

**THE EFFECT OF SOLUBLE SALTS**  
**ON THE**  
**AVAILABILITY OF PHOSPHATE FERTILIZERS**

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Availability of Phosphate Fertilizers<sup>1/</sup>  
J. A. Lutz, Jr. and C. I. Rich<sup>2/</sup>

### INTRODUCTION

The availability of applied phosphate fertilizers to plants is influenced by the presence of soluble salts with the phosphate. The reasons for this effect are not clear and the objective of the investigations reported herein was to gain more information on the extent of this effect and the conditions under which it is operative.

Laboratory, greenhouse, and field experiments were conducted to measure the effect of salts on the availability of phosphate.

### REVIEW OF LITERATURE

Grunes et al. (6) reported that when nitrogen fertilizers were banded with concentrated superphosphate there, generally, was greater absorption of phosphate by barley, sugar beets, and potatoes than where the nitrogen and phosphorus were banded separately. Damaty and Axley (4), after working with nine different soil types, reported that applications of KCl in combination with monocalcium phosphate generally resulted in lower amounts of available phosphorus as determined by soil tests. Starostka and Hill (11) found that phosphorus absorption was greater on three soils when the tableted mixtures of dicalcium phosphate and  $MgSO_4$ ,  $K_2CO_3$ ,  $K_2SO_4$  or  $Ca(NO_3)_2$  were applied than when dicalcium phosphate was applied in a separate position from the salts. There was a depressed phosphorus uptake on all three soils when dicalcium phosphate was mixed with  $CaCO_3$ , or  $MgCO_3$ . Bouldin and Sample

(1) reported that the inclusion of KCl,  $NH_4Cl$ ,  $(NH_4)_2SO_4$ , or  $KNO_3$ , with concentrated superphosphate in pellets increased oat yields and P yields over those with pellets of CSP alone. They also reported that the effect of salts on P availability probably depends on soil properties and that the yield of dry matter is not a unique function of the yield of P.

Rogers (10) presented evidence of a better crop response to fertilizers in which nitrogen, phosphorus, and potassium were associated in each particle than where there was a dry mixture of the individual fertilizers. Olson and Dreier (9) reported that nitrogen stimulated the use of fertilizer P by wheat and oats through a wide range of soil conditions. The  $NH_4^+$  ion was apparently a more effective stimulant than the  $NO_3^-$  ion during early stages of plant growth.

The Chemical behavior of monocalcium phosphate monohydrate in soils was studied by Lehr and Brown (7). Their results suggest that capillary flow was a principal mechanism in the movement of phosphate solution away from the tablet but that vapor-phase transport of water to the tablet apparently controlled the rate of dissolution. The dissolution process was affected by soil type, soil moisture content, humus content, microbiological activity, capillarity of soil and tablet, time, and temperature.

Brown and Lehr (3) presented phase-rule data to predict the amount of dicalcium phosphate residue, the composition of the solution moving from granule to soil, the amount of additional dicalcium phosphate that may form incidental to solution-soil reactions, and effects of salts on the amount of residue and on the composition of the solution when monocalcium phosphate monohydrate is placed in

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<sup>1/</sup> The work was in cooperation with the Division of Agricultural Relations, Tennessee Valley Authority.

<sup>2/</sup> Assistant Professor and Professor of Agronomy, Respectively.

soil. Lindsay and Stephenson (8) studied the nature of reactions of monocalcium phosphate monohydrate in soils, and found that reactions in different soils may be quite different.

### Experimental

The following four experiments were conducted:

Experiment 1. The influence of salts and lime on the solubility of applied phosphate.

Experiment 2. The single effect of soluble salts on the availability of monocalcium phosphate to plants.

Experiment 3. The effect of pH, salt, and particle size of material on the availability of applied phosphate to plants grown on sand and four soils.

Experiment 4. The influence of particle size and the incorporation of N and K into the fertilizer on the absorption of fertilizer P by bluegrass.

### MATERIALS AND METHODS

Experiment 1- Two portions of Davidson clay loam were adjusted with ground limestone to pH levels of 5.8 and 6.5, respectively. Monocalcium phosphate (MCP) was applied at the rate of 100 ppm of  $P_2O_5$  and the various salts were applied at a rate chemically equivalent to 50 ppm. of  $K_2O$ . In addition to urea, the following salts were applied:  $KCl$ ,  $NH_4Cl$ ,  $CaCl_2$ ,  $MgCl_2$ ,  $NH_4NO_3$ ,  $NaNO_3$ ,  $Mg(NO_3)_2$ ,  $KNO_3$ ,  $K_2SO_4$ ,  $K_2CO_3$ ,  $Ca(NO_3)_2$ ,  $(NH_4)_2SO_4$ , and  $Al_2(SO_4)_3$ . One hundred grams of soil, treated with MCP and one of the salts, was placed in 8-ounce tumblers and maintained at field capacity by periodic weighings. At the end of two, four, and eight weeks, the soil in each tumbler was sampled, air dried and determinations of the water soluble P and P extracted by the Bray No. 1 method were made (2). All treatments were replicated four times.

Experiment 2- A divided root system was used in an attempt to separate nutritional effects of the salt from its effect on the availability of the phosphorus.

A Reddish Brown latosol, Davidson clay loam, was selected for the greenhouse study. This soil contained 6.1% Fe as free iron oxides, and had a high P fixing capacity. The soil had a pH of 5.8 and no lime was added for some treatments. For other treatments the soil was adjusted to pH 6.5 with ground limestone. The soil was placed in tin-plated cans, 5 inches high and 6 inches in diameter (Fig. 1). Vertically placed in the center of each can was an aluminum cylinder, 2 inches in diameter and 4 inches high. Soil, uniformly fertilized with 150 ppm each of N,  $P_2O_5$ , and  $K_2O$  from  $NH_4NO_3$ , concentrated superphosphate (CSP) and  $KCl$  respectively, was placed inside the cans, but outside the cylinder, to a depth of 3 1/2 inches. Unfertilized soil was used inside all cylinders and also to cover the uniformly, to a depth of one inch, fertilized soil outside the cylinder. Oats were seeded in a two-inch circle directly over the cylinder so that the roots grew inside and outside the cylinder.

