would be $9.16 per ton of product. With bags and bagging at $4.00 per ton and handling and transportation also at $4.00 per ton, the manufacturing and distribution cost of mixed fertilizer from the average-sized plant in 1955–56 appears to have been $17.16 in excess of the value of the primary plant nutrients. Using a figure of $17.00, the cost to the consumer of the acid-insoluble ash added to mixed fertilizers in 1955–56 amounted to $19,730,880. It is generally recognized that incorporation of liming material partially or completely to offset the acid-forming character of mixed fertilizers serves a useful purpose in some parts of the country, notably the South and Southeast. Assigning a value of $3.50 per ton of $CaCO_3$ equivalent for this purpose, the net manufacturing and distribution cost of the 692,750 tons of $CaCO_3$ equivalent of carbonate carbon added to the mixtures amounted to $9,352,125 (692,750 × $13.50). The total cost to the consumer, therefore, for the 1,853,390 tons of acid-insoluble ash and $CaCO_3$ equivalent of carbonate carbon in excess of any plant-nutrient value amounted to $29,083,005, or $2.00 per ton of mixed fertilizer (an increase of $0.17 per ton or 9.3% over 1949–50). The effect of omitting concentrated superphosphate from consideration as an ingredient of the mixtures would be to reduce the estimate for added acid-insoluble ash by 90,200 tons and the cost to the consumer from $2.00 to $1.90 per ton.

It appears that the unit cost of primary plant nutrients in mixed fertilizer can be substantially reduced, if the consumer limits his purchases to those grades which can be manufactured and distributed economically without excessive inclusion of either limestone or inert materials.

Acknowledgment

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PHOSPHORUS AVAILABILITY

Crop Response to Ammoniated Superphosphates and Dicalcium Phosphate, as Affected by Granule Size, Water Solubility, and Time of Reaction with Soil

G. L. TERMAN, J. D. DeMENT, and L. B. CLEMENTS
Tennessee Valley Authority, Wilson Dam, Ala.

J. A. LUTZ, Jr.
Virginia Polytechnic Institute, Blacksburg, Va.

Crop response to phosphorus in a series of nonammoniated and ammoniated ordinary and concentrated superphosphates and dicalcium phosphate was determined in greenhouse experiments. Heavy ammoniation decreased the water solubility of phosphorus in ordinary superphosphate from 70 to 14% and in concentrated superphosphate from 89 to 57%, chiefly because of conversion to dicalcium and more basic phosphates. With band application, yields of dry matter and of phosphorus with the ammoniated superphosphates were closely related to the amount of water-soluble phosphorus applied; but other than for dicalcium phosphate, granule size was of little importance. With phosphates mixed throughout the soil, both water solubility and granule size of the phosphates greatly influenced yields on most soils. Response decreased with increasing time of reaction (3 and 6 months) of the superphosphates with soil prior to cropping. Decrease in response with time was much less with granular than with fine superphosphates. Liming acid Hartsells fine sandy loam had variable effects on crop response to phosphates.

Recent technological advances in granulation techniques have given a marked stimulus to the production and use of granular fertilizers. The widespread availability of a variety of nitrogen solutions for use in ammoniating and granulating superphosphate-based fertilizers has also been important. Because of the generally lower cost of nitrogen in solutions than in solid materials, some fertilizer producers incorporate as much solution nitrogen as possible into various mixed fertilizers. Ammoniation is also a desirable step in most granulation processes.

Results from a series of greenhouse pot tests with phosphate fertilizers varying in granule size and water solubility of the phosphorus are presented. The results are discussed in terms of first-crop response, and should probably not be extrapolated to residual effects over a much longer period of time.

Experimental Procedure

Characteristics of Fertilizers. A series of seven nitrogen-phosphorus fertilizers was prepared in two granule sizes, −6 +14 and −35 mesh, using modifications of a continuous ammoniation-granulation process (*3*). Ingredients and chemical analyses are shown in Table I. Different contents of water-soluble phosphorus were obtained by ammoniating ordinary and concentrated superphosphates to varying degrees. Ammonia–ammonium nitrate solutions were used for ammoniating and granulating the superphosphates and for granulating anhydrous dicalcium phosphate.

