N-DURE COATED PHOSPHATES COMPARED WITH UNCOATED PHOSPHATE FERTILIZERS

by

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INTRODUCTION

Phosphorus-soil relationships are some of the most mystifying of the major mineral-soil relationships. Researchers have spent much time studying this mystery. In 1907 Cameron and Bell (7) declared that the voluminous and perplexing nature of the agricultural literature on phosphates utterly defied attempts to systematize or rationalize the enormous numbers of observations recorded. The contributions that have been made in the last 53 years are many times as great as those made before 1907 and still only a rough idea of the phenomenon has been developed.

While the soil chemist has been trying to solve the riddle, the soil fertility researcher has been attempting to develop field methods which will minimize phosphate fixation. This experiment was another attempt to reduce phosphate fixation and to improve efficiency of phosphate uptake by plants.

It may be assumed that when fertilizer is applied to soil all available phosphorus is immediately available to plants. The seedling does not need all of the available phosphorus at once and apparently takes only what it needs. Much of the remaining phosphate is available for fixation by various soil constituents and it is rendered unavailable to plants. It is believed that fixed phosphate is slowly released to the soil solution. But on many soils, the amount of solution phosphate is not sufficient to satisfy the needs of the plant.

If a fertilizer were coated with some material, it might be effective in reducing phosphate fixation providing it accomplished one of two things. First, coated phosphate might be resistant to weathering processes of the soil and thus release available phosphorus later in the life cycle of the plant. By varying the coating material or the thickness of the coating, the plant would have a continual source of phosphorus in an available form. Secondly, a very resistant coating might be applied to the particle. If the nature of the material allowed the plant roots to extract phosphorus directly from the coated particle, phosphorus would not enter the soil solution and its fixation might be greatly reduced.

The object of this experiment was to evaluate the effectiveness of one such coating. N-dure, a urea formaldehyde solution which is a basic ingredient in some plastics and is being tested experimentally as a nitrogen fertilizer, was the coating material used on the three fertilizers tested.

REVIEW OF LITERATURE

Kardos (14) has defined fixation as a process whereby readily soluble plant nutrients are changed to less soluble forms by reaction with organic or inorganic compounds of the soil, resulting in a restriction of the mobility of the nutrient in the soil and a decrease in its availability to the plant.

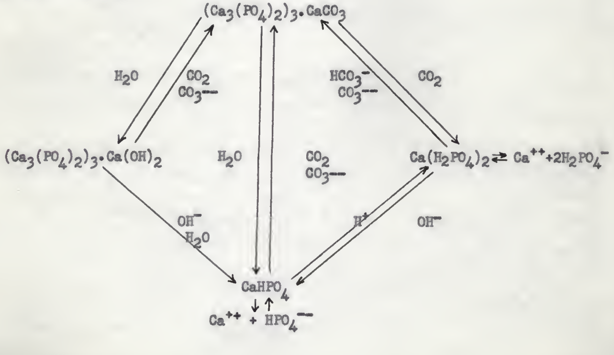
Orthophosphate is usually found in the $H_2PO_4^-$ and the HPO_4^{--} forms in agricultural soils. Below pH of 6.7 the monovalent ion is predominant. Phosphate may be found in the soil solution, adsorbed by soil colloids in a manner somewhat analogous to cation adsorption, or it may be chemically precipitated on the surface of the soil colloids. In addition to the inorganic forms, phosphorus is found in many organic forms in humus and in soil solution.

Pierre and Parker (21) found that displaced soil solutions contained primarily organic phosphorus. Further studies showed that organic phosphorus was not adsorbed by plants and was unavailable as long as it remained in such form. It was only after bacterial action converted the phosphate complexes into orthophosphates, that it was absorbed by plants.

McGeorge et al. (16) stated that carbonatoapatite is the dominant natural phosphate in soils of the southwest. The presence of the carbanatoapatite, even on non-calcareous soils, was believed to be sufficient to supply the phosphate needs of crops for many years to come. However, environmental conditions, particularly the carbon dioxide equilibrium of the soil solution, depresses the ionization or breakdown of the carbanatoapatite complex.

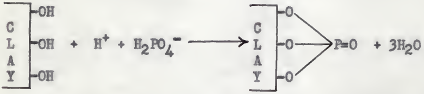
Carbon dioxide in the soil solution lowers pH or hydroxyl ion concentration. Plants show a definite preference for $H_2PO_4^-$. Therefore, increased carbon dioxide concentration, increases phosphate availability and absorption by the plant. Carbon dioxide also reduces solid-phase calcium carbonate and increases solubility of phosphorus in the soil by reducing the common ion effect of the Ca^{++}.

The problem of phosphorus availability in southwestern soils was pictured by Buehrer (5) as a physico-chemical equilibrium controlled by pH and carbon dioxide:



Stout (23) found that adsorption of phosphate by kaolinite and halloysite was many times as great as adsorption by bentonite at pH 7. Differences were even greater at lower pH values. The kaolinitic clays had been ball milled so that the cation exchange capacities of the three clays were of the same magnitude. Phosphate fixation by kaolinite was 10 to 20 times its base exchange capacity, while that of bentonite was only one-tenth its base exchange capacity.

It was suggested that the large concentration of hydroxyl units on the cleavage face of kaolinitic clays enabled it to fix phosphate. It might be possible for a phosphate ion ($H_2PO_4^{--}$) to displace three hydroxyl ions from the gibbsite sheet as follows:



If this were true two things would have to occur. Water would be evolved in the reaction with a loss in dry weight. There would also be an increase in the C-spacing of the crystal due to presence of phosphorus.

Samples of clay and KH_2PO_4 were weighed dry and then moistened. After allowing sufficient time for reaction, the samples were dried and reweighed. The kaolinite mixture lost 13.5 per cent of its original weight, halloysite 21.2 per cent and bentonite 0.2 per cent. The losses in weight were attributed to the above reaction and were of such magnitude as would be expected on the basis of the amount of phosphate fixed.

X-ray studies showed that the C-spacing of the reacted kaolinite was 16.2 Å. Natural kaolinite has a C-spacing of 7.2 Å. and the replacement of three hydroxyl ions by a phosphate ion should increase the spacing by 2.2 Å. Stout concluded that the reaction resulted in a sandwiching of phosphate ions between two kaolinite plates.

Midgley (19) performed similar experiments and found that ball milling of kaolinite greatly increased its capacity to retain phosphate ions. He agreed that fixation of phosphorus in soil was a combination of an adsorption and precipitation process but doubted that kaolinite, in its natural state, contributed much to the process.

Metzger (17) buffered soil samples with 0.002 $\underline{N}$ H_2SO_4 and reduced phosphate fixation capacity of soil by 12 to 78 per cent. This treatment disrupted the crystal structure of clay without appreciably altering the base exchange capacity. This would discredit theories attributing phosphorus fixation to crystal disruption of the base exchange mechanism. He concluded that for acid soils, under field conditions, chemical precipitation largely accounted for phosphorus fixation, and adsorption was of little significance.

In a later study, Metzger (18) found that Kansas prairie soils showed a decided decrease in acid soluble iron in the lower horizons of the soil profile. The per cent acid soluble aluminum appeared to be consistent with depth in the profile. A striking correlation was found between the soluble Fe_2O_3 and the per cent reduction in phosphorus fixation capacity. Furthermore, soil high in soluble Fe_2O_3 was also high in organic matter. It appeared that organic matter must be important in maintaining a portion of the inorganic phosphorus in a form which was soluble in dilute acid and probably available to the plant.

Organic matter exerts a reducing effect upon iron in the soil. Since iron is apparently active in phosphorus fixation, organic matter appears to make an important contribution to phosphorus availability, possibly by maintaining a part of the iron combined with phosphorus in some reduced and available form.