The fertilizer was tagged with  $P^{32}$  and was applied in tablet form at the rate of 100 ppm of  $P_2O_5$ <sup>3</sup>. Urea and the following 13 salts were applied at the rate of one equivalent weight per 1,000,000 grams soil:  $KCl$ ,  $NH_4Cl$ ,  $CaCl_2$ ,  $MgCl_2$ ,  $NH_4NO_3$ ,  $NaNO_3$ ,  $KNO_3$ ,  $Mg(NO_3)_2$ ,  $Ca(NO_3)_2$ ,  $K_2CO_3$ ,  $K_2SO_4$ ,  $(NH_4)_2SO_4$ , and  $Al_2(SO_4)_3$ . Each salt was applied separately from and also in the same tablet with the MCP. When the MCP and salt were applied together, the tablet was placed in the center and one inch from the top of the cylinder.

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<sup>3</sup>Tablets of monocalcium phosphate (MCP) tagged with  $P^{32}$  with and without other salts, were prepared by the fertilizer and Agricultural Lime Section, A.R.S., U.S.D.A., Beltsville, Md. The assistance of Dr. W. L. Hill, Principal Chemist, is particularly appreciated.

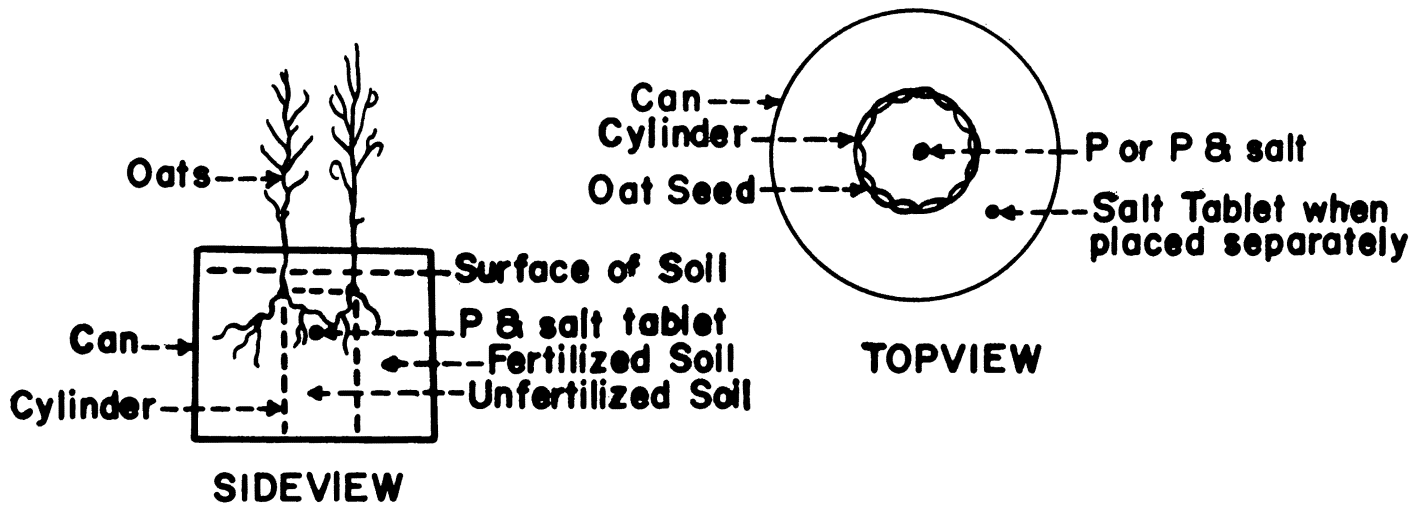


Figure 1. Placement of salt, phosphorus and oat seed.

For the separate placement of the P and salt, the P was positioned in the cylinder as just described but the salt was placed outside the cylinder and one inch from the surface. Four replications of all treatments were made.

Two clippings were made when the oats were about 15 inches high. Yields were measured and the samples were analyzed for percentage fertilizer P ( $P^{32}$ ) in the plant, percentage total P, and nitrogen.

Experiment 3- The greenhouse experiment initiated in 1955 was continued in 1956 in a revised form. Davidson, Wellston, Norfolk, Rumford, and a pure sand were used at the initial pH of 5.5, 4.3, 4.5, 5.6, and 5.4 respectively. The pH of each was also adjusted to about 6.5. Urea and the following salts were used: KCl,  $NH_4NO_3$ ,  $(NH_4)_2SO_4$ , and  $Al_2(SO_4)_3$ . All soil amendments were applied at the same rates as in 1955. The MCP was applied in both pulverized and tableted form. Yields of oats were measured and the samples were analyzed as in the 1955 experiment.

Experiment 4- This experiment was conducted on a natural bluegrass pasture on Groseclose silt loam to measure the influence of particle size and the incorporation of N and K into the fertilizer on the absorption of fertilizer P by bluegrass. The pH of the upper two inches of this soil was 7.40 and in the 2 to 6 inch depth it was 6.68. The dilute acid soluble phosphorus contents (Truog Method) (12) of these two layers were 62 and 5 ppm respectively. Three fertilizers, 0-27-0, 10-10-0, and 10-10-10, each tagged with  $P^{32}$ , were applied broadcast at the rate of 50 pounds per acre of  $P_{2O_5}$  to the sod in March, 1954. All three fertilizers were applied in pulverized as well as granulated form, of the following mesh sizes: 20-28, 14-20, 8-14, and 4-6 mesh. Additional  $(NH_4)_2SO_4$  and KCl were broadcast separately, where necessary, so that each plot received a total of 50 pounds per acre each of N,  $P_{2O_5}$ , and  $K_2O$ . Leaves of the bluegrass were sampled on April 28, 1954, and the fertilizer P content of the plant was measured.

## RESULTS

### Experiment 1. The influence of salts and lime on the solubility of applied P.

At the same pH level, there was no significant difference in the water soluble P content between treatments at either the two, four, or eight week samplings, (table 1). At the four and eight week samplings, the water soluble P content was significantly lower where lime was applied than where no lime was applied.