Soils and Liming Treatments. Analyses of the soils used in the experiments are shown in Table II. For experiment 1, Hartsells fine sandy loam (pH 5.2) was limed to three levels with ground dolomite—to pH 5.5: 1 ton per 2,000,000 pounds of soil just prior to mixing fertilizers; to pH 6.8: 5 tons 1 month previously; to pH 7.5: 5 tons one month previously, plus 2.5 tons prior to mixing fertilizers and seeding. Fort Collins loam subsoil (pH 8.2) was also used.

For experiment 2, Groseclose silt loam (pH 5.4) and Nason silt loam (pH 5.3) were limed to pH 6.5 with 4 and 10 tons of limestone per acre, respectively. Iredell clay loam (pH 6.5), unlimed, was also used.

For experiment 3, Hartsells soil was limed to pH 6.5 4 months prior to seeding. Davidson clay loam (pH 5.8) was used without liming.

For experiment 4, the unlimed Hartsells soil (pH 5.5) and the same soil limed to pH 7.5 with 8 tons of dolomitic limestone 1 month prior to mixing fertilizers for the 6 months' reaction period, were used.

Amounts equal to 3000 grams of dry soil per No. 10 can were used for experiments 1, 3, and 4; and 1800 grams per smaller can in experiment 2.

Fertilizer Application and Cropping. For experiment 1, the phosphates were applied in a layer 1 inch below the surface at rates of 60 and 120 mg. of total phosphorus (P_2O_5) per pot (40 and 80 pounds per 2,000,000 pounds of soil) on November 28, 1956. Anderson wheat was planted November 30 and harvested as heads began to form February 6, 1957. After working up the surface soil only, red clover was planted February 18 without further addition of phosphates. This crop was harvested June 5 as blossoms began to form. Other nutrients were added in solution as follows, per pot: For wheat, nitrogen was equalized at 150 mg. and potassium at 100 mg. as ammonium nitrate and potassium chloride; and for red clover, 65 mg. of nitrogen as ammonium nitrate and 15 mg. of magnesium as magnesium sulfate, were added.

For experiment 2, a total of 180 mg. of nitrogen as ammonium nitrate, 224 mg. of potassium as potassium chloride, and 45 mg. of total phosphorus per pot (50 pounds of phosphate per 2,000,000 pounds of soil) from the various phosphates were mixed with the three soils on July 18, 1957. Sudangrass was planted on the same day and harvested on September 4.

For experiment 3, the phosphates were ground to −100 mesh and mixed with limed Hartsells fine sandy loam and unlimed Davidson clay loam at the rate of 60 mg. of total phosphorus per pot. Anderson wheat was planted November 30, 1957, and later thinned to 20 plants per pot. A total of 150 mg. of nitrogen and 100 mg. of potassium per pot as ammonium and potassium nitrates were added for this crop. Wheat was harvested February 11, 1958.

For experiment 4, the phosphates were mixed throughout the soil at rates of 60 and 120 mg. of total phosphorus per pot (92 and 184 pounds of phosphate per 2,000,000 pounds of soil) at three dates: 6 months prior, 3 months prior, and just prior to seeding. All of the soil was potted at one time, just before the 6 months' reaction period. Nitrogen was equalized at this time with ammonium nitrate at 180 mg. per pot, the maximum amount of nitrogen present with the phosphate fertilizers. Potassium chloride was also added to provide 100 mg. of potassium per pot. The soil was watered occasionally and allowed to

Table I. Characteristics of Fertilizers Used in Experiments

Fertilizer Ingredients[a]	*No.*	*U. S. Mesh Size*	*Total N, %*	*Total P_2O_5, %*	*Avcilable P_2O_5, %*	*Water-Soluble P_2O_5, % of Available*
CSP + AN	1	−6 +14	14.0	26.0	98	89
		−35	15.5	24.7	98	86
OSP + AN	2	−6 +14	7.9	17.2	97	70
		−35	7.6	16.9	96	71
ACSP + AN	3	−6 +14	14.9	30.0	96	57
		−35	14.1	30.0	95	55
AOSP + AN	4	−6 +14	10.1	16.5	88	53
		−35	9.5	16.7	88	52
AOSP + AN	5	−6 +14	8.9	18.0	79	32
		−35	9.0	17.9	79	30
AOSP + AN	6	−6 +14	9.0	18.0	86	14
		−35	8.7	18.0	81	14
DCP + AN	7	−6 +14	13.6	26.3	100	3
		−35	15.7	22.9	100	3

[a] OSP and CSP, ordinary and concentrated superphosphates; AOSP and ACSP, ammoniated OSP and CSP; DCP, anhydrous dicalcium phosphate; AN, ammonium nitrate. Major phosphate phases identified with a petrographic microscope were: water-soluble P—monoammonium in 3, 4, 5, and 6; monocalcium in 1, 2, and 6; water-insoluble P—DCP in all the fertilizers; precipitated apatite in 4, 5, and 6.

