosphorus (*15*), a condition that in usual practice provided ammoniated fertilizers containing 40 to 60% of the phosphorus in water-soluble form. Improvements in processes made it technically feasible to neutralize superphosphate-containing fertilizers with ammonia to an extent that only 20 to 25% of the phosphorus is water-soluble (*9*). Products of some other processes, notably certain nitric-phosphate processes (*17*), contain less than 5% of the phosphorus in water-soluble form. Nevertheless, the water solubility of phosphorus in nitrogen-phosphorus-potassium mixtures marketed in 1949–50, averaged for the country, was slightly higher than in 1935 (*6*).

The results of agronomic experimentation showed lightly ammoniated superphosphate (40 to 60% of phosphorus water soluble) to be as satisfactory, generally, as the nonammoniated product (*1, 15*). This finding might have been anticipated, as monocalcium phosphate decomposes in soil environments with deposition of dicalcium phosphate at the placement site or in the immediate vicinage (*5*). The superiority of monoammonium phosphate, which is not decomposed by water, over superphosphate, under some cultural practices (*8*), is attributable in part to the partial solubility of monocalcium phosphate in the soil water. The trend of the results of experimentation with water-soluble phosphates in mixed fertilizers indicates that 40 to 60% water solubility of the phosphorus provides the most generally effective fertilizer. Departure from this norm in either direction leads to specialization for effective use. On neutral, calcareous, or alkaline soil, high water solubility, approaching 100%, is indicated for most fertilized crops (*4, 7, 8, 11–13, 15, 18–20*). Water solubility is less important on acid soils, especially for cereal and forage crops (*11, 13, 15–17*).

Further experimentation is needed, in order to determine optimal solubility levels for economic crops under cultural practices used in different farming regions. The test fertilizers can be materials of the commercial type, containing three phosphorus compounds (monoammonium phosphate, dicalcium phosphate, and apatite-like basic phosphate), as have been used in most experimental studies, or materials synthesized with the use of well-characterized monoammonium phosphate and dicalcium phosphate, as have been used by a few investigators, notably Lawton (*10*). The rather wide uncontrolled variability often encountered in the preparation of commercial mixtures is discussed in a recent article (*2*). Both types of fertilizer were used in this study and work reported at this time covers an experiment with synthetic fertilizers under corn and vetch.

## Test Materials

**Fertilizers.** The test phosphates for both experiments were 8 to 12 mesh nitrogen-phosphorus fertilizers synthesized in the laboratory by slurry-mixing dicalcium phosphate and monoammonium phosphate in selected proportions. The materials used for corn contained approximately 5, 10, and 20% of the phosphate in the water-soluble form (ammonium phosphate) and those used for vetch contained about 5, 20, and 40%. Monoammonium phosphate and triple superphosphate, also of 8 to 12 mesh particle size, were added as standards of comparison in the vetch experiment. The amounts applied ranged between 0 and 3200 pounds of phosphorus pentoxide per acre for corn, and between 0 and 800 pounds for vetch. Supplemental nitrogen and potash were supplied by applications of ammonium nitrate and potassium chloride to both crops. Trace elements, including boron, manganese, copper, zinc, and molybdenum, were applied as solutions.

**Soil.** Approximately 5.4 pounds per pot of Chester silt loam soil was used for both experiments. This gray-brown podzolic soil contained about 20 pounds per acre of phosphorus pentoxide extractable with 0.5*M* sodium bicarbonate. Its exchangeable cation content totaled 14.2 meq. per 100 grams of soil. The lime requirement for pH 6.5, as determined in the laboratory, was 6000 pounds of calcium carbonate per 2,000,000 pounds of soil. Three fourths of this requirement was supplied by calcium hydroxide and one fourth by magnesium oxide.

## Culture Preparation and Management

The limed soil was permitted to equilibrate for about 3 weeks, during which time the pH rose to about 6.3.