The P content, as measured by Bray No. 1 method, was significantly different between treatments at all three samplings (table 2). The Bray P content of the soil to which lime had been applied, was significantly higher at all three sampling dates than was the P content of unlimed samples.

At the two week sampling, where lime was applied, there were no significant

differences between treatments in the P content as measured by the Bray No. 1 method. Where lime was applied, the amounts of P were significantly higher where  $MgCl_2$ , or  $NH_4NO_3$  had been applied compared to the soil receiving phosphate and no salt. Although not statistically significant, in each instance where lime was applied, the addition of each salt, except  $Mg(NO_3)_2$  and urea, caused an increase in the P extracted by the Bray No. 1 method.

After four weeks where lime was applied, only the amount of P as measured by the Bray No. 1 method, from the  $NH_4NO_3$  treatment was significantly higher than where  $P_2O_5$  was applied alone. In general, where lime was applied, there was a definite trend for the salts to increase the amount of P extracted by the Bray No. 1 method.

Table 1. The effect of soluble salts on the water soluble phosphorus content of Davidson soil after incubation periods of two, four, and eight weeks. (Average of four replications).

Compound added with mono- calcium phosphate	Water soluble Phosphorus (PPM) after.					
	Two Weeks		Four Weeks		Eight Weeks	
	Lime 4000 ppm	No Lime	Lime 4000 ppm	No Lime	Lime 4000 ppm	No Lime
KCl	6.15	3.81	1.50	1.91	1.47	2.22
$NH_4Cl$	3.87	4.16	1.44	2.22	1.60	1.56
$CaCl_2$	4.09	3.84	1.70	1.97	1.75	1.69
$MgCl_2$	4.34	5.00	1.75	2.13	2.47	1.88
$NH_4NO_3$	5.72	3.04	1.57	2.53	1.72	1.63
$NaNO_3$	5.97	5.31	1.83	2.10	2.10	2.35
$Mg(NO_3)_2$	3.25	4.65	1.16	2.63	1.47	2.13
$KNO_3$	4.56	5.59	1.57	3.10	1.85	2.72
$K_2SO_4$	4.28	4.97	2.19	2.53	1.85	2.06
$K_2CO_3$	5.22	5.66	2.41	2.38	2.00	2.57
$CO(NH_2)_2$	4.22	5.34	1.91	2.60	1.75	1.91
$Ca(NO_3)_2$	4.44	5.31	1.57	1.85	1.44	2.25
$Al_2(SO_4)_3$	3.90	5.50	1.38	2.66	1.69	2.22
$(NH_4)_2SO_4$	4.47	5.47	1.25	2.10	1.29	2.22
None	4.78	6.69	1.44	2.57	1.50	2.54

LSD (.05) =

NS.

NS.

NS.

Table 2. The effect of soluble salts on the Bray No. 1 phosphorus content of Davidson soil after incubation periods of two, four, and eight weeks. (Average of four Replications).

Compound added with monocalcium phosphate	Bray No. 1 Phosphorus (PPM) after:					
	Two Weeks		Four Weeks		Eight Weeks	
	Lime 4000 ppm	No Lime	Lime 4000 ppm	No Lime	Lime 4000 ppm	No Lime
KCl	11.8	9.0	9.2	6.7	8.4	6.1
NH <sub>4</sub> Cl	11.8	9.1	8.7	7.3	8.2	6.1
CaCl <sub>2</sub>	11.5	9.0	9.5	7.9	7.4	6.2
MgCl <sub>2</sub>	12.1	9.3	9.7	7.3	8.2	6.2
NH <sub>4</sub> NO <sub>3</sub>	12.3	8.8	10.6	7.9	8.6	5.9
NaNO <sub>3</sub>	10.9	9.8	9.1	7.5	8.5	6.0
Mg(NO <sub>3</sub> ) <sub>2</sub>	8.9	9.6	7.8	8.0	7.3	7.0
KNO <sub>3</sub>	10.8	9.7	8.4	9.2	8.0	7.2
K <sub>2</sub> SO <sub>4</sub>	11.9	9.7	9.0	7.6	7.8	6.5
K <sub>2</sub> CO <sub>3</sub>	10.4	10.4	9.4	9.0	9.1	6.6
CO(NH <sub>2</sub> ) <sub>2</sub>	9.0	9.4	7.6	7.5	6.6	6.8
Ca(NO <sub>3</sub> ) <sub>2</sub>	10.9	9.3	9.0	8.0	8.3	6.0
Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	10.5	10.2	7.3	7.9	7.2	7.0
(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	10.3	9.7	9.9	7.7	8.4	6.8
None	9.9	9.6	8.4	8.5	7.2	7.4
L.S.D. (.05)	2.2		1.9		1.6	

After eight weeks in limed soils, all salts except urea and Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> caused an increase in the P removed by the Bray No. 1 method. Where no lime was applied, all salts caused a significant decrease in the amount of Bray P that was present.

Experiment 2- The effect of soluble salts on the availability of monocalcium phosphate to plants.

The percentage fertilizer P in the plant from the various treatments at both clippings and at both pH levels are given in Figure 2.

At the first clipping of oats grown on soils of pH 5.8, the mixture of P and salt increased the percentage fertilizer P in the plant from all treatments except MgCl<sub>2</sub>, Ca(NO<sub>3</sub>)<sub>2</sub>, and (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>. The percentage of fertilizer P in the plant was greater where phosphate was applied in the same tablet with NH<sub>4</sub>Cl, KCl, K<sub>2</sub>SO<sub>4</sub>, NH<sub>4</sub>NO<sub>3</sub>, NaNO<sub>3</sub>, KNO<sub>3</sub>, CO(NH<sub>2</sub>)<sub>2</sub>, and

Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>, and lowest when (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> was applied in the same tablet with the P. Smaller increases in the fertilizer P content of the plant were measured when either CaCl<sub>2</sub>, Mg(NO<sub>3</sub>)<sub>2</sub>, or K<sub>2</sub>CO<sub>3</sub> was mixed with the P. The percentage of fertilizer P in the plant from the mixture of Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> and phosphate was more than twice as great as where the salt and phosphate were applied separately.