Table II. Analyses of Soils Used in Experiments

Soil Type and Source	*pH*	*P Soluble in 0.5N $NaHCO_3$, P.P.M.*	*Exchangeable Cations, Meq./100 G.* Ca	K
Hartsells fine sandy loam, Ala.	5.1	2.1	1.6	0.24
Ft. Collins loam subsoil, Colo.	8.3	17.6	[a]	0.39
Davidson clay loam, Va.	5.8	6.6	5.3	0.16
Groseclose silt loam, Va.	5.4	6.0	2.8	0.18
Iredell clay loam, Va.	6.5	4.2	6.9	0.06
Nason silt loam, Va.	5.3	9.0	0.9	0.16

[a] Calcareous soil.

react over the full period. Columbia oats were planted February 27, 1958, and later thinned to 25 plants per pot. The crop was harvested April 4 as heads began to form.

Experiments 1, 3, and 4 were conducted at Wilson Dam, Ala., and experiment 2 at Blacksburg, Va. Each phosphate treatment was replicated three times in all experiments. All crops were dried at 80° C., weighed, ground, and analyzed for total phosphorus.

Results

Granular and −35 Mesh Fertilizers. Band Application. Yields of dry matter with various phosphates applied in a layer 1 inch below the surface of the soil (experiment 1) are shown in Table III. Marked response to phosphorus was obtained on Hartsells fine sandy loam with both wheat and red clover. Only wheat responded to phosphorus on the calcareous Fort Collins loam; so red clover yields are not reported. This soil contained much more soluble phosphorus than did the Hartsells.

Table III. Yields of Wheat (First Crop) and Red Clover (Second Crop) as Affected by Granule Size and Water Solubility of Phosphorus. Band Application

Fertilizer and % Water-Soluble P	*Mesh Size*	*Yield of Dry Matter, G. per Pot* — *Hartsells Fine Sandy Loam*[a] — *Wheat*	*Red clover*	*Both crops*	*Ft. Collins loam, wheat*[b]
CSP (89%)	−6 +14	8.04	7.44	15.48	6.70
	−35	7.93	7.46	15.39	6.99
OSP (70%)	−6 +14	7.34	7.39	14.73	6.06
	−35	7.41	7.54	14.95	6.19
ACSP (57%)	−6 +14	7.19	7.27	14.46	6.76
	−35	7.06	7.57	14.63	7.05
AOSP (53%)	−6 +14	7.00	6.85	13.85	6.37
	−35	6.51	7.03	13.54	6.23
AOSP (32%)	−6 +14	5.72	5.96	11.68	6.43
	−35	4.98	6.67	11.65	6.23
AOSP (14%)	−6 +14	4.49	5.68	10.17	6.50
	−35	4.51	6.65	11.16	6.58
DCP (3%)	−6 +14	3.86	6.05	9.91	6.67
	−35	6.86	8.26	15.12	7.22
No P	. . .	2.93	5.10	8.03	5.39
L.S.D., 1% level		0.51	0.62	. . .	0.29

[a] Mean yields for liming to pH 5.5, 6.8, and 7.5 and for 60 and 120 mg. P_2O_5 rates per pot (3000 grams soil).

[b] Red clover was also grown on the Ft. Collins soil, but showed no yield response to fertilizer P.

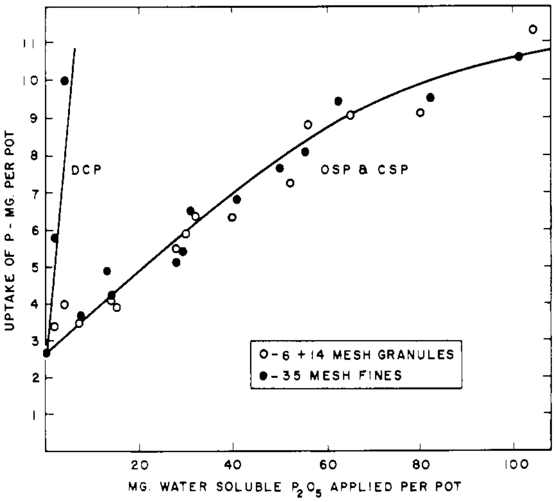

Figure 1. Uptake of phosphorus by wheat, as affected by band application of varying amounts of water-soluble phosphorus from −6, +14 and −35 mesh phosphates

