Table I. Typical Proportions of Liquids Prereacted

Grade	Lb./Ton of Fertilizer Product				
	Anhydrous ammonia	*Nitrogen solution*^{a}	*Sulfuric acid (66° Bé. H_2SO_4)*	*Phosphoric acid (75% H_3PO_4)*	*Additional water*
3–12–12	77 (3)^b		105		210
5–20–20 (Formula A)	125 (5)^b		125		350
5–20–20 (Formula B)	98 (4)^b	50 (1)^b	105		300
5–20–20 (Formula C)	77 (3)^b	96 (2)^b	55	130 (3-$^1/_2$)^c	275
10–20–20	48 (2)^b	410 (8-$^1/_2$)^b	80	150 (4)^c	None
12–12–12		510 (10-$^1/_2$)^b	115		None
15–15–15		750 (15-$^1/_2$)^b	225	150 (4)^c	None

[a] 41.4% N, 6% urea, 19% free NH_3, 65.6% NH_4NO_3, 9.4% H_2O.
[b] Units of N shown in parentheses.
[c] Units of P_2O_5.

Table II. Granulation Plant Operating Data with Prereactor

	3–12–12	*5–20–20 (Formula A)*	*12–12–12*	*15–15–15*
Production rate, tons/hour	36	36	20	15
Recycle rate, tons/hour	25	25	25	40
Water usage, lb./ton produced	210	350	None	None
Material temperatures, ° F.				
Recycle entering mixer	125	115	120	120
Material leaving mixer	205	200	170	175

Performance of the prereactor in plant granulation operations has been satisfactory, and its use has resulted in important improvements. The heavy ammonium chloride fume from the mixer is eliminated by neutralizing the mineral acids inside the pipe. After start-up operations have provided a bed of material above the discharge pipe, a section of the mixer top cover is often removed by the control operator to permit unimpaired observation of the granulating mass. In previous systems, the dense fumes rising from the mass interfered with this practice.

Other advantages to the granulation operation which have resulted from the prereactor include unobstructed mixer paddle action, more uniformly regulated wetting of the materials being granulated, and automatic means for clearing partially clogged discharge orifices (which could also be used on other feed systems).

Table I shows the range of liquids that have been used through the prereactor in plant operations. Maximum and minimum limits on usage of the various liquid raw materials have not been established and performance thus far indicates considerable flexibility. Schedules have not yet permitted granulation of the high nitrogen 2–1–1 and X–O–X ratio grades; but it is believed that both types of grades can be successfully produced.

Table II presents typical prereactor granulation data. The water usages were determined by requirement for granule size control in the mixer. With well controlled operations, less water has been required than with previous sparger systems. It was not previously feasible to use five units of anhydrous ammonia in the formulations. Decreased water usage and improved ammonia neutralization have resulted in increased material temperatures in the mixer. Those shown for 3–12–12 and 5–20–20 grades were 5° to 10° F. above the usual previous figures for the grades. Only a few 12–12–12 and 15–15–15 grade production operations with the prereactor have been made. Consequently it is not known whether the temperatures and recycle rates shown for the grades are optimum. Limited experience has indicated that sufficient moisture can be evaporated from the mass in the mixer to accomplish reduced recycle requirements with high liquid nitrogen usages. However, further plant tests will be needed for verification.

There is no evidence of significant decomposition of nitrogen compounds in the prereactor, nor of the formation of toxic gases, as reported with other types of prereactors. A slight ammonia odor over the pug mill is usually detectable only during start-up operations, before a normal bed of material has accumulated over the discharge pipe and when formulations require high rates of ammoniation for the superphosphates.

Literature Cited

(1) Floyd, C. E., Proc. Fert. Ind. Round Table, National Plant Food Institute, Washington, D. C., p. 24, 1957.
(2) Hignett, T. P., *Farm Chem.* **121**, No. 6, 41 (1958).
(3) Hignett, T. P., Slack, A. V., J. Agr. Food Chem. **5**, 814 (1957).
(4) Reynolds, J. E., Jr., *Agr. Chem.* **12**, No. 2, 41 (1957).
(5) Sharp, J. C., *Croplife* **6**, 22 (1959).