When the pH was adjusted to about 6.5, the results for phosphate mixed with (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> and Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> were reversed with respect to each other. Increasing the pH from 5.8 to 6.5 increased the percentage fertilizer P in the plant from 8.4 to 34.5 when the mixture of P and (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> was used. This increased pH resulted in a decreased percentage of fertilizer P in the plant from (32.1 to 10.2 percent) with the mixture of P and Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>. Increasing the pH to about 6.5 also caused a slight decrease in the percentage fertilizer P in the plant from the mixture of

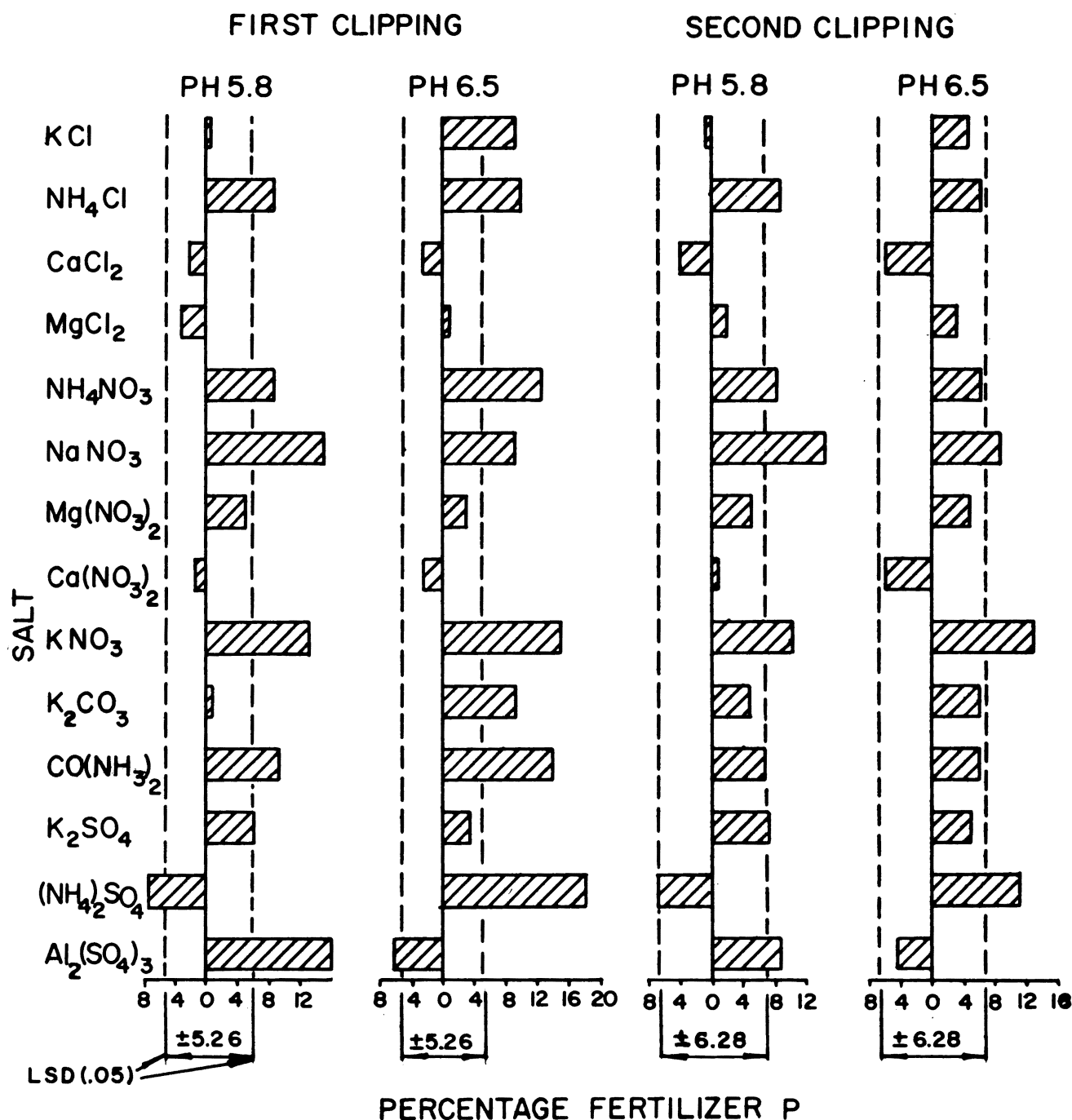


Figure 2 : Effect of Soluble Salts on the Percentage Fertilizer P in Two Clippings of Oats Grown on Davidson Soil at Two pH Levels. Increases and Decreases are Shown on Right and Left of the Ordinate Respectively.

P with  $\text{NaNO}_3$ ,  $\text{Mg}(\text{NO}_3)_2$ ,  $\text{K}_2\text{SO}_4$ ,  $\text{Ca}(\text{NO}_3)_2$ , and  $\text{CaCl}_2$ . Greatest increases in the percentage fertilizer in the plant with increased pH, were noted with the mixture of phosphate with  $\text{KCl}$ ,  $\text{K}_2\text{CO}_3$ , and  $(\text{NH}_4)_2\text{SO}_4$ . At pH 6.5, urea and each of the thirteen salts, except  $\text{CaCl}_2$ ,  $\text{Ca}(\text{NO}_3)_2$  and  $\text{Al}_2(\text{SO}_4)_3$ , increased the percentage fertilizer P in the plant when applied in contact with the phosphate.

The amounts of fertilizer P measured in the plant at the second clipping were similar in many aspects to amounts measured at the first clipping. At pH 5.8, the mixture of phosphate with each salt, except  $(\text{NH}_4)_2\text{SO}_4$  and  $\text{Ca}(\text{NO}_3)_2$ , increased the percentage fertilizer P in the plant over the separate application of P and salt. At pH 6.5 the mixture of P and salt, except  $\text{CaCl}_2$ ,  $\text{Ca}(\text{NO}_3)_2$ , and  $\text{Al}_2(\text{SO}_4)_3$  increased the percentage fertilizer P content of the plant over the separate application of salt and P. The greatest increases were noted when P was applied with  $\text{KNO}_3$ , and  $(\text{NH}_4)_2\text{SO}_4$ .