There were no appreciable interactions in yields between the various fertilizers and either rate of application of phosphorus or liming treatments. Consequently, mean yields for the two rates of phosphorus and three liming levels are shown. Mean wheat yields for 60 and 120 mg. of phosphate were 5.5 and 7.2 grams per pot, respectively, on Hartsells soil and 6.2 and 7.0 grams on Fort Collins soil. Wheat yields were not increased by liming, as shown by the means of 6.8, 6.0, and 6.2 grams at pH 5.5, 6.8, and 7.5 on Hartsells and 6.6 grams on Fort Collins. Corresponding yields of red clover, however, were 6.1, 7.5, and 7.7 grams per pot for the liming treatments on Hartsells and 14.8 grams on Fort Collins soil.

Wheat yields on the Hartsells soil decreased markedly with decrease in content of water-soluble phosphorus as applied in the series of ammoniated superphosphates. Granule size had little effect on yields in this series of fertilizers, but much lower yields resulted with the granular dicalcium phosphate. Crop responses to fine dicalcium phosphate and to superphosphate containing about 50% of its phosphorus in water-soluble form were about equal.

A similar trend in yields of the second crop, red clover, was found on the Hartsells soil, but differences for water solubility of the phosphorus were less than for wheat. With this crop, fine dicalcium phosphate produced higher yields than any of the superphosphates, and granular dicalcium phosphate was comparatively more effective than for wheat.

The differences among wheat yields due to fertilizers applied on the Fort Collins soil were small and not closely related to water solubility. Yields were appreciably higher with concentrated superphosphate and dicalcium phosphate than with ordinary superphosphate.

Relative differences for uptake of phosphorus and yield of dry matter among the various fertilizers were similar. The relationship between uptake of phosphorus by wheat and the amount of water-soluble phosphorus applied is shown in Figure 1. The high linear correlation coefficients for the two crops and soils fertilized with the superphosphate materials, given in Table IV, again emphasize the marked effect of water-soluble phosphorus on uptake from the superphosphate fertilizers. Uptake from fine dicalcium phosphate was obviously not dependent on its content of water-soluble phosphorus.

Table IV. Correlation Coefficients[a] for the Relationship between Uptake of Phosphorus by Wheat and Red Clover and the Amount of Water-Soluble Phosphorus in Superphosphates Applied for Wheat

Soil and pH	*Wheat*	*Red Clover*
Hartsells, 5.5	0.950[a]	0.641[a]
Hartsells, 6.8	0.954[a]	0.913[a]
Hartsells, 7.5	0.940[a]	0.891[a]
Ft. Collins, 8.2	0.562[a]	N.S.[b]

[a] Significant at 1% level.

[b] Not significant.

Apparently very little of the phosphorus not readily soluble in water was utilized by the crops from the ammoniated superphosphates, while fine dicalcium phosphate supplied adequate phosphorus for good yields. Granular dicalcium phosphate dissolved too slowly to supply adequate phosphorus to the wheat crop, but later adequately supplied the clover crop.

Granular and −35 Mesh Fertilizers. Mixed Application. Yields of the first cutting of sudangrass for the fertilizers mixed thoroughly with three soils (experiment 2) are shown in Table V. Yields were rather low, but good response to phosphorus was obtained on all soils.

Yields were markedly lower on the Groseclose and Nason soils with −35 than with −6 +14 mesh superphosphates. This was true only for the nonammoniated superphosphates high in water-soluble phosphorus on the Iredell soil. The reverse was true for dicalcium phosphate on the first two soils and for ammoniated superphosphates and dicalcium phosphate on the Iredell soil. These results indicate the importance of soil characteristics, as yet poorly defined.