Coleman (8) added phosphate to hydrogen saturated montmorillonite and kaolinite. After one month, the pH value of montmorillonite samples which initially had pH values below five had increased, while those initially greater than five had become more acid. None of the kaolinite samples decreased in pH value over the same period. The pH values of those samples which were initially below pH 6, increased.

Any increase in pH must result from an anion exchange. The only anions in solution were the hydroxyl ions from iron and aluminum compounds and from the clay lattice, and added phosphate ions. Undoubtedly phosphate ions in the soil solution replaced some hydroxyl ions of either clay or the iron and aluminum compounds, thus increasing pH. Although free iron and aluminum oxides were available for phosphate fixation, the small amounts present could not account for the large amount of phosphate fixation.

The decrease in pH resulted from a cation exchange mechanism which offset the anion exchange effect. Montmorillonite has greater base exchange capacity than kaolinite, resulting in less increase in pH of acid samples of montmorillonite.

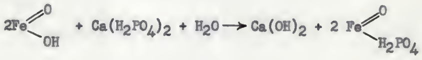
Dean and Rubins (9) pictured anion exchange as a mechanism whereby phosphate ions ($H_2PO_4^-$) are exchanged for hydroxyl ions on edges or corners of the clay crystal. These positions are less restrictive than those on the planar surface or within the crystal. Laboratory techniques for determining anion exchange capacity, using a method similar to those developed for determing cation exchange capacity, are inadequate. While the results are consistent for a given saturating ion, there is a marked difference between anions.

Swenson and others (24) found that maximum precipitation of iron and aluminum phosphates occurred below pH 4.0, well below the normal pH of most agricultural soils. Even when phosphate ions were nine times as concentrated as iron and/or aluminum ions, the ratio of anions to metal in the precipitate was never more than unity. They represented the fixation equilibrium as follows:

$$Al(H_2O)_3\left<\begin{matrix}OH\\OH\\OH\end{matrix}\right. + H_2PO_4^- \rightleftharpoons Al(H_2O)_3\left<\begin{matrix}OH\\OH\\H_2PO_4\end{matrix}\right. + OH^-$$

Ellis et al. (11) found that rock phosphate would dissolve rapidly in the soil at pH 5-5.5. The phosphate was rapidly transferred to insoluble iron phosphates. If this treatment was followed by liming to pH 7, the iron phosphates were transformed to calcium phosphates. In acid soils, carbonic acid reacts with rock phosphate to form $Ca(H_2PO_4)_2$ and $Ca(HCO_3)_2$. Both products are moderately soluble. In near neutral or alkaline soils this reaction does not proceed readily because the soil solution is saturated with bicarbonate. In acid soils, the reaction takes place readily. The $Ca(HCO_3)_2$ formed is exchanged with the soil colloid resulting in an absorption of calcium by the colloid and liberation of carbonic acid.

When $Ca(H_2PO_4)_2$ is added to acid soil, phosphates will tend to react with a substance such as goethite to form a compound low in solubility (stringite):



$$2Fe\left<\begin{matrix}O\\OH\end{matrix}\right. + Ca(H_2PO_4)_2 + H_2O \rightarrow Ca(OH)_2 + 2\ Fe\left<\begin{matrix}O\\H_2PO_4\end{matrix}\right.$$

If soil is limed to pH 6.5 or higher following the addition of phosphate, the stringite formed reacts with the liming material to form finely divided $Ca_3(PO_4)_2$ which is more soluble.

Fried et al. (12) represented the soil-plant-phosphorus interaction by two equations:

$$P(\text{soil}) \rightleftharpoons P(\text{solution})$$

$$P(\text{solution}) \longrightarrow P(\text{in plant})$$

The first is reversible and the second irreversible. In a series of consecutive reactions, the plant uptake is limited by the slowest reaction. They set out to determine which of the two reactions limits the plant uptake of phosphorus.

They conducted three experiments. One to represent each of the above reactions and the combined reaction. In the first, soil was leached with distilled water in successive increments until the rate of release was nearly constant between successive increments. This was chosen as the rate of release of phosphorus from the soil. Excised barley roots were placed in a leaching tube and increments of radioactive KH_2PO_4 were passed through the system. The uptake of phosphorus was determined by the radioactivity of the leached roots. A third leaching experiment involving both soil and roots was conducted. They found that presence of roots in the system did not appreciably alter results. They concluded that release of phosphorus from the soil is not limiting since the soil can supply in 2 to 3 hours all the phosphorus a plant can use in one growing season.

These experiments necessitated two major assumptions. First, that the leaching of the soil with excess distilled water and measuring phosphorus in the leachate is an indication of what happens in the soil where phosphorus is released into a salt solution. Secondly, that the uptake of phosphorus by excised barley roots is analogous to the selective uptake of phosphorus from a mixed salt solution by the whole living plant. If both assumptions are valid, how can phosphorus deficiency in plants be explained in light of their findings? Black (3) concluded that absorption of phosphorus by plants must be a function of concentration rather than rate of release. That is, in a normal soil system, the phosphorus gradient between the soil solution and the plant sap limits uptake.

Most recent investigators (2, 3, 6, 10, 15) agree that the phosphorus-soil relationship must satisfy a number of rather complex, little understood equilibria. The amount of exchangeable phosphorus in a soil is not necessarily a reliable index of the fertility status of the soil. Anion exchange, pH and the amounts and forms of the various phosphate complexes in the soil, influence phosphate availability. The common ion effect of aluminum, iron or calcium depress the availability of phosphate to the plants. The great preponderance of nonphosphatic materials in the soil masks the properties of the phosphatic compounds which might otherwise be detected by X-ray diffraction, electron microscope or differential thermal methods.

It is generally accepted that phosphate is absorbed by plants as inorganic orthophosphate. It is the dominate form of phosphorus found in soils and when it is in solution, the plant can absorb it almost quantitatively. Plants do not seem to absorb phosphorus directly from the solid phase nor absorb the organic phosphates of soil solution.

Olsen and Fried (20) reported that 50 per cent of the total phosphorus uptake of the plant is absorbed during the first 20 per cent of the plant's growth. The small root system of the plant during this period explains the plant's need for much available phosphorus at early stages of growth. The use of water soluble phosphates at planting time and banded applications of the fertilizer are thought to be very beneficial.

Lawton (1) has worked with a coated potash fertilizer on meadow crops. He found that one application would supply the plants with enough potash for two seasons. A coating which does not dissolve, yet allows the moisture to penetrate and allows the root to absorb nutrients through the film, could reduce leaching and volatilization of nitrogen fertilizers, reduce luxury consumption of potash and reduce fixation of phosphorus. It has been found that up to 3000 pounds of coated 12-12-12 could be broadcast on lawns without dehydration of the plants.

MATERIALS AND METHODS

Soil Used

Soil used in the greenhouse study is an unclassified sandy loam from southeastern Jackson County in northeastern Kansas. The soil is of glacial origin and from a region which has shown response to phosphate fertilizer in previous field studies.

The sample was taken from the surface layer of a native grass pasture. It is believed that this field had never been plowed or fertilized.

The pH of the soil was 5.9 and the lime requirement (25) was 2000 pounds per acre. The available phosphorus content was 26.8 pounds of phosphorus per acre as measured by extraction with 0.03 $\underline{N}$ NH_4F in 0.025 $\underline{N}$ HCl, using a soil to solution ratio of 2:50 (4).

Fertilizer Materials

Three fertilizers were used in this experiment; superphosphate (0-20-0), monoammonium phosphate (11-48-0), and ammoniated concentrated superphosphate (8-32-0). Each was applied with and without an N-dure coating. The fertilizers were coated as follows.