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GRANULAR FERTILIZERS

Interaction between Dicalcium and Monoammonium Phosphates Granulated Together

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COMMERCIAL AMMONIATED SUPERPHOSPHATES normally contain monocalcium phosphate, monoammonium phosphate (MAP), and diammonium phosphate singly or in various proportions; dicalcium phosphate dihydrate (DCPD) and anhydrous dicalcium phosphate (DCPA)—principally the latter—and perhaps more basic calcium phosphates such as hydroxyapatite and collophane (*3*). The qualitative and quantitative distribution of these compounds changes with methods and degree of ammoniation of superphosphate. The composition of superphosphates ammoniated to varying degrees is reflected partially by the Association of Official Agricultural Chemists (AOAC) procedures for determining water- and citrate-soluble phosphorus (*3*). Hence, for many practical purposes, AOAC water solubility may be used as a means of characterizing the chemical properties of

With greenhouse cultures, decreasing granule size increased plant response to phosphorus in dicalcium phosphate but decreased plant response to phosphorus in monoammonium phosphate. Plant response to granulated mixtures of dicalcium phosphate and monoammonium phosphate was related to geometric surface area of the fertilizer and monoammonium phosphate content per granule.

ammoniated superphosphates, but as AOAC water solubility is changed the quantitative distribution of the several compounds in the fertilizer also is changed.

In terms of agronomic evaluations for mixed placement, differences in plant response to phosphorus fertilizers varying in AOAC water solubility may be fairly large with large granules, but are usually small with small granules (*4-6*). For a given granule size, plant response may depend upon the assemblages of compounds within the AOAC water- and citrate-soluble phosphorus fractions, as well as upon the ratio of water- to citrate-soluble phosphorus (*1*).

The purpose of the experiments reported here was to study the influence of granule size on plant response to fertilizers prepared from mixtures of dicalcium and monoammonium phosphates in various proportions. These two compounds, which occur commonly in ammoniated superphosphates, were used so as to vary the ratio of AOAC water- and citrate-soluble fractions, and yet keep constant the components in these fractions.

Table I. Fertilizers Used in Greenhouse Experiment

Fertilizer No.	*Components*	*Granule Size (Tyler)*	*Granules/ 30 Mg. P*	*Geometric Surface Area, Sq. Mm./ 30 Mg. P*	*P, %*	*Ca, %*	*Mg. P as MAP/ Granule*	*% P as MAP*
1	DCPA	−9+14	25.8	206	22.9	27.5	. . .	. . .
2	DCPA	−16+20	138	367	. . .	. . .	. . .	. . .
3	DCPA	−28+35	618	495	23.0	27.8	. . .	. . .
4	DCPA	−35+48	2224	896	. . .	. . .	. . .	. . .
5	DCPA	−48+60	4708	1106	23.0	27.4	. . .	. . .
6	DCPA + sand	−9+14	73.1	584	12.6	14.7	. . .	. . .
7	DCPA + sand	−16+20	306	814	13.0	15.0	. . .	. . .
8	DCPA + sand	−28+35	1357	1087	13.8	15.9	. . .	. . .
9	DCPA + sand	−35+48	4394	1771	13.8	15.8	. . .	. . .
10	DCPD	−9+14	63.8	510	17.9	23.1	. . .	. . .
11	DCPD	−28+35	1316	1054	. . .	. . .	. . .	. . .
12	MAP	−9+14	27.8	222	. . .	. . .	1.08	100
13	MAP	−16+20	113	300	. . .	. . .	0.266	100
14	MAP	−28+35	698	559	. . .	. . .	0.0430	100
15	MAP	−35+48	2177	877	. . .	. . .	0.0138	100
16	MAP	−48+60	5055	1188	. . .	. . .	0.00593	100
17	MAP + DCPA	−9+14	26.1	208	23.1	26.3	0.0559	4.9
18	MAP + DCPA	−28+35	704	564	23.0	25.1	0.00391	9.2
19	MAP + DCPA	−9+14	27.7	221	23.6	20.2	0.311	28.8
20	MAP + DCPA	−28+35	790	633	24.0	18.4	0.0137	36.1
21	MAP + DCPA	−9+14	25.8	206	24.9	12.7	0.668	57.6
22	MAP + DCPA	−28+35	867	694	24.8	12.4	0.0202	58.4
23	MAP + DCPA	−9+14	27.1	216	25.7	7.7	0.824	75.1
24	MAP + DCPA	−28+35	818	655	25.8	7.4	0.0278	76.2
25	MAP + DCPD	−9+14	42.6	340	19.7	19.0	0.136	19.3
26	MAP + DCPD	−28+35	1233	988	19.6	19.1	0.00457	18.8
27	MAP + sand	−9+24	44.6	356	18.2	. . .	0.672	100
28	MAP + sand	−28+35	1200	961	19.2	. . .	0.0250	100