Table V. Yields of Sudangrass on Three Soils, as Affected by Granule Size and Water Solubility of Phosphorus. Mixed Application

Fertilizer and % Water-Soluble P	Mesh Size	Yield of Dry Matter, G. per Pot: Groseclose silt loam	Nason silt loam	Iredell silt loam
CSP (89%)	−6 +14	5.83	3.66	4.27
	−35	3.17	1.80	3.80
OSP (70%)	−6 +14	4.77	3.07	4.17
	−35	2.96	1.53	4.06
ACSP (57%)	−6 +14	4.37	2.50	3.73
	−35	1.47	1.00	3.80
AOSP (53%)	−6 +14	3.00	3.16	3.77
	−35	2.20	1.03	4.23
AOSP (32%)	−6 +14	2.87	1.60	3.57
	−35	1.67	0.77	4.83
AOSP (14%)	−6 +14	2.40	1.30	2.76
	−35	1.70	0.80	4.60
DCP (3%)	−6 +14	2.10	0.83	2.23
	−35	3.47	1.23	4.60
No P	...	1.30	0.77	0.83
L.S.D.				
5% level		1.40	0.77	0.99
1% level		1.90	1.04	1.34

Table VI. Uptake of Phosphorus[a] by Wheat (First Crop) and Oats (Second Crop) from −100 Mesh Fertilizers Varying in Water Solubility of the Phosphorus. Mixed Application

Fertilizer and % Water-Soluble P	Hartsells Fine Sandy Loam			Davidson Clay Loam		
	Wheat	Oats	Total	Wheat	Oats	Total
ACSP (57%)	11.95	6.87	18.82	9.87	5.62	15.49
AOSP (53%)	11.77	7.60	19.37	11.17	7.29	18.46
AOSP (32%)	11.63	8.70	20.33	11.33	7.34	18.67
AOSP (14%)	10.89	8.11	19.00	11.01	7.45	18.46
DCP (3%)	13.44	7.83	21.27	11.34	6.96	18.30
No P	2.31	3.57	5.88	7.35	4.51	11.86
L.S.D., 5% level	1.09	1.81	...	1.01	0.93	...

[a] Applied at rate of 60 mg. total P per pot (3000 grams soil).

Table VII. Yields of Oats, as Affected by Granule Size, Water Solubility of Phosphorus, and Time of Reaction with Hartsells Fine Sandy Loam. Mixed Application

Fertilizer and % Water-Soluble P	Mesh Size	Yields of Dry Matter, G. per Pot[a]					
		Applied Just Prior to Seeding		Applied 3 Months Prior		Applied 6 Months Prior	
		Unlimed	Limed[b]	Unlimed	Limed[b]	Unlimed	Limed[b]
CSP (89%)	−6 +14	11.13	11.49	9.44	10.19	8.87	9.55
	−35	9.51	11.20	5.75	9.03	4.86	7.58
OSP (70%)	−6 +14	11.17	10.80	9.01	9.77	8.96	9.14
	−35	9.77	10.03	5.94	8.44	5.14	7.25
ACSP (57%)	−6 +14	10.56	10.61	8.50	9.15	7.97	9.03
	−35	9.23	9.35	5.44	7.77	4.67	6.87
AOSP (53%)	−6 +14	11.01	9.90	9.06	8.91	7.81	7.89
	−35	8.79	8.23	5.24	6.44	5.06	5.77
AOSP (32%)	−6 +14	9.35	8.10	6.37	6.76	6.17	6.10
	−35	7.94	5.74	5.00	4.36	4.45	4.32
AOSP (14%)	−6 +14	7.47	5.54	5.86	4.72	5.30	4.09
	−35	7.65	4.34	4.91	3.93	4.44	3.54
DCP (3%)	−6 +14	5.82	3.98	5.40	3.89	5.61	4.13
	−35	9.72	6.51	6.60	7.33	5.74	7.31
No P	...	2.75	3.08	2.57	3.00	3.02	3.20
L.S.D.							
5% level		0.56	1.09	0.54	0.78	0.74	0.67
1% level		0.75	1.46	0.72	1.04	0.98	0.89

[a] Mean yields for 60 and 120 mg. phosphorus per pot (3000 grams soil).

[b] Eight tons of dolomitic limestone were applied 1 month prior to first date of application.

There was a pronounced increase in yield with increase in water-soluble phosphorus content of the superphosphates of both sizes on the Groseclose and Nason soils, but only for the −6 +14 mesh granules on the Iredell soil. Water solubility of the −35 mesh fertilizers had little effect on yields on this soil. Similar results were reported by Lawton, Apostolakis, Cook, and Hill (*4*).