Increasing the pH from 5.8 to 6.5 increased the percentage fertilizer P in plant when urea and the following mixtures of salt and phosphate were used:  $\text{KCl}$ ,  $\text{MgCl}_2$ ,  $\text{Mg}(\text{NO}_3)_2$ ,  $\text{KNO}_3$ ,  $\text{K}_2\text{CO}_3$ ,  $\text{CO}(\text{NH}_2)_2$  and  $(\text{NH}_4)_2\text{SO}_4$ . The percentage fertilizer P in the plant increased from 10.1 at pH 5.8 to 29.6 at pH 6.5 when the mixture of phosphate and  $(\text{NH}_4)_2\text{SO}_4$  was applied. The same increase in pH reduced the fertilizer P content from 26.4 to 15.3 when the P and  $\text{Al}_2(\text{SO}_4)_3$  were applied in contact with each other.

Phosphorus yield. The absorption of P was calculated for each pH level at both clippings of oats and the results are given in table 3. At the first clipping, and at both pH levels, the presence of  $\text{CaCl}_2$  and  $\text{Mg}(\text{NO}_3)_2$  with the P depressed the adsorption of P. The mixture of  $\text{K}_2\text{SO}_4$  and  $(\text{NH}_4)_2\text{SO}_4$  with the P depressed the absorption of P at the lower pH while  $\text{CaCl}_2$ ,  $\text{MgCl}_2$  and  $\text{Al}_2(\text{SO}_4)_3$  depressed P removal at the higher pH. The presence of  $\text{NH}_4\text{Cl}$ ,  $\text{NH}_4\text{NO}_3$ ,  $\text{KNO}_3$ ,  $\text{K}_2\text{SO}_4$ , and  $(\text{NH}_4)_2\text{SO}_4$  with the P, appeared to have the most beneficial influence on the ab-

sorption of P at both pH levels.

At the second clipping of oats the removal of P was greatest from the mixture of  $\text{NH}_4\text{Cl}$ ,  $\text{NH}_4\text{NO}_3$ ,  $\text{KNO}_3$ ,  $\text{CO}(\text{NH}_2)_2$  and  $\text{Al}_2(\text{SO}_4)_3$  with the P. Urea and certain of the salts such as  $\text{CaCl}_2$ ,  $\text{Mg}(\text{NO}_3)_2$ ,  $\text{KNO}_3$ ,  $\text{K}_2\text{SO}_4$ , and  $(\text{NH}_4)_2\text{SO}_4$  reduced the absorption of P at one or both of the pH levels.

Experiment 3. The effect of pH, salt and particle size of material on the availability of applied phosphate to plants grown on sand and four soils.

The data on the fertilizer P content of the oats grown during the second year are given in Figure 3.

The data indicate that the soil type, pH, salt, size of granule and method of application each, had a highly significant effect on the percentage fertilizer P in the plants. A comparison of the four soils indicate that the recovery of applied P was greatest on the Wellston soil and least on the Norfolk soil. In general, the amounts of P removed were significantly higher at the higher pH and also significantly higher where pulverized P was applied. When comparing the recovery of P on the four soils, with all treatments considered, the P recovery was significantly higher where  $(\text{NH}_4)_2\text{SO}_4$  and  $\text{NH}_4\text{NO}_3$  were applied than where  $\text{CO}(\text{NH}_2)_2$ ,  $\text{KCl}$ , and  $\text{Al}_2(\text{SO}_4)_3$  were applied. When comparing all four soils and sand, two pH levels, five salts, two particle sizes and two methods of application of salt and P, the recovery of P was greatest when it was applied with  $\text{NH}_4\text{NO}_3$ . Recoveries for other salts followed in the order:  $(\text{NH}_4)_2\text{SO}_4$ ,  $\text{KCl}$ ,  $\text{CO}(\text{NH}_2)_2$ , and  $\text{Al}_2(\text{SO}_4)_3$ .

Phosphorus Yield. The soil type, kind of salt and method of application of P and salt did not have any significant effect on the total P removed by the oats (table 4). However, the pH and particle size of material did significantly influence the amount of P removed by the oats. In general, more P was removed when the pH of the soil was adjusted to 6.5 and where the pulverized material was



Table 3. The effect of soluble salts on the mg. per pot of phosphorus removed by two cuttings of oats grown on Davidson clay loam at two pH levels in the greenhouse (Average of four replications).

Salt	Method of Placement*	Mgms of Phosphorus removed			
		First Cutting		Second Cutting	
		pH 5.8	pH 6.5	pH 5.8	pH 6.5
KCl	(Tog.	8.80	7.83	9.54	8.50
	(Sep.	7.94	6.52	7.93	7.46
NH <sub>4</sub> Cl	(Tog.	9.36	7.69	10.22	3.24
	(Sep.	7.33	6.34	8.27	7.33
CaCl <sub>2</sub>	(Tog.	7.84	6.82	8.14	8.81
	(Sep.	7.97	7.22	8.30	7.4
MgCl <sub>2</sub>	(Tog.	7.37	6.74	8.00	7.11
	(Sep.	6.57	7.33	7.91	9.35
NH <sub>4</sub> NO <sub>3</sub>	(Tog.	9.99	9.20	10.29	9.09
	(Sep.	7.25	6.06	8.54	7.71
NaNO <sub>3</sub>	(Tog.	9.76	8.80	10.04	9.34
	(Sep.	9.39	7.97	9.79	8.34
Mg(NO <sub>3</sub> ) <sub>2</sub>	(Tog.	7.80	6.58	8.55	7.81
	(Sep.	8.31	6.82	9.50	
KNO <sub>3</sub>	(Tog.	9.13	9.18	10.41	8.83
	(Sep.	8.17	6.79	9.11	8.97
K <sub>2</sub> SO <sub>4</sub>	(Tog.	7.93	7.93	8.33	8.12
	(Sep.	8.60	5.09	8.72	7.24
K <sub>2</sub> CO <sub>3</sub>	(Tog.	7.85	7.96	9.07	8.93
	(Sep.	6.84	7.44	7.56	8.38
CO(NH <sub>2</sub> ) <sub>2</sub>	(Tog.	8.41	8.13	10.47	7.67
	(Sep.	7.80	7.40	9.08	7.70
Ca(NO <sub>3</sub> ) <sub>2</sub>	(Tog.	8.25	7.85	9.13	8.50
	(Sep.	7.68	7.21	9.11	8.36
(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	(Tog.	6.32	8.63	7.73	8.51
	(Sep.	7.16	7.31	8.06	8.83
Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	(Tog.	9.85	7.34	10.54	7.54
	(Sep.	7.49	7.64	7.47	6.99
P <sub>2</sub> O <sub>5</sub> only		7.25	6.30	7.47	6.82

\* Refers to salt and P<sub>2</sub>O<sub>5</sub> being applied in same tablet or in separate tablets.