Superphosphate. Both the normal and N-dure coated superphosphate were furnished by the Nitrogen Division of the Allied Chemical Corporation. The N-dure superphosphate was a normal superphosphate which had been coated with N-dure, a urea formaldehyde solution (UFC-85) which is a basic ingredient in some plastics. Table 1 shows an analysis of the phosphorus and nitrogen contents of these fertilizers.

Monoammonium Phosphate and Ammoniated Concentrated Superphosphate. Both fertilizers were coated with a urea formaldehyde solution (UFC-85) furnished by the Nitrogen Division of the Allied Chemical Corporation. The solution was thinned with water so that it could be sprayed from an ordinary household flysprayer. Approximately eight coats were sprayed on the fertilizer over a 48 hour period. Each coat was allowed to dry before the next coat was applied. Table 1 shows an analysis of the phosphorus and nitrogen contents of these fertilizers.

Greenhouse Procedure

Soil was passed through a half inch screen and 2700 grams of air dry soil was placed in a No. 10 tin can.

Two fertilizer placement methods were used, mixed and banded. With mixed placement, fertilizer was thoroughly mixed with the soil. Banded fertilizer was placed in a circle directly below the seed and two inches below the soil surface. This was accomplished by removing the top two

Table 1. Chemical analyses of fertilizer materials.*

Chemical Analysis (%)	Fertilizer					
	0-20-0		8-32-0		11-48-0	
	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
Moisture	0.10	1.10	7.30	8.75	1.45	1.05
Total Nitrogen	3.58	-	7.96	7.66	11.78	11.32
Ammonia Nitrogen	-	-	-	-	10.36	-
Urea Nitrogen	0.60	-	-	-	0.10	-
Water Insoluble	2.24	-	2.96	-	1.28	-
Total P_2O_5	19.25	21.24	33.50	33.00	48.20	49.00
Citrate Insoluble P_2O_5	0.60	0.73	0.62	0.60	1.70	1.50
Available P_2O_5	18.65	20.51	32.88	32.40	46.50	47.50
Water Soluble P_2O_5 A**	10.15	13.43	15.98	22.29	41.50	44.77
Water Soluble P_2O_5 B**	14.98	16.30	25.08	25.12	45.09	46.19

* Chemical analyses (except water soluble P_2O_5) courtesy of the Nitrogen Division of the Allied Chemical Corporation.

** Water soluble P_2O_5 was determined on the unaltered granule (A) and on a ground sample (B).

inches of soil, placing fertilizer on a circular band and replacing the soil.

Fertilizer materials were applied at three rates; 100, 200, and 300 pounds of P_2O_5 per acre (two million pounds). Ammonium nitrate was added to all treatments to bring the fertilizer nitrogen level to 100 pounds of actual nitrogen per acre. The ammonium nitrate was mixed with the phosphatic fertilizers prior to placement. Granules of various fertilizer materials varied in size. Therefore, some cultures received only a few granules. Controls received 100 pounds of nitrogen either as a mixed or banded placement. All cultures received an additional 200 pounds of nitrogen during the second regrowth. Ammonium nitrate was applied in solution.

Greenleaf sudangrass was placed in a circle one inch below the soil surface employing the method described above for banded fertilizer placement. The soil was brought to field capacity[1] and watered with distilled water as often as necessary to maintain field capacity.

Seedlings were thinned to 15 plants per pot one week after emergence. They were allowed to tiller freely. The plants were harvested three times on the 29th, 69th, and 120th days after planting.

Chemical Analyses of the Plant Material

Plants were dried in a forced air drying oven at 110° C. Dry weight was recorded and each sample was ground in a Wiley Mill. The plants were analyzed for calcium and phosphorus as follows:

Calcium Determination. A one g. sample was weighed on an analytical balance and placed in a 250 ml. beaker. Twenty-five ml. of oxidizing acid

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[1] Field capacity was determined by the centrifuge moisture equivalent method.

($1\ HClO_4: 3HNO_3$) was added. The mixture was placed on a hot plate at high heat until the HNO_3 was completely evolved (the color of the fumes evolving from the solution changes from brown to white). Then the sample was removed from the hot plate, cooled, and the sides of the beaker were washed with a stream of distilled water. The sample was then returned to the hot plate at low heat.

When the sample was completely dry, 25 ml. of 1 N HCl was added to the residue. This solution was then filtered through E and D No. 613 filter paper into a 200 ml. volumetric flask. Calcium was determined on this solution using a Beckman Flame Spectrophotometer, Model DU. The concentration of the calcium (ppm) was determined by reference to a standard calcium curve made by dissolving $CaCO_3$ in dilute HCl.

Phosphorus Determination of the First and Second Harvests. A one g. sample was weighed on an analytical balance and placed in a small crucible. Five ml. of 40 per cent $Mg(NO_3)_2 \cdot 6H_2O$ in ethyl alcohol was added and the sample ignited. The sample was cooled and then ashed in a muffle furnace at 550° F for two hours. The residue was taken up in 10 ml. of 2 N HCl. The solution was filtered through E and D No. 613 filter paper into a 100 ml. volumetric flask.

Ten ml. of this solution was placed in a 50 ml. volumetric flask and the pH was adjusted to the phenolphthalein end point. It was made to volume with water and placed in a 125 ml. flask. Two ml. each of ammonium molybdate in HCl[1] and sulfonic acid reducing agent[2] were added. The solution was mixed and allowed to stand for 15 minutes. The optical density of the molybdenum blue solution was measured with a Coleman Jr. Spectrophotometer. Concentration of phosphorus (ppm) was determined by reference to a standard phosphorus curve made from KH_2PO_4.

Phosphorus Determination of the Third Harvest. The above procedure was tried on the third cut of sudangrass. However, the samples developed a hard surface crust which produced an explosion when placed in the muffle furnace. Five methods were used in attempting to combat this problem: (1) more $Mg(NO_3)_2$ solution was added before ignition; (2) samples were stirred with a glass stirring rod to break the crust; (3) hand stirring was followed by a second ignition using 95 per cent ethyl alcohol; (4) a solution of 40 per cent $Mg(NO_3)_2$ in 100 per cent methyl alcohol was used; and (5) an aqueous solution of 60 per cent $Mg(NO_3)_2$ was used. Each attempt failed to prevent the exploding; so this method was abandoned.

Phosphorus was extracted from plant tissue by using a wet digestion method. A one g. sample was weighed on an analytical balance and placed in a 250 ml. beaker. Twenty five ml. of acid (1 HCl : 1 HNO_3 : 1 H_2O) was added. The sample was heated at low heat on a hot plate until frothing ceased. It was then removed, cooled and the sides of the beaker rinsed with a stream of distilled water. It was returned to the hot plate at low heat.

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[1] Prepared by dissolving 100 g. of $(NH_4)_6Mo_{24}\cdot 4H_2O$ in 850 ml. of distilled water and mixing 160 ml. of water with 1700 ml. of concentrated HCl. After cooling, the first was added to the second with continuous stirring and the mixture cooled.

[2] Prepared by dry mixing and grinding 2.5 g. of 1-amino, 2-naphthol, 4-sulfonic acid; 5.0 g. Na_2SO_3; and 146.25 g. $Na_2S_2O_5$. Eight g. of this mixture was dissolved in 50 ml. of distilled water. This solution was made fresh every two weeks or as needed.

When the sample was completely dry, 25 ml. of 1 N HCl was added to the residue. This solution was heated below its boiling point for 30 minutes. It was then filtered through E and D No. 613 filter paper to a 200 ml. volumetric flask. Phosphorus content was determined using the procedure outlined above.