Powdered Fertilizers. Mixed Application. Uptakes of phosphorus by wheat (first crop) and by oats (second crop) from powdered (−100 mesh) ammoniated superphosphates and dicalcium phosphate applied to two soils (experiment 3) are shown in Table VI. A marked response to applied phosphorus was obtained on both Hartsells fine sandy loam and Davidson clay loam. Uptake of phosphorus was least from ammoniated concentrated superphosphate (57% water-soluble) on both soils and highest from dicalcium phosphate on the Hartsells soil. Except for ammoniated concentrated superphosphate, there was no appreciable difference in uptake among fertilizers on the Davidson soil. Thus, the effects of water solubility on availability of phosphorus from the powdered fertilizers compared in this experiment were small, but still measurable. Generally, with powdered phosphates mixed with the soil, as pointed out by Lawton, Apostolakis, Cook, and Hill (*4*), the slow dissolution of phosphorus from small particles of low water solubility is just about balanced in terms of plant availability by fixation of phosphorus from highly soluble material.

Granular and −35 Mesh Fertilizers. Various Times of Mixed Application. Yields of dry matter by oats fertilized with the several phosphates mixed with Hartsells fine sandy loam (experiment 4) are shown in Table VII. Marked response to applied phosphorus was obtained, as indicated by the mean yields of 2.8, 6.4, and 8.5 grams per pot on the unlimed soil and 3.1, 6.7, and 8.5 grams per pot on the limed soil with none, 60, and 120 mg. of phosphorus applied per pot. These comparisons also indicate that liming increased mean yields only slightly.

Interactions of rate of application of phosphorus with liming, time of application prior to seeding, and granule size on plant uptake of phosphorus are shown in Figure 2. The widest range of yields, reflecting the greatest effect of fertilizer properties, occurred with granular materials applied just prior to

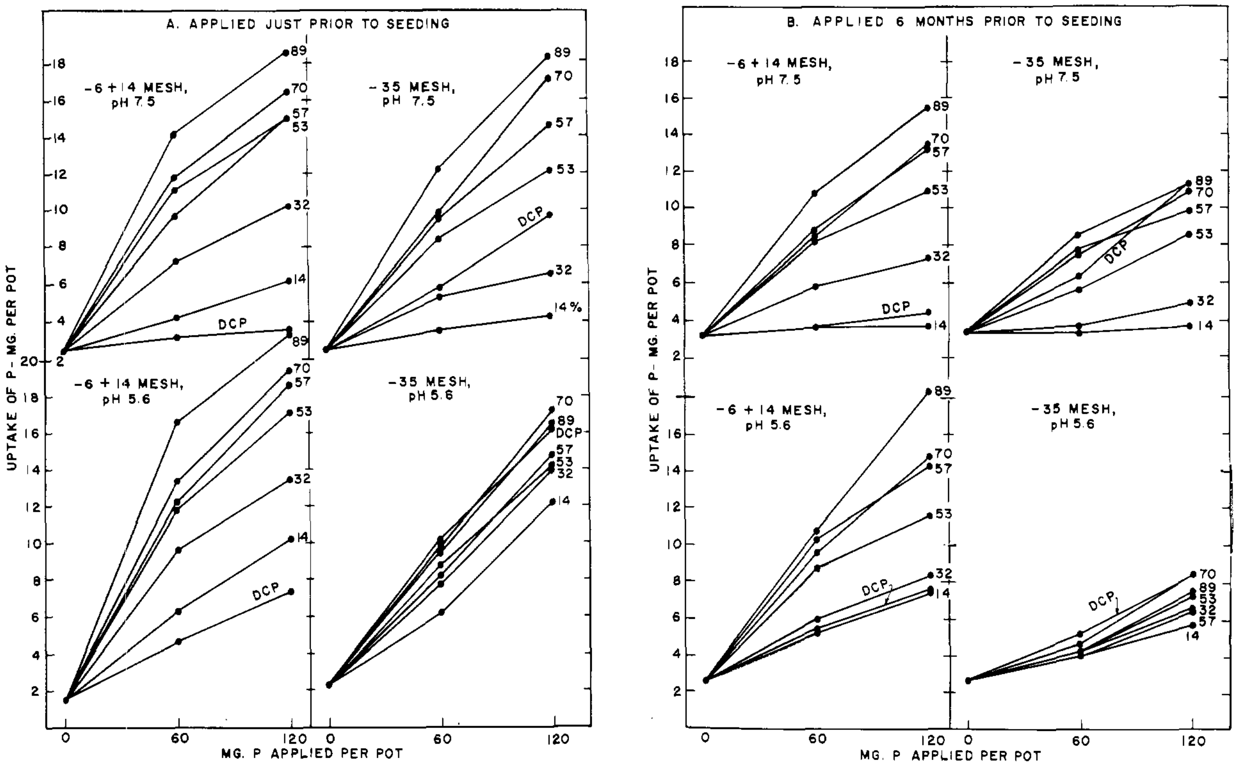

Figure 2. Uptake of phosphorus by oats in relation to rate of mixed application, as affected by granule size, liming, and time of reaction with soil prior to seeding