LSD (.05) =

1.4

1.7

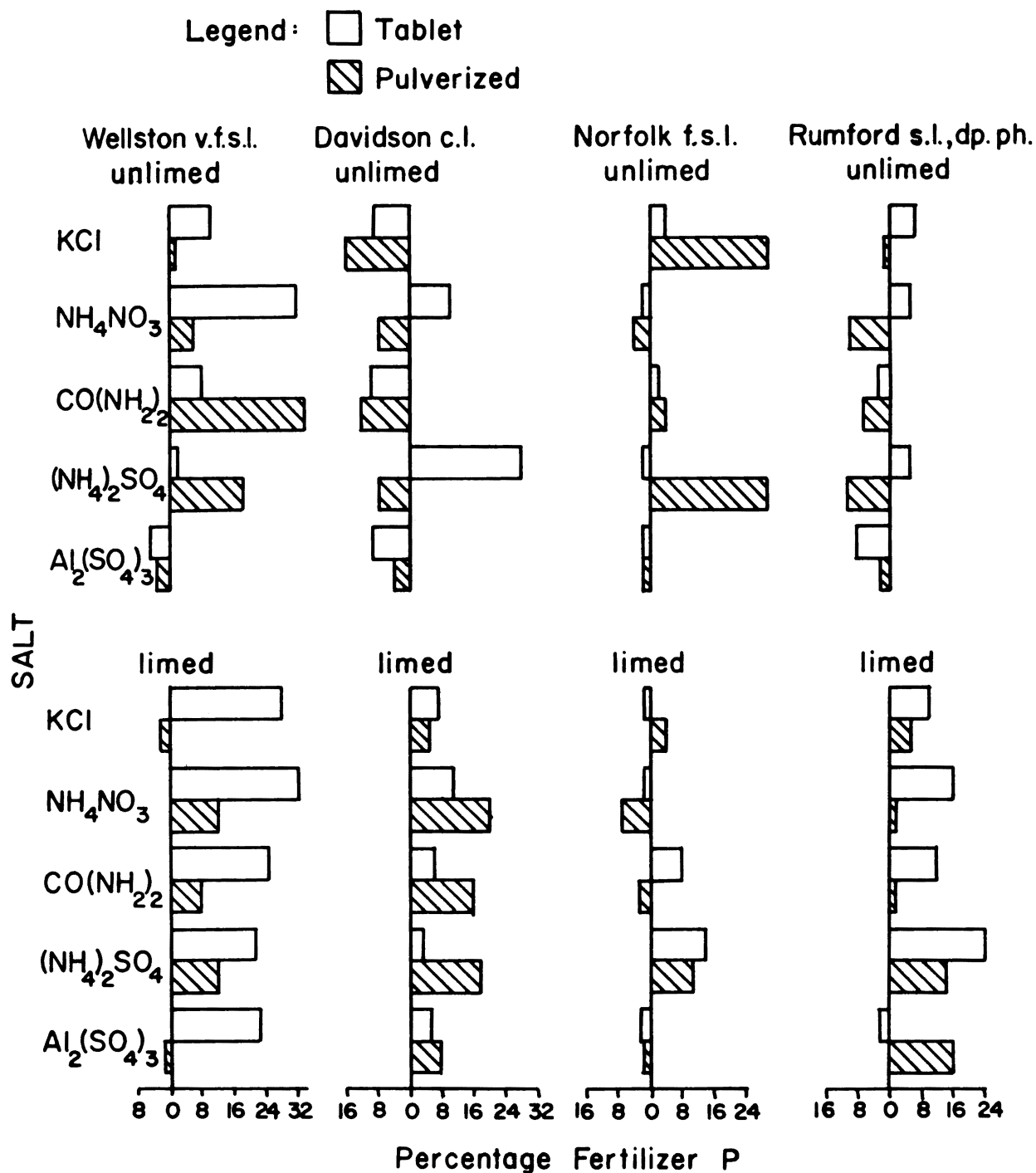


Figure 3: Effect of Soluble Salts on the Percentage Fertilizer P in Oats Grown on 4 Soils at 2 pH Levels and Fertilized with with Tabulated and Pulverized MCP. Positive Values on Right of Ordinate and Negative Values on Left.

Table 4. The effect of soluble salts on the mg. per pot, phosphorus removed by oats grown on four soils and sand at two pH levels in the greenhouse at Blacksburg. (Average of three replications).