Laboratory Analyses of Fertilizer

One g. samples each of coated and uncoated 0-20-0 and 11-48-0 were weighed on an analytical balance. Each sample was placed on an E and D No. 613 filter paper in a long stem funnel. It was then leached with successive 10 ml. aliquots of distilled water until a total of 20 aliquots was used for the 0-20-0 and 15 aliquots for the 11-48-0. Each aliquot was analyzed for phosphorus by using Jackson's Method 1 (Chlorostannous-reduced molybdophosphoric blue color in sulfuric acid system) (13). This leaching experiment was repeated on fresh samples, using 5 ml. of neutral N ammonium citrate.

A second experiment was conducted to determine the total water soluble phosphorus. Analyses were made on both ground and unground samples.

A. Ground sample.

1. The sample was ground with mortar and pestle and passed through a No. 30 sieve.
2. A one g. sample was placed on a 9 cm. filter and washed with successive small portions of water until a total of 250 ml. was obtained. Each portion of water was allowed to pass through the filter before the next aliquot was added. Suction was not used; it was completed within 1 1/2 hours.

3. An aliquot of this solution was neutralized with NaOH. It was heated to 45° C. and 75 ml. of molybdate solution[1] was added.
4. After 30 minutes of heating the solution was decanted through a filter.
5. The precipitate was dissolved in standard base and titrated to the phenolphthalein end point using standard acid.

B. Unground sample.

1. A four g. sample was placed in a 50 ml. beaker.
2. One hundred ml. of distilled water was added; the solution swirled once; and decanted after five minutes.
3. Step 2 was repeated until a volume of 1000 ml. was decanted.
4. Phosphorus was determined on an aliquot of this solution by the method described above.

Statistical Methods

Analyses of variance and determinations of least significant differences (where applicable) were made according to the method of Snedecor (22). Analysis of variance was determined by considering each cutting as a separate complete randomized experiment.

An analysis of variance was computed for each cutting of sudangrass. Total yield from the cuttings of each replication was obtained by addition. Analysis of variance was determined for total yield.

Analyses of variance were determined for plant content and uptake of phosphorus and calcium for each cutting. Total uptake of phosphorus and calcium of the plants was obtained by addition. Analyses of variance were determined for total accumulation of these elements.

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[1] Dissolve 100 g. of MgO_3 in a mixture of 144 ml. of NH_4OH and 271 ml. of H_2O. Pour slowly with stirring into a mixture of 489 ml. of HNO_3 and 1148 ml. of H_2O. Keep solution warm for several days to allow precipitation of ammonium phosphomolybdate. Decant and preserve in a glass stoppered bottle.

Analysis of variance was determined for the tiller count taken at the time of the third harvest.

All values contained in Tables 2 to 20 are the means of four observations.

EXPERIMENTAL RESULTS

Sudangrass Yields

The plants were cut the first time 29 days after planting. Dry weights of the cuttings are shown in Table 2. At the time of harvest, visual differences among the various fertilizer treatments were not apparent. Plants receiving fertilizer were considerably greener than those which did not receive fertilizer. The yields produced by 0-20-0 and 8-32-0 fertilizers did not differ. Each produced an average of 8.1 g. of plant material. Plants receiving 11-48-0 fertilizer gave an average yield of 8.6 g. This was significantly better than either 0-20-0 or 11-48-0. Yields increased as the rate of applied P_2O_5 increased. When fertilizers were banded, coating did not affect yields, but when mixed, uncoated fertilizers were better than coated. Banded applications of fertilizer gave higher yields than mixed fertilizer applications, regardless of coating.

Dry weights of the second cutting of sudangrass are given in Table 3. The plants were cut 60 days after planting and 40 days after the first cutting. There was a full cloud cover for 24 days during the regrowth. Artificial lights were not used in the greenhouse and the resulting yields were about one-half those of the first harvest. Fertilizer treatments caused plants to tiller extensively. Plants receiving higher rates of fertilizer showed phosphorus deficiency symptoms at the time of the second cutting. Control cultures had greener plants, but these did not tiller. Plants which

Table 2. Yield of first cutting of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Yield of plant material, g./pot.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
Banded	0	1.4						
	100		8.1	8.3	8.1	8.2	8.4	8.0
	200		9.0	8.9	8.4	8.6	8.8	9.2
	300		9.2	8.3	9.6	8.9	9.4	9.0
Mixed	0	1.6						
	100		6.8	6.9	7.0	6.8	7.6	8.1
	200		7.4	8.2	7.3	8.9	8.2	8.2
	300		8.2	8.5	7.6	8.6	9.2	9.0

* Received 100 lbs. nitrogen in manner indicated.

L.S.D. (.05) Placement × Coating = 0.4
Fertilizer = 0.3
Rates = 0.3

Table 3. Yield of second cutting of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Yield of plant material, g./pot.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
Banded	0	3.1						
	100		3.7	3.8	4.4	4.9	4.1	4.2
	200		4.2	4.0	4.2	4.6	4.0	4.0
	300		3.7	3.1	3.8	4.4	4.3	4.4
Mixed	0	2.9						
	100		3.8	4.9	4.0	4.5	4.6	3.4
	200		5.5	4.3	4.4	4.8	3.8	3.7
	300		4.4	3.7	4.0	3.9	4.2	3.6

* Received 100 lbs. nitrogen in manner indicated.
L.S.D. (.05) Placement × Fertilizer = 0.4.

had a banded application of 8-32-0 did better than those which had banded 0-20-0. Band application of 11-48-0 gave intermediate yields which were not significantly different from the other fertilizers. When mixed, 0-20-0 and 8-32-0 gave higher yields than 11-48-0. The 0-20-0 fertilizer produced higher yields when mixed, the 11-48-0 when banded and the 8-32-0 performed equally well with both applications. Neither coating the fertilizer nor rate of application affected yield results.

The sudangrass was cut the third time after 60 days of regrowth. Dry weights of plants are shown in Table 4. The average for this cutting was slightly above that of the second cutting. Again, light was probably a limiting factor. The plants were harvested in mid-December, a period of short day length. The plants were frosted slightly once but did not appear to be appreciably affected by such. Control cultures had taller and greener plants than did fertilized cultures. Control plants tillered freely but did not appear to be as bushy as the fertilized plants. There was a linear yield increase with increased rate of fertilizer application. Plants receiving 0-20-0 yielded more when fertilizer was not coated. The reverse was true for plants receiving 11-48-0. Coating 8-32-0 did not affect yield. Plants receiving 11-48-0 did not produce as well as those receiving the other two fertilizers.

Total dry weights of three cuttings of sudangrass are shown in Table 5. Fertilized plants produced nearly twice as much dry matter as unfertilized ones. Plants which received either 200 or 300 pounds of P_2O_5 did equally well and produced more than those which received only 100 pounds of P_2O_5. Banded fertilizer application was better than mixed application. Uncoated 8-32-0 and coated 11-48-0 were the best fertilizer preparations. Coating 0-20-0 did not affect yield results.

Table 4. Yield of third cutting of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Yield of plant material, g./pot.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
Banded	0	4.6						
	100		4.7	4.8	5.0	5.4	4.8	4.6
	200		4.9	5.3	5.0	5.4	5.0	4.6
	300		4.9	5.4	5.4	5.4	5.4	4.8
Mixed	0	4.1						
	100		4.6	5.4	5.2	5.1	4.2	4.4
	200		5.2	5.2	5.6	5.4	5.2	4.2
	300		4.9	5.8	5.5	5.2	5.1	4.5

* Received 100 lbs. nitrogen in manner indicated.

L.S.D. (.05) Fertilizer × Coating = 0.3
Rates = 0.2

Table 5. Total yield of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Yield of plant material, g./pot.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
Banded	0	9.2						
	100		16.5	16.9	17.4	18.5	17.3	16.9
	200		18.1	18.2	17.5	18.5	17.8	17.8
	300		17.8	16.7	18.9	18.7	19.2	18.2
Mixed	0	8.6						
	100		15.2	17.1	16.1	16.4	16.3	15.8
	200		18.1	17.7	17.3	19.0	17.2	16.1
	300		17.6	17.9	17.0	17.8	18.4	17.0

* Received 100 lbs. nitrogen in manner indicated.