Methods and Materials

Fertilizers. The properties of the fertilizers used are listed in Table I. The anhydrous dicalcium phosphate fertilizers were prepared by pelleting anhydrous dicalcium phosphate (−100 mesh), moistening the pellets with a solution prepared from monocalcium phosphate monohydrate, and then drying for 2 days at 110° C. The pellets were crushed and then soaked in water for 2 days to remove water-soluble phosphate. After drying, the fertilizer was screened into fractions of various sizes. The anhydrous dicalcium phosphate-plus-sand fertilizers were prepared as above by pelleting mixtures of anhydrous dicalcium phosphate and acid-washed quartz sand (−48 + 60 mesh). The water washing was limited to 2 hours to prevent disintegration of the granules. The dicalcium phosphate dihydrate fertilizers were prepared by placing a thin layer of fine dicalcium phosphate dihydrate (−100 mesh) in the bottom of a crystallizing dish, adding a thin layer of solution saturated with monocalcium phosphate monohydrate, and then placing in an atmosphere of 0.5*N* ammonium hydroxide for several days at 5° C. The resulting cake was broken up, washed with water, and screened.

The monoammonium phosphate fertilizers were screened from reagent grade monoammonium phosphate. The monoammonium phosphate-plus-sand fertilizers were prepared by pelleting a moist mixture of −48 + 60-mesh monoammonium phosphate and acid-washed quartz sand. The pellets were dried at room temperature over calcium chloride, crushed, and screened. The monoammonium phosphate and dicalcium phosphate (anhydrous or dihydrate) fertilizers were prepared by pelleting appropriate mixtures, moistening the pellets with saturated solutions of monoammonium phosphate, and drying over calcium chloride at room temperature. The pellets were crushed and screened.

Samples of the fertilizers were dissolved in 1.0*M* perchloric acid. An aliquot was analyzed for phosphorus, using the vanadate color reagent (*7*). In a second aliquot, calcium was separated from phosphorus by precipitation as calcium oxalate and determined by titration with (ethylenedinitrilo)-tetraacetic acid (EDTA) after destruction of the oxalate by heating to 500° C. The average calcium-phosphorus weight ratio for the anhydrous dicalcium phosphate fertilizers was 1.20. Using this ratio, the phosphorus content of the monoammonium phosphate–anhydrous dicalcium phosphate fertilizers in the form of anhydrous dicalcium phosphate was calculated from the analytical values for calcium. The remainder of the phosphorus was assumed to be present as monoammonium phosphate.

The average number of granules per unit weight of fertilizer was determined by counting the number of granules in several weighed samples. The geometric surface area was calculated assuming spherical granules with diameter equal to the average openings in the sizing screens.

Greenhouse Procedures. The fertilizers were mixed with 3-kg. samples of Hartsells fine sandy loam (pH 5.2) or Mountview silt loam (pH 6.5). All fertilizers were added in amounts to supply 30 and 60 mg. of phosphorus per culture. With fertilizers 3 and 14, amounts to supply 90 and 120 mg. of phosphorus also were added. Three replications of each treatment were prepared.

Columbian oats were seeded December 16, 1958, and thinned to 30 plants per culture December 29. Fertilizer nitrogen and potassium levels were equalized at 100 mg. per culture on December 30 by addition of solutions of ammonium nitrate and potassium sulfate. On January 21, 100 mg. of nitrogen were added to each culture as ammonium nitrate. Above-ground portions of the plants were harvested February 5, 1959.

The surfaces of the pots were cultivated and oats replanted February 12, 1959. On February 19, 200 mg. of nitrogen as ammonium nitrate and 100 mg. of potassium as potassium sulfate were added in solution. On March 4, 100 mg. of nitrogen as ammonium nitrate were added in solution. Above-ground portions of the plants were harvested March 30. After drying at 80° C., the above-ground portions of the plants were weighed and analyzed for phosphorus.