Salt	Meth- od of place- ment	Wellston				Davidson				Rumford				Norfolk				Sand	
		Unlimed		Limed		Unlimed		Limed		Unlimed		Limed		Unlimed		Limed		Unlimed	Limed
		Tab-	Pulv.	Tab-	Pulv.	Tab-	Pulv.	Tab-	Pulv.	Tab-	Pulv.	Tab-	Pulv.	Tab-	Pulv.	Tab-	Pulv.	Tab-	Tab-
		let	let	let	let	let	let	let	let	let	let	let	let	let	let	let	let	let	let
KCl	Tog	10.8	8.9	10.4	14.7	11.3	10.4	9.5	11.7	12.5	9.8	11.2	12.1	11.4	12.6	11.2	11.5	11.2	8.7
	Sep	7.3	10.9	11.5	11.9	7.0	11.4	11.9	13.6	13.2	11.1	12.2	11.0	6.0	11.2	12.5	11.7	14.0	10.4
NH <sub>4</sub> NO <sub>3</sub>	Tog	9.8	10.6	13.3	13.4	8.0	12.0	10.2	12.1	12.5	11.1	11.5	10.4	6.0	3.0	10.5	12.3	13.2	12.9
	Sep	10.2	12.3	11.1	12.1	12.4	12.5	10.2	13.2	11.2	13.6	11.5	10.4	12.2	7.3	12.9	13.7	11.7	10.3
CO(NH <sub>2</sub> ) <sub>2</sub>	Tog	9.0	13.7	13.4	13.3	12.3	9.8	9.7	12.8	9.9	10.5	10.3	10.5	9.0	12.0	11.9	11.1	13.7	10.7
	Sep	8.0	14.2	11.5	13.6	7.0	12.9	12.4	11.8	8.1	10.8	9.9	10.4	11.5	12.3	12.7	9.8	11.0	12.4
(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	Tog	11.0	12.4	10.1	14.6	14.0	9.0	9.7	13.8	9.5	9.2	11.4	11.1	10.5	14.3	10.3	14.0	11.5	10.7
	Sep	12.3	10.3	11.4	11.7	13.0	8.8	10.2	13.1	10.9	13.3	10.4	12.3	11.9	10.9	12.4	12.3	12.5	10.5
Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	Tog	7.0	6.5	9.0	12.1	9.4	12.0	9.9	11.5	10.0	7.8	9.4	11.7	10.5	7.0	11.3	12.2	9.1	8.9
	Sep	7.6	6.9	11.9	11.7	12.6	12.5	10.4	14.4	13.2	7.4	11.7	10.5	10.0	12.6	12.3	11.9	11.8	11.4
P <sub>2</sub> O <sub>5</sub> only		10.5	12.5	11.5	12.4	11.9	12.8	11.6	14.8	12.4	12.9	10.7	13.9	11.0	10.5	9.5	10.9		

\*Refers to phosphate and salt being applied together or separately

applied.

There were interactions between soil type and pH, between soil type and salt, between soil type and particle size of material and between soil type, pH and salt.

Oat Yields. The difference in oat yields of the four soils was highly significant (table 5). Yields were lowest on the Rumford soil, next highest on Norfolk soil and highest on Wellston and Davidson with no significant difference between the latter two.

There was an interaction between soil type and pH, soil type and particle size of material, and between pH, particle size of material and method of application of salt and P.

When considering the four soils there were no significant differences in yields between pH levels, salts, particles size of material or method of application of salt and phosphorus. When comparing all four soils and the sand, the method of application of P and salt had a significant influence on oat yields.

Experiment 4. The influence of particle size and the incorporation of N and K into the fertilizer on the absorption of fertilizer P by bluegrass.

The data on the fertilizer P content of the bluegrass plant are given in table 6. It will be noted that the presence of N in the granule with the P increased the percentage fertilizer P in the bluegrass at both clippings and with each particle size of fertilizer used. However, the

Table 6. Percentage phosphorus in two clippings of bluegrass as influenced by granulation and by incorporation of N and K<sub>2</sub>O into fertilizer. Average of six replications.

Size of Granulation (Mesh)	Percentage Fertilizer Phosphorus					
	Sampled April 28			Sampled June 10		
	0-27-0 <sup>1/</sup>	10-10-0	10-10-10	0-27-0	10-10-0	10-10-10
Pulverized	34.2	40.4	38.0	27.2	30.3	28.2
20-28	34.4	38.5	37.4	28.4	30.6	26.9
14-20	34.4	42.1	40.9	25.8	31.5	29.6
8-14	30.9	42.0	41.4	24.8	31.6	29.3
4-6	29.4	45.9	39.9	24.4	31.9	28.3

<sup>1/</sup> Composition of fertilizer.

increase was significantly different only with granules larger than 14 mesh. When the 10-10-0 was applied, the percentage fertilizer P content of the plant increased with a decrease in size of granules. the inclusion of N and K<sub>2</sub>O in the granule with the phosphate, caused an increase in The percentage fertilizer P content of the plant as compared with the 0-27-0 but a decrease as compared with the 10-10-0. Therefore, the presence of N in the P

granule increased the fertilizer P content of the plant while the K behaved in a reverse manner.

#### DISCUSSION

It can be seen from the data presented that soluble salts have a different effect on the availability of fertilizer P depending on soil type, pH of the soil and the particle size of the phosphate being

Table 5. The effect of soluble salts on the yield of oats grown on four soils and sand at two pH levels in the greenhouse at Blacksburg. (Average of three replications).

Salt	Meth- of Place- ment*	Dry Material (Grams)																	
		Wellston				Davidson				Rumford				Norfolk				Sand	
		Unlimed		Limed		Unlimed		Limed		Unlimed		Limed		Unlimed		Limed		Unlimed	Limed
		Tab- let	Pulv	Tab- let	Pulv	Tab- let	Pulv	Tab- let	Pulv	Tab- let	Pulv	Tab- let	Pulv	Tab- let	Pulv	Tab- let	Pulv	Tab- let	Pulv
KCl	Tog Sep	3.7 3.4	3.4 4.0	3.4 3.9	4.3 3.9	3.8 3.7	3.6 3.6	3.4 3.4	3.4 3.8	3.8 3.6	3.3 3.4	3.3 3.6	3.4 3.1	3.5 3.0	3.3 3.4	3.7 4.0	3.7 3.6	3.0 3.6	3.2 3.4
NH <sub>4</sub> NO <sub>3</sub>	Tog Sep	3.0 3.0	3.7 3.6	3.6 3.6	4.1 3.7	4.0 3.6	3.7 3.8	3.0 3.4	3.9 3.7	3.8 3.4	3.5 3.8	3.7 4.0	2.9 3.2	3.4 3.4	3.4 3.5	3.3 3.7	3.6 4.2	3.4 3.2	3.7 3.5
CO(NH <sub>4</sub> ) <sub>2</sub>	Tog Sep	3.8 3.6	3.8 4.0	3.5 3.9	3.8 3.9	3.8 3.3	3.4 3.9	3.9 3.6	3.8 3.5	3.6 3.4	3.2 3.4	3.5 3.4	3.5 3.2	3.4 3.5	3.6 3.5	3.7 4.1	3.6 3.3	3.3 3.6	3.3 4.1
(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	Tog Sep	3.6 3.5	3.5 3.6	3.2 3.7	4.2 3.9	3.7 3.7	3.8 3.9	3.7 3.6	3.7 3.9	3.7 3.5	3.4 3.5	3.5 3.7	3.2 3.3	3.3 3.4	3.8 3.5	3.2 3.9	2.7 3.8	3.3 3.7	3.9 3.5
Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	Tog Sep	3.4 3.8	3.3 3.5	3.2 3.9	3.8 3.8	3.5 3.8	4.1 3.5	3.7 3.6	3.7 3.8	3.4 3.7	3.7 3.4	3.3 3.8	3.5 3.1	3.7 3.0	3.6 3.5	3.5 3.7	3.7 3.8	3.4 3.7	3.1 3.8
P <sub>2</sub> O <sub>5</sub> only		3.5	4.1	3.8	3.7	3.7	3.6	3.7	4.1	3.5	3.4	3.6	3.8	3.4	3.3	3.4	3.5		