L.S.D. (.05) Fertilizer × Coating = 0.6
Rates = 0.4
Placement = 0.3

Tiller Count

The number of tillers produced per pot generally reflected results already noted for total yields. More tillers were produced by plants receiving 200 or 300 pounds of P_2O_5 per acre. Fewest tillers were produced where fertilizer was not used. Coating 0-20-0 was beneficial when fertilizer was banded, and coating 11-48-0 was beneficial when mixed. Coating 8-32-0 did not affect tillering.

Analyses of Plant Material

Phosphorus Content of Sudangrass. In general, increased application of fertilizer resulted in higher phosphorus content in plant material. Phosphorus content of plants produced with banded application of fertilizer equaled or exceeded that from mixed applications in most cases. As Table 7 indicates, coating generally did not affect plant phosphorus content. When it did, coating was beneficial with banded placement and detrimental with mixed. Phosphorus content of plants from the 11-48-0 treatment was higher than that of plants from the other two fertilizer treatments.

Increased application of fertilizer generally increased plant phosphorus content for the second cutting of sudangrass. However, as Table 8 indicates, control cultures did better than those receiving 100 pounds of P_2O_5. Neither 0-20-0 nor 8-32-0 did as well as 11-48-0. Low light intensity probably affected plant growth as much as fertilizer treatment.

Phosphorus content of the third harvest is indicated in Table 9. Increasing rates of fertilizer increased plant phosphorus contents. Neither sources of phosphorus, coating nor method of application affected phosphorus content of plant material.

Table 6. Influence of placements and rates of three coated and uncoated fertilizers on tillering of sudangrass.**

Placement Methods	Rate of P_2O_5, lbs./A	Tillers produced per pot.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
Banded	0	35						
	100		47	36	40	45	34	38
	200		47	45	41	46	41	38
	300		44	36	47	42	40	38
Mixed	0	36						
	100		43	40	40	40	40	34
	200		40	46	51	45	44	36
	300		48	48	44	45	43	39

* Received 100 lbs. nitrogen in manner indicated.

L.S.D. (.05) Placement × Fertilizer × Coating = 4
Rates = 2

** Counted at third harvest.

Table 7. Phosphorus content of the first cutting of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Phosphorus content of plants, per cent P.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
Banded	0	0.09						
	100		0.15	0.16	0.19	0.16	0.17	0.21
	200		0.21	0.20	0.23	0.23	0.30	0.26
	300		0.25	0.26	0.28	0.28	0.34	0.36
Mixed	0	0.08						
	100		0.15	0.14	0.16	0.20	0.17	0.16
	200		0.19	0.20	0.20	0.20	0.24	0.22
	300		0.15	0.24	0.22	0.25	0.31	0.27

* Received 100 lbs. nitrogen in manner indicated.
L.S.D. (.05) = 0.03

Table 8. Phosphorus content of second cutting of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Phosphorus content of plants, per cent P.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
	0	0.12						
	100		0.10	0.11	0.11	0.11	0.11	0.12
Banded	200		0.13	0.14	0.14	0.14	0.16	0.14
	300		0.16	0.13	0.17	0.16	0.18	0.19
	0	0.12						
	100		0.11	0.09	0.12	0.12	0.11	0.10
Mixed	200		0.11	0.14	0.12	0.14	0.15	0.15
	300		0.13	0.15	0.18	0.18	0.19	0.15

* Received 100 lbs. nitrogen in manner indicated.
L.S.D. (.05) Fertilizer × Rates = 0.01

Table 9. Phosphorus content of third cutting of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Phosphorus content of plants, per cent P.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
Banded	0	0.10						
	100		0.17	0.17	0.16	0.17	0.18	0.17
	200		0.19	0.17	0.20	0.18	0.19	0.21
	300		0.23	0.21	0.18	0.19	0.19	0.21
Mixed	0	0.12						
	100		0.16	0.15	0.16	0.18	0.15	0.16
	200		0.20	0.19	0.19	0.18	0.20	0.20
	300		0.21	0.23	0.22	0.21	0.21	0.22

* Received 100 lbs. nitrogen in manner indicated.
L.S.D. (.05) Rates = 0.01

Phosphorus Uptake by Sudangrass. Table 10 shows the uptake of phosphorus by the first cutting of sudangrass. In general, these data show the same general trends as reported for yield data for the first cutting, an increase in uptake with increased rate of fertilizer and very little effect from coating. When coating did affect uptake, it caused a decrease. Banded placement resulted in greater uptake than mixed application. Plants accumulated most phosphorus where 11-48-0 was used and plants accumulated the least where 0-20-0 was used.

Uptake of phosphorus by the second cutting is shown in Table 11. Phosphorus uptake by plants receiving 11-48-0 and 8-32-0 fertilizers increased linearly with increased rates of application. The two greater rates of 0-20-0 did not result in significantly different plant accumulations of phosphorus. Placement of 8-32-0 did not affect uptake. Uptake was greater when 11-48-0 was mixed and when 0-20-0 was banded. Coating of fertilizer did not affect uptake.

Table 12 shows that neither source nor placement of the phosphorus affected phosphorus uptake by the third cutting of sudangrass. Uncoated fertilizer caused greater uptake when 100 or 300 pounds of P_2O_5 was applied. When 200 pounds was applied, the reverse was true.

As was expected, total phosphorus uptake increased linearly with increased rate of application. Table 13 also indicates that banding of the ammendment increased phosphorus uptake. Again, 11-48-0 resulted in the greatest uptake and 0-20-0 the least. In general, coating had no effect when fertilizer was banded. When mixed, there was more uptake from coated 11-48-0 and from uncoated 0-20-0 and 8-32-0.

Table 10. Phosphorus uptake of first cutting of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Phosphorus uptake by plants, mg./pot.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
Banded	0	0.1						
	100		1.2	1.3	1.5	1.3	1.4	1.6
	200		1.9	1.8	1.9	2.0	2.7	2.4
	300		2.3	2.1	2.6	2.5	3.2	3.2
Mixed	0	0.1						
	100		1.0	0.9	1.1	1.3	1.3	1.3
	200		1.4	1.6	1.4	1.8	2.0	1.8
	300		1.2	2.0	1.7	2.1	2.8	2.4

* Received 100 lbs. nitrogen in manner indicated.
L.S.D. (.05) = 0.3

Table 11. Phosphorus uptake of second cutting of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Phosphorus uptake by plants, mg./pot.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
	0	0.38						
	100		0.37	0.42	0.48	0.53	0.45	0.50
Banded	200		0.53	0.57	0.60	0.66	0.62	0.55
	300		0.61	0.40	0.66	0.68	0.79	0.83
	0	0.34						
	100		0.43	0.46	0.46	0.53	0.51	0.35
Mixed	200		0.60	0.59	0.55	0.68	0.57	0.57
	300		0.59	0.54	0.71	0.69	0.80	0.55

* Received 100 lbs. nitrogen in manner indicated.

L.S.D. (.05) Fertilizer × placement = 0.07
Fertilizer × rates = 0.08

Table 12. Phosphorus uptake of third cutting of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Phosphorus uptake by plants, mg./pot.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
	0	0.46						
	100		0.79	0.81	0.78	0.93	0.85	0.80
Banded	200		0.94	0.92	1.00	0.96	0.96	0.95
	300		1.11	1.11	0.96	1.04	1.06	1.02
	0	0.48						
	100		0.72	0.80	0.82	0.92	0.64	0.72
Mixed	200		1.04	0.96	1.06	0.94	1.06	0.84
	300		1.02	1.34	1.18	1.08	1.06	0.98

* Received 100 lbs. nitrogen in manner indicated.