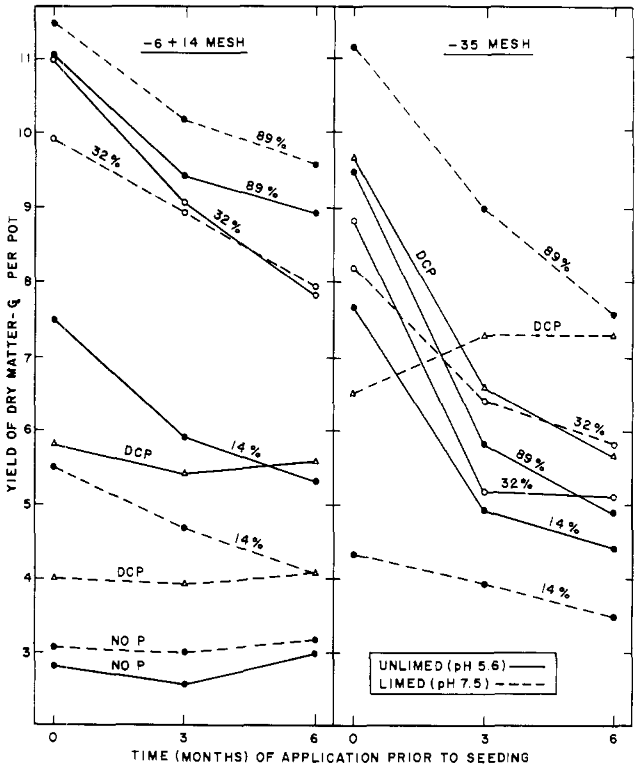

Figure 3. Yields of oats in relation to time of reaction with soil, as affected by water solubility of phosphorus, granule size, and liming

seeding. For 6 months' reaction with the soil, the narrowest range of yields occurred with −35 mesh fertilizers on the acid soil. The smaller yield differences with longer time of reaction with the soil apparently reflect the formation of reaction products similar in plant availability.

Effect of liming on crop response to individual fertilizers was marked, especially in relation to time of application prior to seeding the crop. With application just prior, liming tended to increase crop response to the phosphates of high water solubility, especially if finely divided, but decreased response to those of low water solubility. This was particularly marked with dicalcium phosphate and ammoniated ordinary superphosphate (14% water-soluble). With application of fertilizers 3 or 6 months prior to seeding, liming increased crop response to all the phosphates except ammoniated ordinary superphosphate (14 and 32% water-soluble) and to granular dicalcium phosphate, for which the reverse was true. Effects of liming on crop response to granular ammoniated ordinary superphosphate (53% water-soluble) were not appreciable. Apparently liming resulted in the formation of more soluble reaction products between water-soluble phosphates and soil. Except for fine dicalcium phosphate, liming reduced crop response to phosphates of low water solubility, with which rate of solution is the chief factor governing availability to plants.

The effect of time of reaction in relation to water solubility, granule size, and liming is illustrated in Figure 3. Yields with all of the superphosphate fertilizers decreased with time on both unlimed and limed soil. The extent of decrease was greater with fine than with granular materials and on unlimed than on limed soil. Decrease in yields with fine dicalcium phosphate on unlimed soil was similar to that for the super-