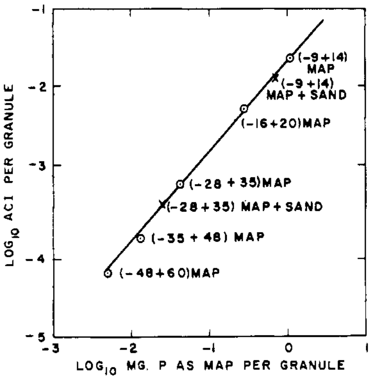


Figure 1. Availability coefficient index per granule plotted against monoammonium phosphate content per granule

Results and Discussion

Yields of dry matter were plotted against yields of phosphorus for each crop and each soil. In all cases, visual examination of the resulting graphs indicated that yields of dry matter were the same function of phosphorus uptake with all sources of phosphorus. Mitscherlich equations were fitted to the yields of dry matter and availability coefficient indexes were calculated for both crops on both soils (*2*). Because all sources behaved in a similar manner in both soils, only the average availability coefficient indexes are listed in Table II. The significance of availability coefficient indexes in relation to fertilizer evaluation is discussed by Bouldin and Sample (*2*).

When monoammonium phosphate is placed in moist soil, dissolution and movement into the surrounding soil are complete within about 2 weeks. The distribution and solubility of soil–fertilizer phosphorus reaction products in this volume of soil about each granule determine plant response to phosphorus. If monoammonium phosphate is mixed with an equal volume of sand or some other inert material, but the quantity of monoammonium phosphate per granule remains constant, the distribution and solubility of soil-fertilizer reaction products about each granule should not be changed appreciably. Hence, plant response is expected to depend upon monoammonium phosphate per granule and not granule size as such. The data obtained with monoammonium phosphate and monoammonium phosphate-plus-sand fertilizers are consistent with this hypothesis. In Figure 1, the availability coefficient index (ACI) per granule (crop 1) is plotted against the monoammonium phosphate content per granule (on a log-log scale). This relationship indicates that the availability of granular monoammonium phosphate depends primarily on monoammonium phosphate per granule and not granule size as such.

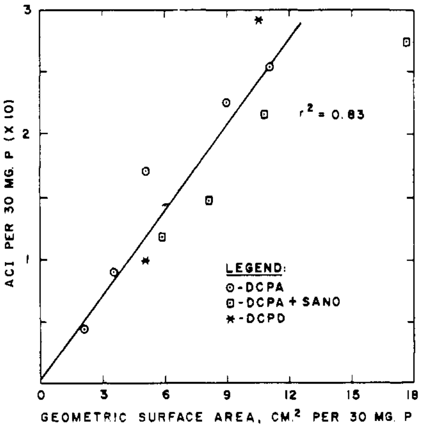


Figure 2. Availability coefficient index per 30 mg. of phosphorus plotted against geometric surface areas of fertilizers

When the dicalcium phosphate fertilizers are considered, somewhat different processes are involved. Previous work (*2*) indicated that geometric surface area was the important variable in comparisons of different granule sizes of the same fertilizer.

According to the hypothesis presented earlier (*2*), reaction of dicalcium phosphate fertilizer with the soil is a diffusion-controlled process. If a portion of the surface of a dicalcium phosphate granule is replaced with small pores or sand grains, diffusion of phosphorus from the granule into the soil will be rather complicated geometrically. Diffusion zones surrounding each particle of dicalcium phosphate in the surface of the granule will move outward with components both tangential and normal to the surface of the granule. If the size of the pores (or sand) is relatively small in relation to the distance of diffusion normal to the surface, then sooner or later the region of soil immediately surrounding a granule of dicalcium phosphate with many pores (or sand grains) should be very similar in nature to the

Table II. Average Availability Coefficient Index ($\times 10^3$) per 30 Mg. of Phosphorus for Different Mesh Sizes of Fertilizers

(Based on dry matter yields of oats grown on Hartsells fine sandy loam and Mountview silt loam)

	−9 + 14			*−16 + 20*			*−28 + 35*			*−35 + 48*			*−48 + 60*		
Components	*Crop I*	*Crop II*	*Av.*	*Crop I*	*Crop II*	*Av.*	*Crop I*	*Crop II*	*Av.*	*Crop I*	*Crop II*	*Av.*	*Crop I*	*Crop II*	*Av.*
DCPA	30	57	43	50	133	92	90	253	172	119	320	220	136	376	256
DCPA + sand	107	120	114	100	197	148	107	323	215	129	422	276			
DCPD	54	146	100				152	434	293						
MAP	608	211	410	601	168	384	423	246	334	387	220	303	331	217	274
MAP + sand	551	205	378				405	252	328						
MAP + DCPA															
10%[a]	86	64	75				107	246	176						
25%[a]	235	85	160				236	250	243						
50%[a]	382	146	264				300	234	267						
75%[a]	504	162	333				381	225	303						
MAP + DCPD															
50%[b]							261	184	222						
25%[a]	196	100	148				217	425	321						

[a] Approximate % of total P supplied as MAP. [b] 50% of P applied as −28 + 35-mesh DCPA and 50% as −28 + 35-mesh MAP.