L.S.D. (.05) Coating × Rates = 0.08

Table 13. Total phosphorus uptake of three cuttings of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Phosphorus uptake by plants, mg./pot.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
	0	0.97						
	100		2.37	2.52	2.77	2.74	2.70	2.95
Banded	200		3.39	3.29	3.51	3.60	4.24	3.84
	300		4.03	3.64	4.28	4.21	5.06	5.07
	0	0.95						
	100		2.17	2.19	2.37	2.80	2.45	2.36
Mixed	200		3.03	3.14	3.04	3.41	3.61	3.22
	300		2.81	3.93	3.56	3.90	4.69	3.93

* Received 100 lbs. nitrogen in manner indicated.

L.S.D. (.05) = 0.44

Calcium Content of Sudangrass. Table 14 shows that the fertilizer did not affect calcium content of plants of the first cutting. Coating was beneficial when 100 pounds of P_2O_5 was banded. Banding was beneficial only when 300 pounds of P_2O_5 was furnished in a coated fertilizer or 200 pounds in an uncoated fertilizer. There was no difference when either 100 or 200 pounds of P_2O_5 was applied in a coated fertilizer. When banded, uncoated fertilizer resulted in greater calcium content at the two higher rates of P_2O_5. Rate did not affect calcium content of plants grown on cultures which received uncoated fertilizer mixed with the soil.

Tables 15 and 16 suggest that calcium content of the second and third cuttings of sudangrass were not affected by various fertilizers, methods of placement or rates of application.

Calcium Uptake of Sudangrass. Tables 17 to 19, inclusive, show the calcium uptake by sudangrass for each of the three cuttings. Table 20 indicates the total uptake of calcium. In general, calcium uptake was similar to yield. Linear effects were indicated for first and second cutting. Both banding and coating increased calcium content of first cutting.

Calcium content was increased in second cutting by banding 8-32-0 and 11-48-0. Uncoated 8-32-0 resulted in more calcium content of plants than was obtained for any other treatment.

Neither banding nor coating of 0-20-0 or 8-32-0 affected calcium uptake. Both banding and coating of 11-48-0 increased calcium uptake of the third cutting.

The total calcium uptake increased linearly with rates of application of fertilizer. In general, banding of fertilizer did not affect total calcium uptake. Uncoated, mixed 11-48-0 fertilizer was the poorest of

Table 14. Calcium content of first cutting of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Calcium content of plants, per cent Ca.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
	0	0.96						
	100		0.96	0.88	0.95	0.89	0.98	0.87
Banded	200		0.99	0.98	0.98	1.02	0.98	0.94
	300		1.07	0.94	1.01	0.98	1.04	1.02
	0	0.96						
	100		1.01	0.98	1.01	0.98	0.84	0.83
Mixed	200		0.96	0.89	0.94	0.94	0.97	0.84
	300		0.84	0.97	0.88	0.93	0.94	0.91

* Received 100 lbs. nitrogen in manner indicated.
L.S.D. (.05) Placement × Rate × Coating = 0.06.

Table 15. Calcium content of second cutting of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Calcium content of plants, per cent Ca.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
Banded	0	1.2						
	100		1.2	1.2	1.2	1.2	1.4	1.3
	200		1.4	1.3	1.3	1.3	1.4	1.3
	300		1.5	1.3	1.4	1.4	1.4	1.4
Mixed	0	1.0						
	100		1.2	1.1	1.2	1.1	1.2	1.1
	200		1.1	1.2	1.2	1.2	1.2	1.2
	300		1.2	1.4	1.3	1.3	1.3	1.2

* Received 100 lbs. nitrogen in manner indicated.

Table 16. Calcium content of third cutting of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Calcium content of plants, per cent Ca.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
Banded	0	1.3						
	100		1.4	1.3	1.2	1.3	1.3	1.2
	200		1.4	1.3	1.3	1.3	1.3	1.2
	300		1.4	1.2	1.4	1.3	1.3	1.4
Mixed	0	1.2						
	100		1.5	1.2	1.2	1.2	1.2	1.1
	200		1.3	1.3	1.3	1.3	1.2	1.1
	300		1.4	1.3	1.3	1.3	1.3	1.2

* Received 100 lbs. nitrogen in manner indicated.

Table 17. Calcium uptake of first cutting of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Calcium uptake by plants, mg./pot.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
Banded	0	14						
	100		77	73	77	73	83	70
	200		89	87	82	87	86	86
	300		99	78	97	87	98	92
Mixed	0	15						
	100		68	67	71	65	64	67
	200		71	73	69	84	81	69
	300		70	82	67	81	87	82

* Received 100 lbs. nitrogen in manner indicated.

L.S.D. (.05) Placement × Coating = 5
Rates = 4

Table 18. Calcium uptake of second cutting of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Calcium uptake by plants, mg./pot.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
Banded	0	37						
	100		46	47	50	59	55	55
	200		58	52	55	60	55	52
	300		54	40	54	61	59	61
Mixed	0	30						
	100		46	53	48	49	54	37
	200		62	52	53	57	44	44
	300		55	49	52	51	54	45

* Received 100 lbs. nitrogen in manner indicated.

L.S.D. (.05) Fertilizer × Placement = 5
Fertilizer × Coating = 5

Table 19. Calcium uptake of third cutting of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Calcium uptake by plants, mg./pot.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
	0	58						
	100		64	61	61	70	61	56
Banded	200		68	67	66	68	64	56
	300		69	62	77	72	71	67
	0	48						
	100		68	67	65	62	48	50
Mixed	200		67	69	73	68	64	46
	300		67	75	69	68	66	54

* Received 100 lbs. nitrogen in manner indicated.

L.S.D. (.05) Fertilizer × Placement = 5
Fertilizer × Coating = 5
Rates = 3

Table 20. Total calcium uptake of three cuttings of sudangrass as influenced by placements and rates of three coated and uncoated fertilizers.

Placement Methods	Rate of P_2O_5, lbs./A	Calcium uptake by plants, mg./pot.						
			0-20-0		8-32-0		11-48-0	
		Control*	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
Banded	0	109						
	100		188	181	188	202	200	180
	200		215	207	203	215	205	194
	300		222	180	228	219	228	220
Mixed	0	93						
	100		182	187	184	176	166	154
	200		200	193	195	209	189	159
	300		192	206	188	200	206	181

* Received 100 lbs. nitrogen in manner indicated.

L.S.D. (.05) Fertilizer × Coating × Placement = 14
Rates = 7

treatments. Coating 0-20-0 fertilizer increased total calcium uptake when fertilizer was banded.

Analyses of Fertilizer

Table 1 shows the effects of coating on nitrogen and phosphorus composition and chemical availability of phosphorus. As would be expected, the urea containing coating slightly increased nitrogen content of fertilizer. Only 0-20-0 showed appreciable increase in nitrogen content. It was not coated in the same manner as were the 8-32-0 and 11-48-0.

There was generally a slight decrease in total and citrate soluble phosphorus when the particles were coated. This was probably due more to sampling variation and dilution by added N-dure, than to any chemical alteration of the phosphate compounds. Coating did seem to affect water solubility of phosphorus. The ground samples reflected somewhat larger differences in water solubility of phosphorus between coated and uncoated fertilizers than was found for citrate soluble phosphorus. However, there were marked differences when the particles were not ground. This was especially true of 8-32-0. It seemed, therefore, that any effect of coating resulted from physical, rather than a chemical alteration of the fertilizer granule when it was coated.