\*Refers to phosphorus and salt being applied together or separately.

used.

It is known that certain salts may influence the fixation of solubility of P. Under certain conditions, P may be precipitated by certain cations such as Fe, Al, Ca, and Mg. In this experiment, the placement of  $\text{CaCl}_2$  and  $\text{Mg}(\text{NO}_3)_2$  in contact with the P has generally resulted in a lower yield of P than when the salt and P were separately applied, thus indicating that some of the P may have been precipitated as Ca or Mg phosphates. This appears to agree with the work by Lehr and Brown (6) in which calcium sulfate in 0-21-0 tablets simulating ordinary superphosphate, decreased the rates at which tablets dissolved and at which solution moved into the soil, without changing the general pattern of dissolution. After 120 days of soil contact, the residues in all five soils were examined and were found to be mixtures of gypsum and anhydrous dicalcium phosphate. Traces of dicalcium phosphate dihydrate were found but only on tablet surfaces. It has been observed by previous investigators that calcium clays fix more phosphorus than sodium clays.

The data indicate that some of the fertilizer may have been precipitated by the Al or possibly Fe. Fried and Dean (5) found that surface coatings of Fe and Al on the exchange material retained a large proportion of the added phosphate. The percentage of the retained P that exchanged with radiophosphorus in solution was a function of both the concentration of P in solution and the time allowed for equilibration. Their results indicate that P retention probably involves exchange of phosphate ions from solution with ions on the surface of particles. The hydrous oxides of Fe and Al are undoubtedly involved in this retention. The presence of other cations, probably affect the extent of this retention.

The data for the second year of the experiment indicate that  $(\text{NH}_4)_2\text{SO}_4$  and  $\text{Al}_2(\text{SO}_4)_3$  in contact with the P reduced the yield of P as compared with the separate placement of salt and P. This may have been caused in part by an increase in soluble aluminum directly through addi-

tion and indirectly through increase in acidity, and the precipitation of Al phosphates.

Other workers (6) reported that the dissolution of monocalcium phosphate either in tableted or pulverized form would be expected to be quite rapid in soils when maintained at field capacity. At the end of two, or possibly four weeks, the dissolution would be complete after which the plants made most of their growth.

The effect, therefore, of many of the salts used, must have been on the solubility of the phosphorus. Because of the varied results of the different soils, it is likely that the soil properties have an important influence on the effect of the soluble salts on the availability of phosphate fertilizer.

#### SUMMARY AND CONCLUSIONS

The individual effect of 13 salts and urea on the availability of P in monocalcium phosphate, tagged with  $\text{P}^{32}$ , was measured with oats in the greenhouse. Oat yields and the percentage fertilizer P in the plant were measured and P removal was calculated.

Further greenhouse experiments were conducted in which four soils adjusted to two pH levels were used. There were five salts and two particle sizes of monocalcium phosphate (tagged with  $\text{P}^{32}$ ) applied by two methods. Oat yields, the percentage fertilizer P in the oats, and the removal of P by the oats were measured.

In the field experiment, the effect of the five particle sizes of 0-27-0, 10-10-0 and 10-10-10 each tagged with  $\text{P}^{32}$ , on the fertilizer P content of bluegrass was measured.

From the data obtained from these experiments the following conclusions are made:

1. The salts did not increase the percentage water soluble P in soil in the laboratory experiments.
2. In general, the salts increased the amount of P removed from the

soil by the Bray No. 1 method where lime was applied.

3. In the majority of treatments, the mixture of salt and P increased the fertilizer P content of the oat plant. The most outstanding exception was  $(\text{NH}_4)_2\text{SO}_4$  at a soil pH of 5.8.
4. When  $(\text{NH}_4)_2\text{SO}_4$  was applied in contact with the phosphate it decreased the percentage fertilizer P in the plant at the lower pH but increased it at the higher pH at the first clipping.  $\text{Al}_2(\text{SO}_4)_3$  had the reverse effect.
5. During the second year, both soil type and kind of salt had highly significant effects on the fertilizer P content of the plant.
6. The recovery of applied P was greatest on Wellston and lowest on Norfolk; Rumford and Davidson soils were intermediate.
7. More fertilizer P was absorbed when the soil was adjusted to about pH 6.5 than at the lower initial pH's of 5.5, 4.3, 4.5 and 5.6 of the four soils. More P was absorbed where pulverized material was applied than where tableted material was used.
8. In the field experiment, the presence of N in the granule with the P increased the percentage fertilizer P in the bluegrass at both clippings and with each particle size of fertilizer used.
9. When 0-27-0 was applied in the field experiment there was a decrease in fertilizer P content of the plant with increase in size of granulation.
10. The inclusion of N and  $\text{K}_2\text{O}$  in the granule with the phosphate caused an increase in the percentage fertilizer P content of the bluegrass.
11. With few exceptions, the salts increased the solubility of applied P as measured by the Bray No. 1 method and increased the availability of applied P to the plant in the greenhouse and field experiments.

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