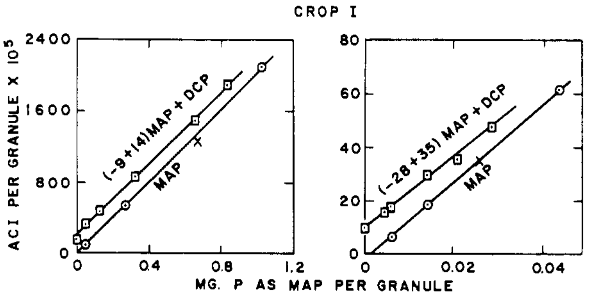


Figure 3. Availability coefficient index per granule for crop I plotted against monoammonium phosphate content per granule

☐ MAP + DCP ⊙ MAP X. MAP + sand

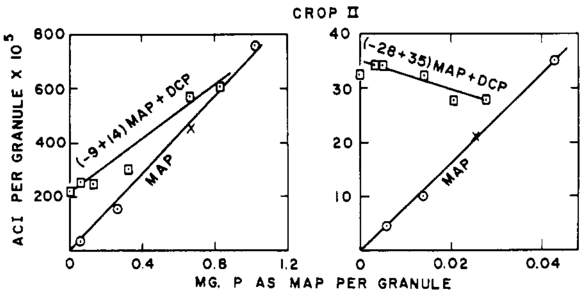


Figure 4. Availability coefficient index per granule for crop II plotted against monoammonium phosphate content per granule

☐ MAP + DCP ⊙ MAP X. MAP + sand

region of soil immediately adjacent to a nonporous granule of dicalcium phosphate of the same size. Hence, increasing the porosity of granules of dicalcium phosphate or granulation of it with sand, keeping granule size constant, should increase plant response to unit weight of dicalcium phosphate.

Consistent with the foregoing hypothesis, all of the anhydrous dicalcium phosphate-plus-sand fertilizers listed in Table II were more available per unit weight of phosphorus than the same granule size of anhydrous dicalcium phosphate alone. In Figure 2, the average availability coefficient indexes (over both crops) per 30 mg. of phosphorus are plotted against the geometric surface areas. Generally, on a unit geometric surface area basis, the anhydrous dicalcium phosphate-plus-sand fertilizers were less available than the ones without sand, which, of course, indicates that the reaction zone adjacent to an anhydrous dicalcium phosphate-plus-sand granule was somewhat less effective in promoting plant response than the zones adjacent to the same size granule of anhydrous dicalcium phosphate. This is particularly true with the −35 + 48 anhydrous dicalcium phosphate-plus-sand granules. Examination of these granules revealed that very often the individual granules were composed of a sand grain cemented to a granule of anhydrous dicalcium phosphate. With granules of this nature the reasoning discussed above does not apply, as the sand grains are essentially appendages on the surface rather than replacement of part of the surface. As an average of the four comparisons listed in Table II, one granule of anhydrous dicalcium phosphate-plus-sand was 72% as effective as a granule of anhydrous dicalcium phosphate of the same size. Thus, the results are intermediate between the expected extremes—that is, a granule of anhydrous dicalcium phosphate-plus-sand is less available than a similar granule without sand, but more than one half as available as a granule of anhydrous dicalcium phosphate, although approximately one half of the granule volume and surface consists of sand.

Considering all of the anhydrous dicalcium phosphate, dicalcium phosphate, and anhydrous dicalcium phosphate-plus-sand fertilizers, geometric surface area measurements explained 74% of the variation in availability coefficient indexes. When the −35 + 48-mesh anhydrous dicalcium phosphate-plus-sand fertilizer is omitted, the geometric surface area measurements explain 83% of the variation in availability coefficient indexes.