The results of the leaching experiments are shown in Tables 21 and 22 and Figures 1 and 2. With each fertilizer, coating caused a reduction in rate of release of phosphorus. It appeared that if leaching had been continued, the total amount of phosphorus extracted from the fertilizers would have been the same regardless of coating. Uncoated 0-20-0 released more water soluble phosphorus initially; however, coated fertilizer approached it in later extractions.

Table 21. Phosphorus leached from one g. of 0-20-0 with successive increments of extracting solution (10 ml. of H_2O or 5 ml of ammonium citrate).

Extraction	Phosphorus removed by each extraction, mg. Water: Coated	Water: Uncoated	Ammonium Citrate: Coated	Ammonium Citrate: Uncoated
1	0.04	1.50	0.48	1.10
2	0.62	1.20	0.64	5.00
3	0.67	1.10	0.56	1.30
4	0.34	0.56	0.64	1.30
5	0.48	0.52	0.35	1.10
6	0.76	0.36	0.38	0.88
7	0.28	0.36	0.24	1.00
8	0.25	0.24	0.24	0.88
9	0.18	0.15	0.24	0.96
10	0.13	0.14	0.32	0.88
11	0.12	0.11	0.40	0.64
12	0.12	0.10	0.40	0.72
13	0.10	0.08	0.96	0.60
14	0.11	0.08	0.80	0.60
15	0.13	0.07	0.68	0.24
16	0.14	0.06	0.78	0.19
17	0.11	0.05	0.84	-
18	0.10	0.06	0.82	-
19	0.07	0.05	0.80	-
20	0.08	0.03	0.76	-

Table 22. Phosphorus leached from one g. of 11-48-0 with successive increments of extracting solution (10 ml. of H_2O or 5 ml. of ammonium citrate).

	Phosphorus removed by each extraction, mg.			
	Water		Ammonium Citrate	
Extraction	Coated	Uncoated	Coated	Uncoated
1	3.50	7.20	2.40	8.00
2	2.10	7.80	5.60	13.00
3	1.90	1.20	4.40	8.80
4	2.40	0.03	5.20	4.80
5	2.10	0.10	4.40	2.00
6	2.70	0.06	3.40	0.09
7	3.40	0.03	2.90	0.08
8	0.84	0.02	3.00	0.05
9	0.66	0.02	2.40	0.04
10	0.41	0.02	1.50	0.04
11	0.33	0.02	0.88	-
12	0.23	0.01	0.01	-
13	0.24	-	0.01	-
14	0.09	-	0.01	-
15	0.06	-	-	-

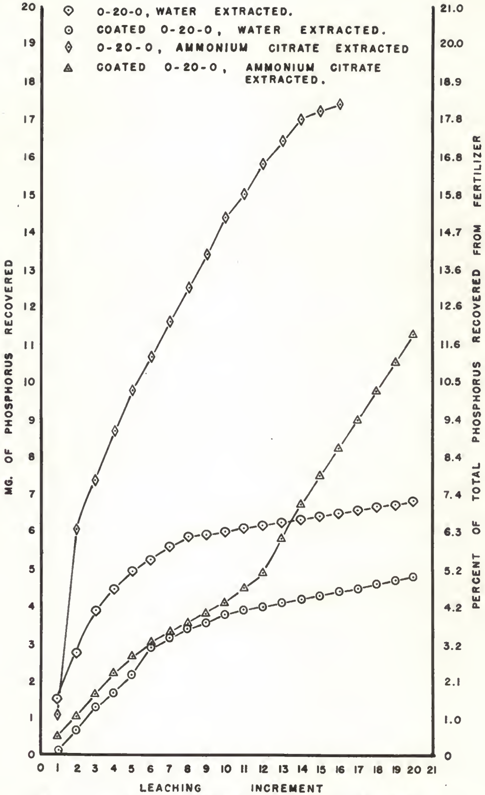

Fig. 1. Phosphorus removed from one g. of coated and uncoated superphosphate (0-20-0) leached with successive increments of distilled water (10 ml.) and neutral N ammonium citrate (5 ml.).

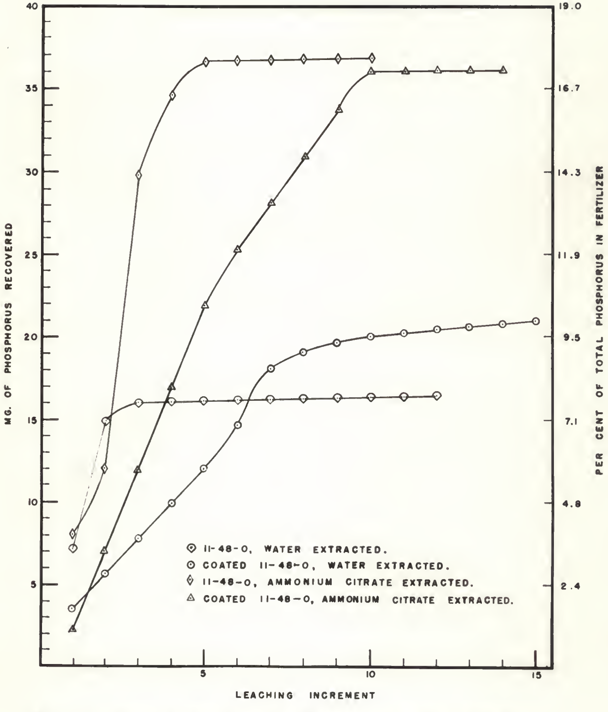

Fig. 2. Phosphorus removed from one g. of coated and uncoated monoammonium phosphate (11-48-0) leached with successive increments of distilled water (10 ml.) and neutral N ammonium citrate (5 ml.).

Ammonium citrate extraction caused rapid initial leaching of phosphorus from uncoated material whereas at first it removed phosphorus slowly from coated material. Later release from coated fertilizer was more rapid. Ammonium citrate extraction of 11-48-0 showed a more rapid rate of release from uncoated phosphate. The water extract showed a slower initial release from the coated material but within the limits of this experiment, uncoated 11-48-0 released more phosphorus.

DISCUSSION

The N-dure (Urea-Formaldehyde Concentrate 85) solution did not just coat the fertilizer. N-dure was applied in aqueous solution and the fertilizer materials were water soluble. The result was an impregnation of N-dure into the particle rather than establishment of a film on the surface. The N-dure treatment of fertilizer did seem to effect the stability of the granule by decreasing its rate of disentegration in water.

If the conclusions of Fried (12) and Black (3) are correct, this product will not decrease fixation of fertilizer phosphorus. If the rate of release of fixed soil phosphorus is as rapid as Fried has shown, and the reaction is reversible; the slow release of fertilizer phosphorus over an extended period of time will result in fixation of released phosphorus soon after it enters the soil solution. The low phosphorus gradient between the soil solution and cell sap may be the cause of the slow uptake of phosphorus by the plant (3). This would, in part, explain the increased uptake from banded or water soluble phosphatic fertilizers. Water soluble phosphorus would increase the solution concentration of phosphorus when added to the soil. This would give a high solution-cell gradient and a faster uptake of P_2O_5 until the normal equilibrium was once more attained. Banded application of fertilizer would accomplish the same thing by concentrating phosphorus in a small volume.

Plants are not known to absorb phosphorus from the solid phase (3). Therefore, in order for a coating to be beneficial, it would have to allow imbibation of water through the coating so as to form a phosphorus solution within the coating. The plant would have to be able to extract phosphorus directly through the coating. Only if such a system functions entirely independently of the natural phosphorus equilibria in soil, will it materially reduce fixation and still be able to provide the plant with the needed phosphorus at a rate faster than could be expected from the soil solution.