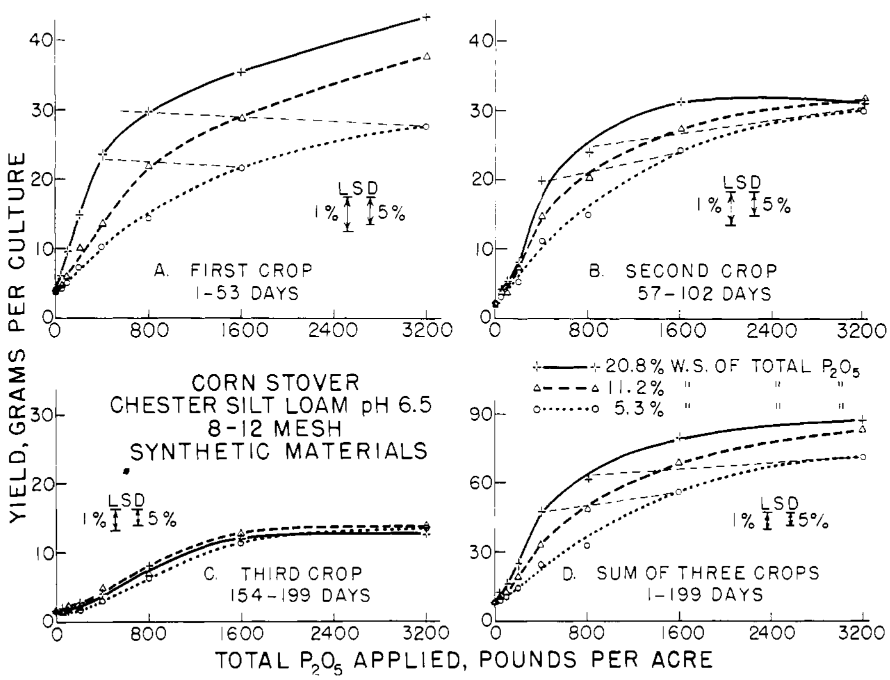


Figure 1. Response of corn stover to total phosphorus

The moist soil was then sieved and all of the fertilizer materials were mixed throughout the soil. Although the amounts of applied phosphorus varied, the amounts of nitrogen and potash were the same for all cultures of each crop. All cultures received 200 pounds of potassium oxide calculated on an area basis. The corn and hairy vetch received 400 and 200 pounds of nitrogen per acre, respectively. Ammonium nitrate was the only source of nitrogen used with the no-phosphorus and superphosphate cultures. The crops were planted and trace elements, as solutions, added on the same day that the cultures were fertilized. The cultures were brought to moisture equivalent, and, in order to maintain the moisture near this level, the cultures were weighed about twice a week throughout the growing season. Three replications were used.

The first crop of corn was harvested 53 days after planting. The second and third crops were harvested after growth periods of 45 days each. Between crops the soil was dried, roots were removed, and supplemental applications of 500 pounds of nitrogen and 200 pounds of potassium oxide per acre were added by mixing throughout the soil. The harvested corn stalks were split to facilitate moisture loss in the drying oven. Two cuttings of hairy vetch were grown during growth periods of 1 to 84 days and 85 to 157 days after fertilization.

The dry-weight yield was determined by drying the plant material in a forced-draft oven at 65° C. The plant material was then ground, ashed, and analyzed for phosphorus. A statistical analysis, of the yield and phosphorus uptake data, was made for each cutting as well as for the sums of all the cuttings.

### *Response of Corn and Vetch to Levels of Water-Soluble Phosphorus*

Differences due to materials and to amounts applied were highly significant in both experiments. The results reveal a reasonably clear division of the total response between the water-soluble and water-insoluble phosphorus in the test fertilizers.

**Corn Stover.** The yield response of the first crop of corn stover was nearly proportional to the amount of water-soluble phosphorus applied (Figure 1,*A*). The fertilizer, with 20% of its phorphorus water soluble, produced approximately the same yield of corn stover as twice the amount of fertilizer with 10% water-soluble phosphorus, and four times the amount of fertilizer with 5% water-soluble phosphorus. The response became relatively less as the phosphorus solubility decreased (shown by the downward slope to the right of the tie lines joining equal applications of water-soluble phosphorus), and is attributed to the condition that the fertilizer granules, being stable in the moist state, dissolved as granules. The delay in the escape of water-soluble phosphorus from the granule was greatest in the presence of the largest proportion of insoluble substance. This effect on response was less at high phosphorus applications.

The second corn crop, grown during the period 57 to 102 days after fertilization, gave some response, not only to the water-soluble, but also to the citrate-soluble phosphorus, particularly on treat-

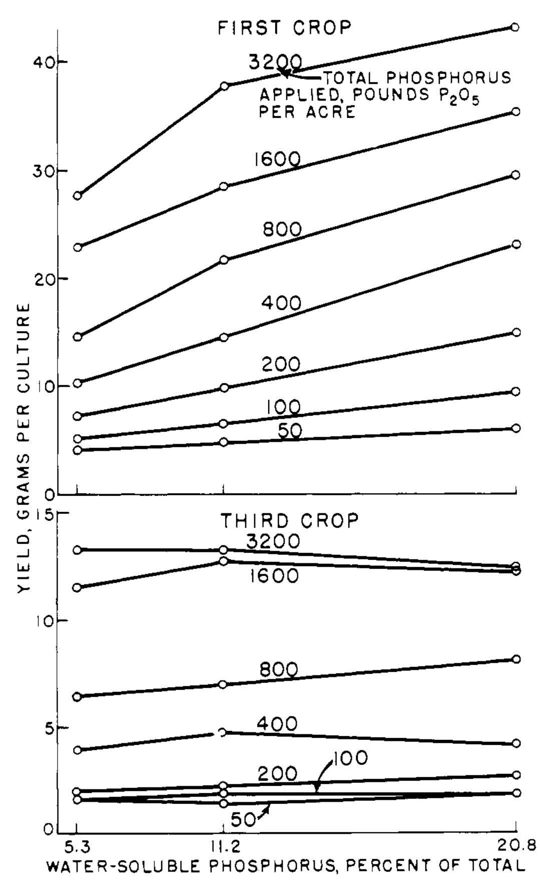


Figure 2. Response of corn stover to water-soluble phosphorus

ments having low water solubilities (Figure 1,*B*). Here the tie lines slope upward to the right, indicating a contribution of the water-insoluble phosphorus to the response. Differences due to water solubility, however, were still highly significant. The third crop of corn stover (154 to 199 days) responded well to increased applications of phosphorus, but there were no significant yield differences due to sources (Figure 1,*C*).