When mixtures of anhydrous dicalcium phosphate and monoammonium phosphate are placed in moist soil, the monoammonium phosphate will dissolve rapidly (in less than 2 weeks) and move into the surrounding soil. The anhydrous dicalcium phosphate is relatively insoluble in the monoammonium phosphate solutions (pH 3.4, 3*M* phosphorus) and will remain at the granule site as a porous residue. If anhydrous dicalcium phosphate is viewed as a diluent in much the same sense as sand, then any additional plant response not attributable to monoammonium phosphate may be regarded as being due to the presence of dicalcium phosphate (anhydrous or dihydrate) in the granules.

In Figure 3, the availability coefficient index per granule for crop I is plotted against milligrams of phosphorus as monoammonium phosphate per granule. The lower line in each graph includes the results with monoammonium phosphate and monoammonium phosphate-plus-sand. The upper line in the graph on the left represents the results with −9 + 14-mesh mixtures of anhydrous and dihydrated dicalcium phosphate-plus-monoammonium phosphate and of anhydrous dicalcium phosphate alone. The presence of dicalcium phosphate (anhydrous or dihydrate) has displaced the line upward from the monoammonium phosphate line. This difference represents the influence of the dicalcium salts on plant response. The upward displacement of the line is essentially equal to the availability coefficient index of one −9 + 14-mesh granule of anhydrous dicalcium phosphate. As the monoammonium phosphate content per granule increased, the anhydrous and dihydrated forms of dicalcium phosphate content per granule decreased. Hence, for all practical purposes the availability coefficient of the −9 + 14-mesh mixtures of monoammonium phosphate-plus-anhydrous or dihydrated dicalcium phosphate can be represented as a function of the geometric surface area and monoammonium phosphate content per granule. The same results were obtained with the −28 + 35-mesh granules (graph on right of Figure 3).

Crop II results are presented in the same manner in Figure 4. With crop II the availability coefficient indexes are somewhat less than would be expected on the basis of geometric surface area and monoammonium phosphate content per granule, particularly with the granules containing a large portion of phosphorus in the form of monoammonium phosphate. This may be the result of several factors. One factor is that the dicalcium phosphate in the granules composed largely of monoammonium phosphate may have dissolved completely during the cropping interval. A second factor may be that the very porous granules remaining after dissolution of the monoammonium phosphate have collapsed with a consequent decrease in geometric surface area.

The results indicate that the major differences in availability coefficient indexes can be explained on the basis of geometric surface area and monoammonium phosphate content per granule. The following equations approximately apply.

$$A_t = A_m + A_d$$

where A_t = availability coefficient index per unit of phosphorus

$$A_m = N(a + bX)$$

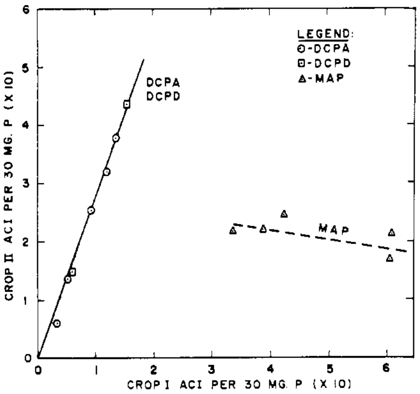
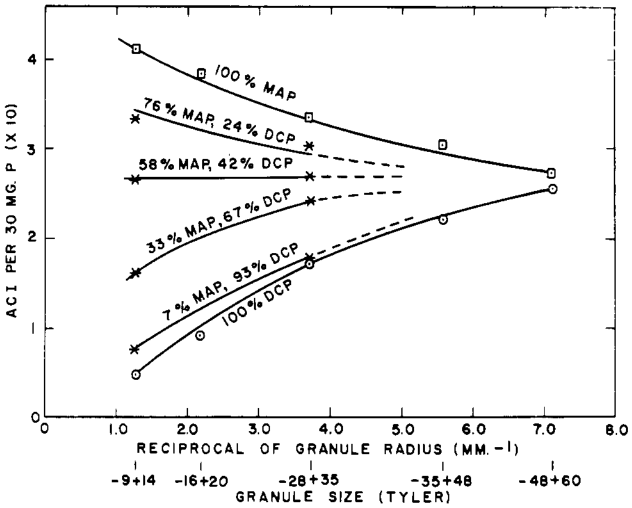