There is some question as to whether leaching of a disturbed soil with distilled water so as to determine phosphorus release actually simulates soil conditions. If such leaching does not properly simulate soil-phosphorus functionings, the rate of release of fixed phosphorus to the soil solution might be a limiting factor. If such is the case, banded or water soluble phosphate should still increase phosphorus uptake by increasing the amount of phosphorus in solution. Again, fixation should occur as normal equilibria were attained. If concentration is subordinate to the rate of release, a coating which causes slow release of phosphorus to the solution might be beneficial. If such were the case, the N-dure coating may be effective in reducing phosphorus fixation and increasing plant yields.

Greenhouse data showed that coating of fertilizers, when banded, did not affect yields of the first harvest. But when mixed, uncoated fertilizers were better. This might indicate that initially there was sufficient fertilizer in the band to supply the phosphorus need of the plant regardless of coating; and that coating, therefore, did not significantly interfere with the plant's ability to get phosphorus. But when mixed, the fertilizer was scattered through the soil. Then, the coating on these relatively isolated particles tended to keep the phosphorus from both the soil solution and the plant. Low concentration in the soil solution and low availability to plants was not a desirable condition.

The third cutting of sudangrass showed benefit from application of coated 11-48-0 and uncoated 0-20-0. These trends are reflected in the water extraction of the two fertilizers. Coated 11-48-0 released more phosphorus to the water extractant than the uncoated fertilizer. The reverse was true of 0-20-0. Within the limits of the leaching experiment, water leachings removed 40 per cent more P_2O_5 from the 0-20-0 when it was uncoated and 25 per cent more P_2O_5 from the 11-48-0 when it was coated.

SUMMARY AND CONCLUSIONS

The effect of N-dure treatment of phosphatic fertilizers on phosphorus fixation was studied in the greenhouse. Coated and uncoated fertilizers were banded or mixed at 100, 200 and 300 pounds of P_2O_5 per acre. Fertilizers used were 0-20-0, 8-32-0, and 11-48-0. Sudangrass was used as the test crop.

The results obtained from the greenhouse were variable and inconsistent. The only obvious trend was an increase in both yield and phosphorus uptake with increased rates of fertilizer application. It appeared from the similarity in plant calcium contents and accumulations, that fertilizer treatments generally did not affect calcium uptake by sudangrass.

Because of considerable variability among the cuttings, totals may have given the best indication of the effects of fertilizer treatment. Coating 8-32-0 decreased, while coating 11-48-0 increased yield. Coating 0-20-0 did not affect yield. Coating did not affect phosphorus uptake when fertilizer was banded. When mixed with soil, coated 0-20-0 and coated 8-32-0 fertilizers actually resulted in less phosphorus uptake by plants. The reverse was true for 11-48-0 fertilizer. It seemed, therefore, that coating 11-48-0 might have had some value.

Sunlight was probably a limiting factor during the first regrowth and may have been influential during the second regrowth. It might, therefore, be assumed that the first harvest gave a better evaluation of the coating effects. Analysis of the data for the first harvest indicated that coating decreased yields when the fertilizer was mixed and had no effect when it was banded. Identical observations occurred with respect to phosphorus uptake. Plants receiving 11-48-0 fertilizer yielded more than plants receiving either of the other two fertilizers, regardless of coating.

It would appear then, that regardless of the effect of light on the results, coating was of little value with the possible exception of 11-48-0. Coating apparently did decrease the solution rate of the fertilizer phosphorus. When fertilizer was mixed, isolated fertilizer particles released phosphorus to the solution at scattered points through the soil. The reduction in rate of release of phosphorus, as a result of coating, was sufficient to reduce early growth as indicated by smaller yield of the first cutting. Plants receiving the coated fertilizers, as mixed applications, grew sufficiently during the two regrowth periods to overcome the initial lag in growth.

Plants receiving coated 11-48-0 yielded more than those receiving uncoated 11-48-0 for both the third harvest and total yield. This was due as much to a reduction in yield of the plants receiving the uncoated 11-48-0, when compared to the other fertilizers, as to an increase from the coated fertilizer. Coating of 0-20-0 did not affect yield; coating of 8-32-0 apparently reduced sudangrass yields.

Phosphorus in 11-48-0 is relatively more water soluble than phosphorus in either of the other two fertilizers. It was the only fertilizer that seemed to be beneficial yield-wise after receiving an N-dure coating. Coating may have successfully reduced the rate of release of phosphorus to the soil solution and at the same time maintained sufficient phosphorus in the soil solution to benefit the plant.

On the basis of results of this experiment, the N-dure treatment of either of the superphosphate materials did not seem to be expecially effective. N-dure coating of 11-48-0 was slightly beneficial. Because of the unknown effect on yield of the restricted sunlight during a major portion of the experiment, definite conclusions can not be made as to the effectiveness of the N-dure coating. However, because of the response from coated 11-48-0 and because of the apparent theoretical merit of the coating, more research in this general area should be beneficial.

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N-DURE COATED PHOSPHATES COMPARED WITH UNCOATED PHOSPHATE FERTILIZERS

by

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Lack of understanding of the intricacies of phosphorus fixation processes in soil has resulted in considerable research relative to various aspects of this phenomenon. Research has included attempts in the field which were designed to reduce or at least minimize the process as well as laboratory attempts to discover the chemistry of the process.

An ideal phosphatic fertilizer should undergo minimum fixation in the soil and still supply the plant with an optimum level of phosphorus in the soil solution. Allied Chemical Corporation has developed a product (N-dure) which might serve as a coating on phosphatic fertilizer. Three fertilizers (0-20-0, 8-32-0, and 11-48-0) were coated with N-dure, a urea formaldehyde solution which is a basic ingredient in some plastics. It was the object of this experiment to evaluate this treatment insofar as its use as a coating on phosphates might result in agronomic improvement of the fertilizers.

The N-dure solution actually did not just coat the fertilizer particle. Rather it impregnated the fertilizer granule instead of just surrounding it with a film. Nevertheless, the treated products had slower rates of disintegration when placed in water.

Both coated and uncoated fertilizers were applied at three rates (100, 200 and 300 pounds of P_2O_5 per acre). Greenleaf sudangrass was used as the test crop. It was grown on a phosphorus deficient sandy loam soil. The plants were harvested three times.

The results obtained were variable and inconsistent. The only obvious general trend was an increase in both yield and phosphorus uptake with increased rates of fertilizer application. It appeared from data pertaining to calcium content and uptake that the fertilizer treatments used did not materially affect calcium nutrition of the sudangrass.

Because of great variability among the cuttings, the total data may have given the best indication of the effects of fertilizer treatments. Banding of fertilizer produced more growth than mixing with the soil. The yield response from 11-48-0 fertilizer was greater than from either 0-20-0 or 8-32-0. Coating did not affect phosphorus uptake when fertilizer was banded. Less phosphorus was absorbed by plants when coated 0-20-0 and coated 8-32-0 were mixed with the soil than was absorbed when the uncoated materials were used. More phosphorus was absorbed from mixed 11-48-0 when it was coated than when left uncoated.

The second crop grew during a period of restricted light because of cloudy weather and the third crop grew during a period of short day lengths. Because of this, the first crop may have given better indication of the effects of coating. Coating decreased yields when the fertilizer was mixed and had no effect when it was banded. Identical results were obtained for phosphorus uptake. Both yield response and phosphorus uptake were greater from 11-48-0 than from either 0-20-0 or 8-32-0.

Regardless of the effect which light may have had on yield, coating apparently was not beneficial when used on either of the superphosphate materials. N-dure coating increased total yield only when applied to 11-48-0, the highly water soluble phosphate.

The results of this experiment indicated that N-dure treatment of 11-48-0 may have reduced phosphorus fixation and caused a beneficial effect on plant growth. When coated fertilizer was mixed, it apparently reduced the initial solution rate of phosphorus sufficiently to restrict plant development during the early stages of growth.