The phosphorus uptakes (not shown in the figure) exhibited approximately the same pattern as the yields of the first and second crops, with highly significant differences between levels of water solubility. Contrary to the yield pattern, the uptakes of the third crop showed a highly significant difference between sources. The sum of yields (Figure 1,*D*) and phosphorus uptakes of the three crops of corn stover for the 199-day period were significantly greater for each increase in level of water-soluble phosphorus.

The effect of water-soluble phosphorus on the yield of corn is depicted in another manner in Figure 2. An upward slope of the line indicates a greater response to the water-soluble form, a horizontal line indicates a comparable response to both the water-soluble and citrate-soluble forms, and a downward slope indicates a greater reponse to the citrate-soluble form. The quantity of citrate-soluble phosphorus present at any one rate of application is less when the proportion of water-soluble phosphorus is greater. The results of the first crop indicate that with each increase in rate of total phosphorus application, water-solubility assumed greater importance for increasing yield. At the three highest rates of application, the difference was greater between the two materials of lower water-solubility than with the materials of higher water-solubility. The results of the third crop are not entirely consistent, although it appears that the response was about equal to both forms of phosphorus.

The results of the three crops of corn stover indicate that water solubility of the phosphorus was extremely important for at least 2 months after fertilization. With continuous cropping, it was of less importance 2 to 4 months after fertilization, and was of little or no consequence beyond the fourth month.

**Hairy Vetch.** The yields (Figure 3,*A*) and phosphorus uptakes of the first cutting of hairy vetch were significantly greater for each increase in level of water-soluble phosphorus up to 40%. The upward slope of the tie lines reflects the influence of water-insoluble phosphorus on the response, which in the case of the much shorter growth period of corn had not made noticeable contribution to the response. The material with 40% water solubility gave yields and uptakes comparable to those with monoammonium phosphate and triple superphosphate. In the second cutting (Figure 3,*B*), yield response to the fertilizer with 40% of its phosphorus water soluble was identical with that to superphosphate with a solubility of 92%. Responses to the fertilizers with solubilities of 5 and 20%, though nearly equal, were notably lower than in the case of superphosphate. Considering the total vetch crop, the yields from the growth during 5 months from seeding time (Figure 3,*C*), show significant response to water solubility of the phosphorus. The same pattern is followed by the uptakes (Figure 3,*D*).

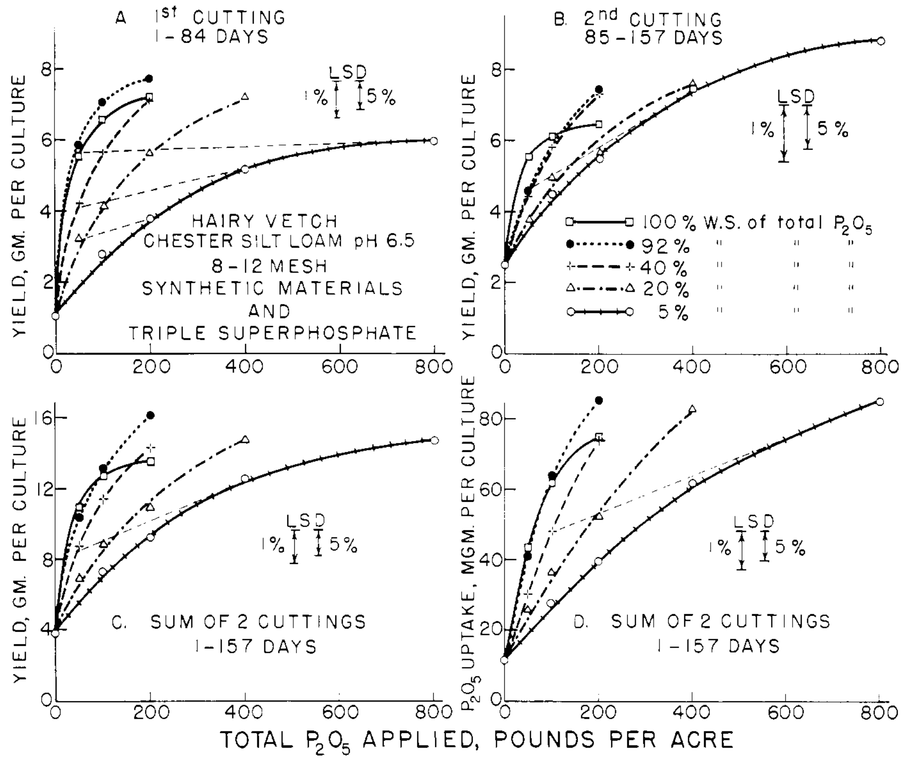


Figure 3. Response of hairy vetch to total phosphorus


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