Figure 5. Availability coefficient index per 30 mg. of phosphorus

Crop I *vs.* crop II

Figure 6. Availability coefficient index per 30 mg. of phosphorus (average of crops I and II) plotted against reciprocal of granule radius



where N = number of granules per unit weight of fertilizer phosphorus

$a + bX$ = availability of monoammonium phosphate per granule

when X = monoammonium phosphate per granule, and a and b are constants

$$A_d = c + gY$$

where $c + gY$ = availability of dicalcium phosphate with geometric surface area, Y, and c and g are constants

In the above equations, N is determined by counting the number of granules per unit weight of fertilizer. Geometric surface area of the fertilizer is calculated from the number of granules per unit weight of fertilizer and the average openings in the sizing screens. The monoammonium phosphate content per granule is calculated from analysis of the fertilizer and the number of granules per unit weight of fertilizer. Constants a, b, c, and g are calculated from plant response data obtained with the different granule sizes of monoammonium and dicalcium phosphates. Using these equations, the availability coefficient indexes of the mixtures of monoammonium phosphate and dicalcium phosphate (both forms) were calculated and compared with the measured availability coefficient indexes listed in Table II. When all the data (both crops) were used, the estimated availability coefficient indexes explained 75% of the variation in the measured availability coefficient indexes. In addition, within the limitation outlined above, the results of this experiment indicate that there is very little interaction between AOAC water- and citrate-soluble phosphorus when monoammonium phosphate and dicalcium phosphate (both forms) are granulated together. The availability of the two dicalcium phosphates depends upon geometric surface area and the availability of monoammonium phosphate depends upon monoammonium phosphate content per granule.

Some interesting comparisons between the results with crops I and II may be made. In Figure 5, the availability coefficient index for crop II is plotted against the availability coefficient index for crop I for the dicalcium (anhydrous and dihydrate) and monoammonium phosphate fertilizers. There is a very good correlation between crop I and crop II results with the anhydrous and dihydrated dicalcium phosphate fertilizers; the crop II availability coefficient index is about three times that of crop I. With the monoammonium phosphate, the reverse is true; crop I availability coefficient indexes are about two to three times larger than those with crop II and there is a tendency for the crop II availability coefficient indexes to be smaller the larger the values with crop I.

Furthermore, with crop I the monoammonium phosphate fertilizers were two to four times better than the smallest granule sizes of dicalcium phosphate, anhydrous and dihydrate (Table II). In crop II, however, the smallest granule sizes of anhydrous and dihydrated dicalcium phosphate were approximately two times better than the monoammonium phosphate fertilizers. Perhaps the most important conclusion to be drawn is that the dicalcium phosphate (anhydrous or dihydrate) fertilizers become more nearly like the monoammonium phosphate fertilizers as the cropping interval is increased. Thus, rather marked differences in response to anhydrous dicalcium phosphate and monoammonium phosphate would be expected with short season crops or differences in early growth with long season crops. However, with long season crops at harvest, the differences in response might become relatively small or disappear completely, particularly with small granules.

The data are effectively summarized in Figure 6, in which the availability coefficient index of both crops is plotted against the reciprocal of the radius of the granules. Several points are noteworthy about Figure 6: Decreasing granule size increased plant response with the anhydrous dicalcium phosphate fertilizers, but decreased plant response with the monoammonium phosphate fertilizers; the granule size effects with the two-component mixtures are intermediate between those for the single components, and when the two components are present in equal amounts in a mixture there is no appreciable effect of granule size; as granule size is reduced, all sources behave more nearly alike, and the two-component mixtures are all intermediate between the single component fertilizers applied alone.

Literature Cited

(1) Black, C. A., Webb, J. R., Kempthorne, O., *Soil Sci. Soc. Am. Proc.* **20,** 186 (1956).
(2) Bouldin, D. R., Sample, E. C., *Ibid.*, **23,** 276 (1959).
(3) Jacob, K. D., Hill, W. L., *Agronomy* **4,** 324 (1953).
(4) Lawton, K., Apostolakis, C., Cook, R. L., Hill, W. L., *Soil Sci.* **82,** 465 (1956).
(5) Lawton, K., Cook, R. L., *Farm Chem.* **118**(4), 44 (1955).
(6) Norland, M. A., Starostka, R. W., J. Agr. Food Chem. **5,** 217 (1957).
(7) Quinlan, K. P., De Sesa, M. A., *Anal. Chem.* **27,** 1626 (1955).

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