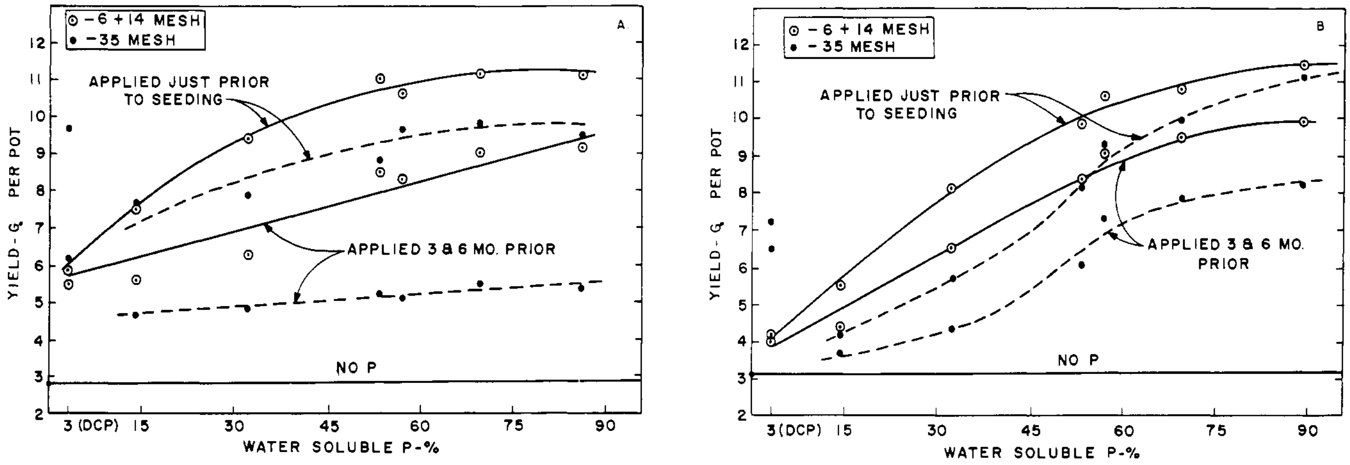

Figure 4. Yields of oats in relation to water solubility of phosphorus as affected by liming, granule size, and time of reaction

A. Oats, unlimed
B. Oats, limed

phosphates. Response to fine dicalcium phosphate increased somewhat with time on the limed soil, while response to granular material did not change appreciably with time on either unlimed or limed soil.

Effects of water solubility of phosphorus in the fertilizers on yields in relation to liming, granule size, and time of application prior to seeding are illustrated in Figure 4. Yields increased with increase in water solubility of the granular superphosphate fertilizers under all situations. The same was true for the −35 mesh superphosphates, except that after 3 and 6 months of reaction with the unlimed soil, availability of phosphorus to the crop was markedly reduced and water solubility no longer exerted an appreciable effect on yields. As in the other experiments, crop response to fine dicalcium phosphate was not related to its water solubility.

Discussion

Results from this series of experiments provide additional evidence that crop response to phosphorus in fertilizers is markedly influenced by a number of fertilizer and soil properties. Some fertilizer properties, such as water solubility of phosphorus, granule size, and composition, have been reasonably well defined, but the effects of soil properties, such as liming status, pH, and many others, are still rather poorly defined.

In experiment 4 (Figure 3) liming clearly influenced not only the initial phosphate behavior in soils, but also the course of reactions with time. These effects were particularly striking with −35 mesh materials, and differed with water solubility. Although crop response to the −35 mesh materials of highest water solubility decreased sharply with time on both limed and unlimed soil, liming lessened the rate of change to less soluble reaction products. The contrasting effects of liming on behavior of ammoniated ordinary superphosphate (14% water-soluble) and dicalcium phosphate strongly suggest that the characteristics of the insoluble residues differed initially and changed progressively with time. The increase in response to dicalcium phosphate with time in the limed soil probably results from release of phosphorus due to formation of octocalcium phosphate, as found by Lehr and Brown (*5*).

Differences in response by oats in favor of the granular superphosphates were greatest for application just prior to seeding and decreased with time. Response to granular was much less initially than to fine dicalcium phosphate and did not change appreciably with time. Because of relatively rapid migration of water-soluble phosphorus from fertilizer particles into, and reaction with the adjacent soil, plants obtain phosphorus largely from the reaction products rather than from the form initially present in the fertilizer. The effect of water-soluble fertilizer phosphorus, together with associated salts, is undoubtedly important both in increasing the concentration of phosphorus around the granules and in determining the volume of soil influenced by the applied phosphorus (*1*). These factors, together with differences in the rates of solution, probably account for higher availability from granular superphosphates than from granular dicalcium phosphate [Bouldin and Sample (*2*)].

Effectiveness of granular and fine superphosphates with further time and cropping, and the implications with respect to uptake of phosphorus throughout an entire cropping season of several months are subjects of continuing research.

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